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Assessment of Latvia's renewable energy supply-demand economic potential and policy recommendations, VPP-EM-2018/AER_1_0001

Mapping of renewable and local energy resources, energy sources and loads, and literature analysis of their potential

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CONTENTS

INTRODUCTION

In the first stage of the project “Assessment of Latvia’s renewable energy supply-demand economic potential and policy recommendations”, several tasks have been completed, including: literature analysis on the assessment of economic potential of energy resources; mapping of energy sources, loads and produced energy; assessment of renewable energy potential from the perspective of technological development and costs. In the second and third stage of the project results have been complemented with the analysis of the spatial distribution of renewable energy resources and with a review on the use of renewable energy sources in different sectors of the economy.

1. ASSESSMENT METHODS, SPATIAL DISTRIBUTION AND ANALYSIS OF RENEWABLE ENERGY SOURCES IN LATVIA

The first sub-chapter provides an overview of the literature analysis on the assessment of the economic potential of renewable and local energy resources, which allows to choose the best methods for assessing the potential in Latvia.

In order to assess the economic potential of the production and use of renewable energy sources, it is essential to identify the current level of development of renewable energy sources and power plants. Given that renewable energy resources largely dependent on location, it is important to use a spatial approach. The second sub-chapter, therefore, provides an overview of the spatial distribution of the existing energy sources, fuels consumed and energy produced.

In order to further assess the development possibilities for different types of renewable energy, the third sub-chapter provides a spatial analysis on the availability of renewable energy resources at regional level and municipal level, as well as a review on the development of renewable energy technologies and costs.

1.1. Methods for assessing the economic potential of renewable energy sources and their application

The issue of the economic benefits of renewable energy sources (hereinafter referred to as "RES") has been raised for decades. Over time, technology has developed significantly and new, diverse opportunities have emerged for energy generation from RES. In society, there is a view that RES are economically disadvantageous for energy production. Currently, RES is increasingly competing with fossil fuels, and although scientists highlight the benefits of RES in terms of maintaining and improving environmental quality, fossil resources are often preferred, as the use of fossil resources is mostly a more economically viable option at current market conditions. However, a support policy for the development of RES technologies and the use of RES can make the production and use of RES more economically viable. In this context, it is essential to identify the methods for assessing the economic potential of energy sources.

There are different criteria for assessing the economic potential of products. Criteria such as required investment, demand and net and gross profit relative to production costs are widely used. The main question in terms of the economic potential of the goods or services can be considered: will the manufacturer be interested and able to produce the product or service at such price and to the extent that the consumer is interested in buying the product or service at a given price at an appropriate level?

It is essential to take into account the specificities of the energy sector in the assessment of economic potential. The energy sector is significantly different from other sectors of the economy, with the fact that it is strongly centralized, often combining energy suppliers and consumers with different interests in a single system. Also, country is more involved in decision-making than in other sectors. This is also confirmed by the state's role in energy policy as defined in the Long-term Energy Strategy of Latvia 2030 (Enerģētikas stratēģija 2030 (projekts), 2013).

As early as 1995, the US published a manual for carrying out an economic assessment of energy efficiency and renewable energy resources, with an aim to identify the most appropriate analytical method, the scale and the level of detail (Walter Short, 1995). It highlights the importance of choosing or applying an assessment method that helps to achieve the objective of the analysis effectively, taking into account the availability of data and other aspects relevant to the situation. In some cases, this means selecting a lower level of detail, if accurate and reliable data on individual aspects of the system is not available.

Energy supply systems tend to become more interconnected and complex. Electricity networks, heat generation and supply, transport, households and production sectors are becoming increasingly complex and their interconnectedness is increasing. This creates opportunities and challenges that require an approach from a systemic perspective (USA Department of Energy, 2015). Such a systemic approach is used, for example, by Lauka to look at the sustainability of renewable energy sources in her dissertation (D.Lauka, 2018) . In this work Lauka highlights 3 components of the economic assessment of renewable energy sources: demand analysis, investment analysis and analysis of renewable energy sources. The analysis of renewable energy sources focuses on whether the energy potential is sufficient to meet demand/give economic benefits. Meanwhile, the National Renewable Energy Laboratory of the US Department of Energy, in its 2016 study, distinguish 3 indicators for assessing the economic potential of renewable energy sources: net revenue in relation to expenditure over the whole life cycle; the ratio of energy production costs and a certain threshold (for example, the cost of energy production from fossil resources), as well as by expressing the economic potential of renewable resources as part of the technological potential, where the minimum cost of electricity production is lower than the benefits of replacing fossil energy and installed capacity (Brown, et al., 2016). The latter is used to assess the economic potential of wind, solar (PV panels and concentrated solar power plants), geothermal energy (hydrothermal resources) and the use of biomass for energy production in combustion plants in the US. Another US study uses positive net present value (NPV) as a key criterion for the use of wind energy locally (opposed to the use of wind energy for large-scale electricity distribution networks) (McCabe, Sigrin, Lantz, & Mooney, 2016).

1.1.1. Methods for evaluating the economic potential of energy

In order for entrepreneurs and investors to be interested in investing in RES projects, it is necessary to demonstrate that the opportunities to benefit from the project over its entire life cycle are equivalent to or greater than the risks related to the project. The main indicator determining whether the produced product is cost-effective, is the profit. From the perspective of policy makers and society, the final price of electricity and thermal energy for the consumer is important, as well as the impact of the RES use on the economy as a whole: job creation or shrinkage, competition within the energy market, security of the energy supply system. Both the producer's ability to operate at a profit rather than a loss and the final energy price to the consumer are represented by the levelized cost of energy/electricity – LCOE (Brown, et al., 2016). Multi-criteria analysis methods, such as the Analytical Hierarchy Process (AHP) and TOPSIS, have also historically been used for the economic assessment of renewable energy sources. The use of multi-criteria analysis methods makes it possible to include and look in more detail at criteria that are not included or singled out in the LCOE analysis, such as the impact on the local economy or consumer choice in favour of green energy. The use of multi-criteria analysis methods can be useful for policy makers, as it allows to identify which of the criteria have a higher priority. In this case, LCOE can be included as one of the criteria. Therefore, from the perspective of policy makers, it is useful to look at the opportunities provided by RES, using multi-criteria decision-making methods and a system dynamics approach.

1.1.1.1. Levelized cost of electricity (LCOE) and their application

Levelized cost of energy / electricity is an easy-to-use indicator of the economic potential of renewable energy sources, allowing for comparisons between different energy sources. LCOE is a widely used indicator used in both the United States (Brown, et al., 2016) (U.S. Energy Information Administration, 2018) and Germany (Kost, Shammugamverena, Chhuyen-tran, & Schlegl, 2018). This indicator has also been used Lauka (D.Lauka, 2018) to assess the economic potential of RES and is based on EIA (U.S. Energy Information Administration, 2018) reports, which are used as a data source by both policy makers and individuals outside the United States.

Thomas F. Stacy and George S. Taylor from Canada, on the other hand, are cautious about LCOE (F.Stacy & S.Taylor, 2015), noting that this method looks at new generation energy resources but does not take into account the losses that will result from shutting down existing energy and heat plants before the end of their economic life cycle. To avoid this method, a supplemented LCOE-E system is proposed, which is more suitable for calculating the adjusted energy costs of currently used resources.

Another alternative LCOE-LACE criterion was presented in 2013 by Namovicz as a new method developed by the EIA that would be closer to energy market prices and based on an energy value system (Namovicz, 2013). With practical examples of solar and wind energy, Namovicz demonstrated that LACE better integrates capacity growth over the period under assessment. The author also points out that both these indicators can be used simultaneously and the situation when the energy source LCOE – LACE indicates a stable solution, the technology has reached a positive net market value.

Table 1.1 summarises the frequency of application of the LCOE and LACE criteria in studies from 2015 to May 2019. In order to ensure that the data examined give the most accurate insight into the frequency of use of the criteria examined in studies over the past 5 years, with a minimum deviation from the truth (Example deviation could be when an author with a surname Lace has published a chemistry-related article on hydrocarbons and the searcher recognizes it as meeting the search criteria "LACE" AND "hydrocarbon energy") 2 databases has been selected – *ScienceDirect* and *SCOPUS*.

Table 1.1

Application of LCOE and LACE criteria in scientific literature

Type of renewable energy	Data base	LCOE	LACE	Both criteria have been used
Wind energy	*ScienceDirect* *SCOPUS*	1504 1327	54 138	14 15
Solar, PV	*ScienceDirect* *SCOPUS*	1187 1030	15 28	8 8
Geothermal energy	*ScienceDirect* *SCOPUS*	423 354	19 22	6 8
Hydrocarbons, related technologies (including energy storage)	*ScienceDirect* *SCOPUS*	108 85	–	0 0

As shown in Table 1.1, LCOE is the most commonly used of the criteria considered and is most used in relation to wind energy. Solar PV energy is the second most frequently examined, while in studies on geothermal energy and hydrocarbons, LCOE and LACE criteria have been applied relatively rare. This situation may also be due to the fact that much more research is currently being done on solar and wind energy as such. Only a few studies have used both criteria at the same time.

1.1.1.2. LCOE calculation methodology

Renewable energy evaluation criteria can be divided into four groups: economic, technical, environmental and social criteria. These criteria interact with each other. The economic potential of each energy resource is closely related to its technical, environmental and social aspects. As H. Lee and Ch. Chang (Lee & Chang, 2018) have concluded – the most commonly used economic criteria are investment costs (C1), operating and maintenance costs (C2), and the price of electricity or heat (C3). Investment costs include technology research and construction costs, as well as the construction of the necessary infrastructure. Operating and maintenance costs in this context include both the cost of resources and labor required for the daily production of energy, as well as the cost of transport and maintenance and repair of equipment/systems. The final price of electricity or heat consists of investment costs, operating and maintenance costs, raw material costs, equipment depreciation and interest payments to investors.

Considered sources that study the application of multi-criteria decision-making methods (MCDM) in various aspects (Scott, Ho, & dey, 2012), (A. Mardani, 2015), (Lee & Chang, 2018) or use separate MCDM methods (Ghosh, Chakraborty, Saha, Majumder, & Pal, 2016) in relation to RES take into account the above cost criteria.

Life Cycle Costing as well is used to estimate the costs of a specific plant (Slisane, Romagnoli, Kamenders, Veidenbergs, & Blumberga, 2015). This approach is described by the Department of Infrastructure and the Built Environment of the US National Research Council (The Federal Facilities Council, 2001). According to this approach, five cost groups are distinguished: investment (C1), design, construction and dismantling costs (C2), maintenance costs (C3), operating costs (C4) and transport costs (C5).

LCOE is also based on these cost categories. The structure of LCOE is shown in the equation:

$$LCOE = \frac{\sum_{t=1}^{n} \frac{I_t + OM_t + F_t}{(1+DR)^t}}{\sum_{1}^{n} \frac{E_t}{(1+DR)^t}}, \quad (1)$$

where

I_t – initial project costs or investment costs;

OM_t – annual work and maintenance costs;

F_t – fuel/raw material costs;
E_t – the annual amount of electricity produced;
DS – discount rate, %;
N – economic life cycle of the power plant.

1.1.1.3. Application of multi-criteria analysis methods in assessing the potential of renewable energy resources

Wide-application analysis methods that do not specialize necessarily in the analysis of economic aspects can also be used to assess the economic potential of renewable resources. LCOE is an effective indicator when it comes to estimating and comparing the costs of individual isolated RES, but it is not always possible to integrate the system elements necessary to regulate energy system consisting of various sources, such as reserve capacity provision and energy storage during peak hours (IRENA (1), 2018). Therefore, MCDMs are also used for energy assessment, for they are more flexible and can be adapted to more specific needs.

Although machine learning or artificial intelligence (AI) approaches can be used today to assist decision-making and the assessment of alternatives (including the assessment of economic potential), the importance of expert knowledge and choice in policy-making issues is also emphasized (Shen & Tzeng, 2018). To some extent, multi-criteria decision-making tools (MCDMs) allow the opinion of experts in the field to be quantified and used simultaneously under specific factual or technological conditions. In a study conducted by A. Mardani, A. Jusoh, K. MD Nor, Z. Khalifah, N. Zakwan and A. Valipour on MCDM techniques and their application in scientific research in the period from 2000 to 2014 (A. Mardani, 2015) research on the environment, sustainability and energy was found to be the second most popular application of MCDM, lagging behind only research on operational performance and soft computing. Of all MCDM applications, 13.49% were in studies that can be classified as 'energy, environment and sustainability'. Some authors review the application of MCDM methods specifically in sustainability (Shen & Tzeng, 2018) and bioenergy (Scott, Ho, & dey, 2012) sectors. A study on the use of MCDM in the bioenergy sector found that most often (27%) MCDM methods are used for technology selection, much less (8%) they are used to study the economic aspects of bioenergy. The application of multi-criteria decision-making methods in RES-related research is shown in Fig. 1.1. The source indicates that until 2012, MCDM methods were also used in a regional context.

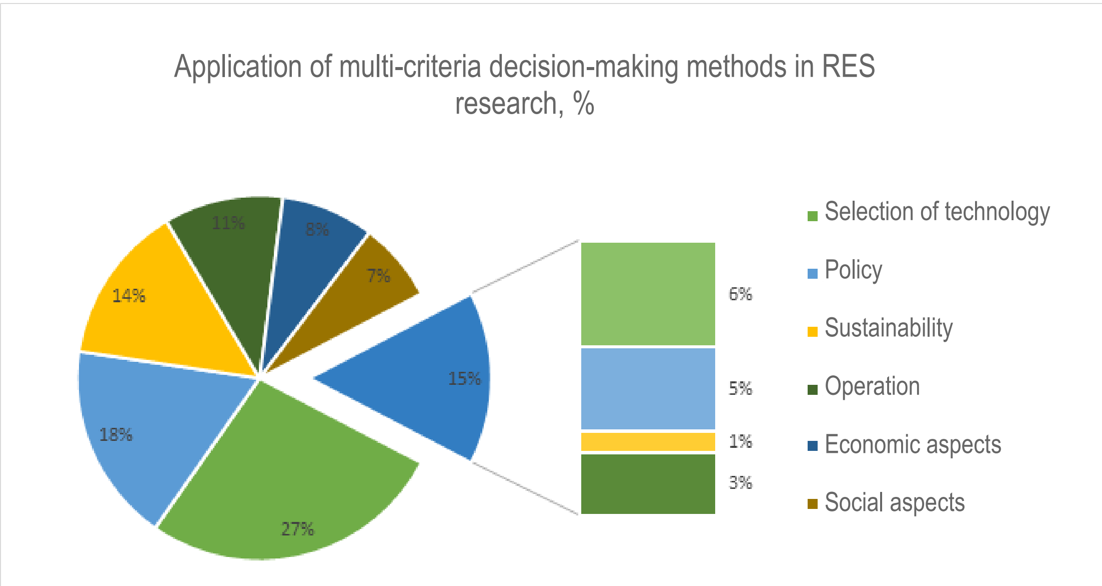

Fig. 1.1. Application of MCDM in RES research in the period from 2000 to 2010

A literature review on MCDM methods and their application in the period from 2000 to 2014 (A. Mardani, 2015) concluded that MCDM methods are a popular type of analysis. The distribution of MCDM by frequency of use is shown in Fig. 1.2.

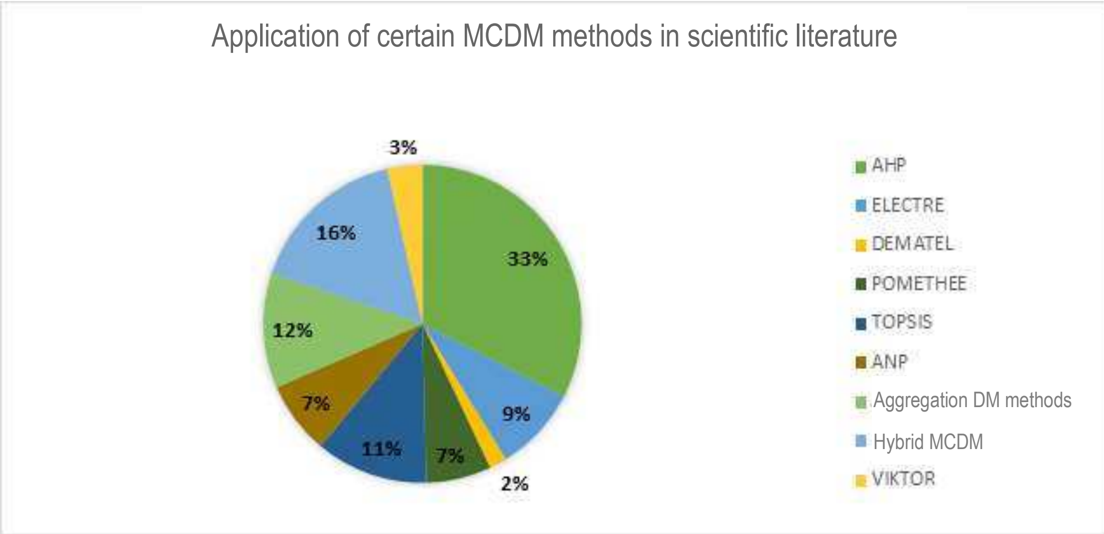

Fig. 1.2. Decision making methods and their application in the period from 2000 to 2014 (A. Mardani, 2015)

As shown in Fig. 1.2., the analytic hierarchy process (hereinafter – AHP) has been widely used. This method is also sometimes used to determine the significance level or 'weight' of the criteria, which can further be used in other MD methods. A combination of several MCDMs is common in more recent sources (Aly, Steen, & Pedersen, 2017), (Asakereh, Soleymani, & Sheikhdavoodi, 2017). Slightly more than 10% of cases apply TOPSIS.

In the following, each of the considered multi-criteria decision-making techniques will be briefly discussed.

1.1.1.4. Multi-criteria decision-making methods. Brief description

Analytical Hierarchy Process (AHP) and Analysis Network Process (ANP)

AHP has been used both for decision-making at national level (Keeleya & Matsumotoc, 2017) (Saaty, The Analytic Hierarchy Process: Planning, Priority Setting, Resource Allocation, 1980) and for selecting the most appropriate system for an individual consumer – household. The AHP method is based on dividing the problem into categories or parameter levels, where hierarchies are the main issue, for example, as mentioned in the source (Keeleya & Matsumoto, 2018), attracting investors to use solar and wind energy resources in developing countries. This includes factors that directly affect the issue under consideration, in the case of (Keeleya & Matsumoto, 2018) – investors' interest in investing in the development of solar and wind energy in developing countries. Further the source provides a broad "tree" of categories and criteria. Once such a hierarchy of influencing factors and criteria has been established, criteria of similar categories are compared in pairs. The comparison can be made using various rating scales, such as Saaty, T.L., a 1 to 9-point rating scale developed in 1980. The essence of the use of AHP is based on the division of a complex problem, expressed as a hierarchy with one specific goal at the top of the hierarchy and several categories and sub-categories below it. This method is suitable for the operational assessment of complex issues and as a support for decision-making in cases where the issue involves a lot of uncertainty, competing sub-criteria and data in different formats as the base information

(Antonella, u.c., 2016). The Analytic Network Process is an extended version of the AHP introduced in 1999 by Saaty T.L. (Saaty, 1999).

As mentioned in the previous section, AHP is widely used to determine the significance or weight of criteria. AHP has also been used for this purpose by R. K. Samal and M. L. Kansal (Kansal, 2015) in a study on the contribution of renewable energy projects to sustainable development. The following is a brief description of the application of such AHP based on the method used in (Kansal, 2015).

The nature of the AHP method is based on the construction of a pairwise comparison matrix A, which reflects the decision-maker's choice of the relative importance of different criteria.

It is assumed that a_{jk} denotes element A of the matrix (j, k), if the criteria j and k are equally relevant, a_{jk} will be equal to 1 (a_{jk} = 1), if $a_{jk} = 5$ criterion i is five times more important than criterion j, if $a_{jk} = 9$ criterion j is absolutely more important than k. Other possible a_{jk} values between 1 and 9 are interpreted according to the above model.

In order to ensure the homogeneity of the matrix data, a_{jk} = b automatically means that $a_{jk} = 1/b$ and matrix A diagonal value will be equal to 1, as the criterion will be compared to itself. When such a matrix is created, the elements of each column are divided by the sum of the elements of this column, thereby obtaining the N elements of the normalized weighted matrix $\bar{a}_{jk}$:

$$\bar{a}_{jk} = \frac{a_{jk}}{\sum_{i=1}^{m} a_{jk}}. \tag{1.2}$$

The weight of the relative criteria is calculated as the average for each row of matrix N. Criteria Weight Vector w_j is calculated by summing the value in each column $\bar{a}_{jk}$ and dividing it by the number of columns *m:*

$$w_j = \frac{\sum_{i=1}^{m} \bar{a}_{jk}}{m}. \tag{1.3}$$

If the objective of the analysis is not only to determine the weight of the criteria as it was in (Kansal, 2015), but to carry out an alternative analysis, such as in (Keeleya & Matsumotoc, 2017) study, the calculation of the assessment of alternatives should be carried out.

The Alternative Ratings Matrix S consists of elements s_{ij} representing an i-ths alternative rating according to criterion j. For these ratings, a matrix is created for each criterion m $B^{(j)}$, where j=1,…,m. Matrix $B^{(j)}$ dimensions are n x n, where n – number of alternatives. Each matrix element entered $b^{(j)}_{ih}$ is the assessment of the i-ths alternative compared to the h alternative in fulfilling the specific criterion j. If $b^{(j)}_{ih} > 1$, then alternative i is better than the alternative h, if $b^{(j)}_{ih} < 1$, then i is worse than h. If the performance of alternatives is equivalent, $b^{(j)}_{ih}=1$.

The condition must be fulfilled that:

$$b_{ih}^{(j)} \times b_{hi}^{(j)} = 1. \tag{1.4}$$

As previously, the comparison of each alternative with itself $b^{(j)}_{ii}=1$. An evaluation scale can be drawn up for the evaluation of alternatives, similar to the evaluation of criteria.

When each criterion matrix $B^{(j)}$ is filled with an alternative pair comparison, it is followed by the same steps as described for the criterion matrix. A normalized weighted matrix is created by dividing each element by the sum of the elements in the column, and the evaluation of the alternative is determined by calculating the average value in each row of the matrix. Thus obtaining evaluation vectors $s^{(j)}$, j = 1, .., m.

Vector $s^{(j)}$ contains the assessment/performance of the analysed alternatives according to criterion j.

Finally, the S matrix is drawn up:

$$S = [s^{(1)} \quad \cdots \quad s^{(m)}], \tag{1.5}$$

in which the j-th column corresponds to $s^{(j)}$.

In conclusion, an alternative rating is obtained by multiplying the weight of the criterion w by the corresponding alternative rating in the matrix S:

$$v = w \times S. \tag{1.6}$$

The final score of the AHP method assigned to the i-th alternative is represented by v_i. As a last step, the alternatives are arranged in descending order according to their final evaluation.

One of the challenges to be faced in using the AHP approach when comparing many different alternatives is the discrepancy in the assessment of experts or policy makers. AHP is based on a comparison of criteria and alternative pairs. In cases where there are a large number of criteria or alternatives, there may be a situation where alternative 1 is assessed as slightly better than alternative 2, alternative 2 is assessed slightly higher than alternative 3, while when comparing alternatives 1 and 3, the decision maker evaluates alternative 3 higher than alternative 1. A consistent assessment in this case would be if alternative 3 were also assessed slightly lower than alternative 1. To avoid this situation, the AHP includes a consistency check of decision makers' assessments for matrices A and B (j). The consistency level is represented by a consistency index (CI) calculated according to the formula:

$$CI = \frac{\mathrm{x-m}}{\mathrm{m-1}}, \tag{1.7}$$

where x is the original score in matrix A (or $B^{(j)}$ if the consistency index is calculated as an alternative to the j-th criterion) multiplied by the resulting weight matrix, and m is the number of columns (and hence the criterion or alternative).

A useful insight into the use of AHP and ANP methods for cost – benefit assessment are provided in (Khademi, Behnia, & Saedi, 2013). The authors focus on the application of methods in developing countries, while at the same time provide a good example of the use of AHP/ANP to address economic issues.

ELEKTRE (Elimination and Choice Expressing REality) method

ELEKTRE (ELimination and Choice Expressing REality) method originated in the 1960s (Antonella, u.c., 2016) and is based on comparing the ranking of alternatives to determine whether or not alternatives meet a set of criteria where the rank of the most appropriate alternatives outperforms others. To date, several versions of this method have been developed, gradually supplementing ELEKTRE with options such as adding fuzzy criteria. ELEKTRE and its derivatives are used in various fields. Their application in energy and sustainability issues is not very pronounced, examples of such applications are the local evaluation of hydropower plants (Saracoglu, 2015), as well as applications in the selection of renewable energy policies (M. Mousavia), (Lee & Chang, 2018).

PROMETEE method

Since the foundations of the PROMETEE method were defined by Professor Jean-Pierre Brans in 1982, it has become one of the most widely used multi-criteria decision support methods. Based on this method, the Visual PROMETEE application has been developed. A trial version of it can be obtained from Professor Bertrand Marshall's website (Mareschal, 2011). The website also provides a variety of useful information on the PROMETEE method and explanations of multi-criteria decision-making methods in general.

TOPSIS (The Technique for Order of Preference by Similarity to Ideal Solution) method

TOPSIS (The Technique for Order of Preference by Similarity to Ideal Solution) was first proposed by Hwang CL, Yoon K. in 1981 (Hwang & Yoon, 1981) as a method for determining the best alternative. Unlike the multi-criteria decision-making method discussed above AHP, TOPSIS is not based on a comparison of alternatives, but on a comparison of each alternative with the ideal possible solution. This gives an alternative rating that shows how close the alternative is to the best possible solution and how far from the worst possible option. This rating then allows to compare alternatives and choose the most suitable alternative.

The TOPSIS method is widely used in research on the use of various renewable resources, for example, looking at the social impact of biomethane production throughout its life cycle (Slisane, Romagnoli, Kamenders, Veidenbergs, & Blumberga, 2015) or the selection of optimal biomass cogeneration parameters (Cimdiņa, 2014). This method has also been used to assess the most suitable site for the use of solar and wind energy (Rezaei, Mostafaeipour, Qolipour, & Tavakkoli-Moghaddam, 2018).

The TOPSIS method is used to determine an alternative rating based on a number of criteria. The criteria can be both quantitative and qualitative.

To start the data analysis using the TOPSIS method, the initial data matrix must be created as shown in Fig. 1.3.

$$\begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_i \\ \vdots \\ A_n \end{array}
\begin{array}{c} \begin{array}{cccccc} x_1 & x_2 & \cdots & x_j & \cdots & x_n \end{array} \\
\begin{bmatrix} x_{11}^k & x_{12}^k & \cdots & x_{1j}^k & \cdots & x_{1n}^k \\ x_{21}^k & x_{22}^k & \cdots & x_{2j}^k & \cdots & x_{2n}^k \\ \vdots & \vdots & \cdots & \vdots & \cdots & \vdots \\ x_{i1}^k & x_{i2}^k & \cdots & x_{ij}^k & \cdots & x_{im}^k \\ \vdots & \vdots & \cdots & \vdots & \cdots & \vdots \\ x_{n1}^k & x_{n2}^k & \cdots & x_{nj}^k & \cdots & x_{nm}^k \end{bmatrix} \end{array}$$

Fig. 1.3. Decision-making matrix

Alternatives are indicated as $A_1, A_2, ..., A_n$, criteria by $x_1, x_2, …, x_n$. The criteria values are indicated with the elements of the matrix x_{ij}. Each of the criteria has a different range of values (for example, the amount of energy produced can be estimated in thousands of kWh, while LCOE values can be less than 1), so it is necessary to normalize them to make them comparable. Normalization is performed using the Jüttler's-Körth's normalization method, which gives a result in the range from 0 to 1.

This method requires the use of two formulas, one where the decision maker prefers the highest maximum value in this criterion and the other criteria where the minimum value is desirable (e.g. when purchasing a car, minimum emissions and fuel consumption, but maximum driving safety is preferred).

If minimum criteria values are desired, the following formula applies:

$$b_{ij} = \frac{x_{ij} - \min x_{ij}}{\max x_{ij} - \min x_{ij}}. \tag{1.8}$$

If maximum criteria values are desired, the following formula applies:

$$b_{ij} = \frac{\max x_{ij} - x_{ij}}{\max x_{ij} - \min x_{ij}}. \tag{1.9}$$

Normalized data are placed in a matrix and multiplied by predefined criterion significance factors (wj). Criteria significance factors or weights are usually determined by experts in the field. Other MCDM methods, such as AHP, can also be used as a support in determining criterion weights.

The next step of TOPSIS is to determine the ideal positive and the ideal negative solution (essentially the best theoretical and the worst theoretical alternative according to all the criteria used).

The positive ideal solution (A^+):

$$A^{+} = \mathrm{Max_i}\, w_j b_{ij}. \quad (1.10)$$

Negative ideal solution (A^-):

$$A^{-} = \mathrm{min_i}\, w_j b_{ij}. \quad (1.11)$$

Alternative distance to the positive ideal solution (S^+) is calculated:

$$S^{+} = \sqrt{\sum_{j=1}^{n}\left(v_{ij} - v_j^{+}\right)^2},\ \text{i =1,2,..,m.} \quad (1.12)$$

Alternative distance/ratio to the ideal negative solution (S^-) is calculated:

$$S^{-} = \sqrt{\sum_{j=1}^{n}\left(v_{ij} - v_j^{-}\right)^2},\ \text{i =1,2,..,m.} \quad (1.13)$$

The final step is to calculate the relative distance of the alternative from the ideal solution:

$$C_i^{*} = \frac{S_i^{+}}{(S_i^{+} - S_i^{-})},\ \text{i= 1,2,..,m.} \quad (1.14)$$

VIKTOR method

The VIKTOR method was developed with the aim of solving MCDM problems that face incompatible criteria, such as those expressed in different units of measurement or otherwise conflicting. Similar to TOPSIS, the VIKTOR method evaluates alternatives according to their degree of closeness to the ideal solution. This method has been used several times in recent years to assess the technical, environmental and economic conditions of renewable energy projects (Lee & Chang, 2018).

Weighted Sum Method (WSM)

One of the simplest and most widely used MCDM methods is the weighted sum method. According to this method, for example, the criterion of the lowest price is given the highest rating, and the highest price is given the lowest rating, thus the method works only with positive values, which, when adding the highest rating, gives the best alternative (Lee & Chang, 2018).

Application of mixed and hybrid MCDM methods

In 16.29% of the cases considered by A. Mardani, hybrid MCDM methods are used, adapted to the specific needs of the specific problem or field (A. Mardani, 2015). For the assessment of renewable energy resources, the geographical aspect is especially important – technological and economic parameters of the same resource will differ in different territories, therefore MCDM is used in parallel with Geographic Information System (GIS) for the processing of data. In particular, for solar (Doorgaa, Rughooputha, & Boojhawon, 2019), (Keeleya & Matsumotoc, 2017), wind (The Federal Facilities Council, 2001), (REN21, 2019) and sea waves (Abaei, Arzaghi, Abbassi, Garaniya, & Penesis, 2017), (Ghosh, Chakraborty, Saha, Majumder, & Pal, 2016) energy.

Sometimes it is useful to combine several methods to create a new method that is useful for a specific application. A set of modified *Bayesian* network and impact diagram methods is used by Abei et al. (Abaei, Arzaghi, Abbassi, Garaniya, & Penesis, 2017) to create a new multi-criteria decision-making tool for assessing locations suitable for the use of sea wave energy, taking into account energy fluctuations, shipping traffic and various risks. The authors suggest that the method allows to include the risk of technical and system failures in the assessment and can be adapted and used for the assessment of other systems.

1.1.1.5. The selection of suitable multi-criteria decision-making (MCDM) method

There is not much research that focuses on evaluating and comparing the performance of multi-criteria decision-making methods. However, as early as 2001, an evaluation of MCDM methods was carried out in the US specifically for application in the integrated assessment of climate control policies (Robinson, 2001). This study conducted an experiment in which 20 climate change experts analyzed hypothetical climate policies using a variety of MCDM methods, as a result evaluating methods for their ease of use, transparency, reliability of the results, complexity, and the necessary amount of work. The study concludes that the main benefit of using the MCDM considered by experts is the structuring of decision-making, which allows for a better understanding of the rationale for the decision and its better explanation and justification to others. A study on the use of multi-criteria decision-making methods in the economic sector conducted in 2011 in Lithuania, summarizes the distribution of MCDM methods by classes and looks at their main differences. It concludes that, although it is not possible to say unambiguously which method is best in all cases, it is important to select an appropriate decision-making method and apply it appropriately (Zavadskas & Turskis, 2011).

A more recent study comparing MCDM methods with fuzzy values in 2016 reviews the application of 10 MCDM methods – SAW, WPM, CP, TOPSIS, ELECTRE, VIKTOR and four types of AHP – with indeterminate output data matrices (Zamani-Sabazi, King, Gard, & Abudu, 2016). The study concludes that the steady increase in data uncertainty did not significantly affect the results obtained, while changes in the number of alternatives and criteria have a significant impact. By applying each of the methods in practice, the authors conclude that SAW, WPM, CP and TOPSIS are mathematically easy to apply, while ELEKTRE, VIKTOR and all four types of AHP are large in terms of calculation volume and relatively complicated. Zamani-Sabazi, King, Gard, and Abudu calculated and plotted the correlation between the results obtained with each of the above multi-criteria analysis methods in 4 different scenarios – 3 alternatives and 3 evaluation criteria, 8 alternatives and 4 criteria, 8 alternatives and 8 criteria, 15 alternatives and 8 criteria. As the results of some methods in specific scenarios show very similar ranking of alternatives and different methods have different degrees of complexity, the obtained data allow to choose the simplest method that gives statistically very close or the same result in the given scenario, thus saving system resources and time. In all scenarios considered in the study, the correlation between the results generated by the methods increased with increasing matrix size (number of criteria and alternatives), however, the increase was different between different pairs of methods (Zamani-Sabazi, King, Gard, & Abudu, 2016). However, it should be noted that the above study takes into account only the mathematical aspect, while the MCDM analysis method should not only provide a “top” of alternative rankings, but also provide a transparent and structured representation of the decision-making process and justifications for decision makers and users, as well as the confidence in the decision and the understanding of the alternatives that have to be “donated” when making a choice. This is the role of the MCDM underlined in (Robinson, 2001) regarding the application of MCDM methods for the integrated assessment of climate control policies.

Given that the authors of the studies examined conclude that it is not possible to unambiguously determine the best MCDM method in general, while there are different aspects to be assessed depending on the purpose of the analysis, this study will examine the usefulness of different MCDM methods in assessing 3 RES alternatives for electricity generation – solar PV, wind energy, biomass cogeneration and traditional electricity generation by burning natural gas – according to economic criteria relevant to policy makers – LCOE, compliance of the supply with the demand (provides supply during peak hours or vice versa – most energy is produced at night when the consumption is scarce and requires additional electricity source in times of high energy consumption), the need for and cost of electricity storage, the projected impact on the local economy.

In this case, the essential aspects of the analysis are:

- a relatively small amount of alternatives and criteria (4 x 4);
- an easy-to-use and transparent method to structure and understand the problem, while not time-consuming;
- increase confidence in the decision;
- allows the use of both qualitative and quantitative criteria;
- provides a result that is easily perceived by non-professionals and justified to the general public.

Role of decision analysis in public sector matters:

- initial impact assessment.

1.1.2. Assessment of the economic potential of renewable energy sources worldwide

1.1.2.1. Europe

According to the International Renewable Energy Agency (IRENA) report on the prospects for renewable energy in the European Union (IRENA (1), 2018), the EU is a world leader in green energy. Its strong commitment and long-term vision, combined with today's cost-effective renewable energy opportunities, have allowed the region to almost double its share of renewable energy between 2005 and 2015. The EU is thus on track to meet its 2020 renewable energy target, and its 2030 target of a 27% share of renewable energy is easily achievable.

Although the EU has made impressive progress towards meeting its climate goals, IRENA estimates that, assuming the continuation of existing and planned policies, the EU-28 will achieve a 24% share of renewable energy in the energy sector by 2030.

Since the adoption of the EU Renewable Energy Directive (Directive 2009/28/EC on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC, 2009) in 2009 substantial changes have been made to support schemes for renewable energy sources (Directive (EU) 2018/2001 on the promotion of the use of energy from renewable source, 2018). In October 2014, the European Commission agreed on a new set of energy and climate targets for 2030 (European Commission (1), 2014), including a minimum target of 27% share of renewable energy of the EU's energy consumption. This agreement was followed by the Energy Union Framework Strategy of February 2015, which aims to make the EU a "world leader in renewable energy" (European Commission (2), 2015).

The European Union has ratified the Paris Agreement, which set the goal of limiting global temperature rise to "well below 2° C" this century compared to pre-industrial levels. In practice, this means reducing carbon emissions from energy to zero by 2060 and maintaining this level till the end of century. This long-term decarbonisation target has a significant impact on Europe's climate and energy goals until 2030. Timely action on climate change is essential to ensure an efficient transition in all aspects of energy use, avoiding the need for sharper emission reductions after 2030. At the request of the Commission, IRENA has carried out an assessment of the European Union's renewable energy prospects up to 2030.

This study describes the potential of renewables in terms of their levelized cost of energy (LCOE) and compares them with an alternative of fossil technologies to determine 'replacement costs'. The study covers all sectors, including energy supply (energy supply and district heating) and final consumption sectors (buildings, industry and transport). A detailed study was carried out for the countries participating in the *REmap* program and for countries which had already undergone an in-depth REmap analysis: Sweden, Poland, Germany, the United Kingdom, Italy, France, the Netherlands, Denmark, Belgium, Cyprus and Luxembourg. The IRENA study on the Renewable Energy Prospects for the European Union is based on studies carried out in these countries and supplemented by a high-level analysis of the situation in the other Member States of the European Union (IRENA (1), 2018).

In 2015, the share of renewable energy sources in the EU Member States ranged from 5% to 54%. Fluctuations are projected to continue until 2030, reflecting a number of factors such as different starting points, the potential of available resources, existing and planned policies, and the specific market conditions for renewable energy in each country, however, these differences until 2030 can decrease, because Member States with a lower share of primary renewable energy may increase it more rapidly. IRENA's *REmap* analysis reveals significant renewable energy potential beyond the proposed target of 27% by 2030. Unlocking the additional potential to reach 34% is cost-effective, even taking into account the associated benefits to health and environment and significant economic benefits. Although an EU-wide goal is an important declaration of intent, commitment and implementation at national level will be a key factor in achieving this goal cost-effectively at regional level. A comparison with historical progress in the share of renewable energy shows that most Member States could meet their renewable energy targets by 2020, but some Member States, such as France, Ireland, Luxembourg, Malta, the Netherlands and the United Kingdom, may find it more difficult. These countries will need a growth rate of renewable energy that is higher than the growth they have achieved in previous years. Assuming the continuation of existing and planned policies, IRENA expects the EU-28 to reach a 24% share of renewable energy by 2030. This is less than the currently proposed 27% target. It can therefore be concluded that, although Europe has the potential to reach the 27% RES threshold, changes in the existing policy instruments are necessary.

Each EU Member State has its own objectives and different policy tools to achieve them. The latest European Commission report on the use of renewable energy, published in February 2017, indicates that the EU-28 is very close to reaching the 20% share of renewable energy by 2020. However, in order to achieve a 27% share of renewable resources, it is necessary to develop more RES. The study identifies additional technological and geographical potential to the development of solar PV, solar thermal, HPP, geothermal and wind energy, and emphasizes that these resources can be developed in the EU at a lower cost than traditional fossil fuels. The EU also has the potential to use biomass and bioethanol in transport and, in the case of biomass, in district heating as well. However, the costs of using these resources are projected to be higher than the costs of the fossil resources they replace. The share of wind and solar energy in total energy consumption is expected to increase the most.

In 2015, Latvia ranked third in the European Union in terms of the share of RES, lagging only behind Sweden and Finland. The IRENA study concludes that by increasing the rate of introduction of renewable energy resources, Latvia could produce more than half of the total amount of energy consumed with RES.

The above study also pays a special attention to economic aspects. To estimate the total system savings by increasing the share of RES, the LCOE of renewable energy sources was used in contrast to the LCOE traditional energy sources. In order to determine the benefits of increasing the share of RES in monetary terms, the projected avoided health care costs and the projected reduction of environmental costs as the rate of climate change decreases have been assessed. The IRENA *REmap* economic analysis concludes that realizing the full potential of RES identified in the study will require an annual investment of around USD 73 billion in the development of renewable technologies in the European Union (IRENA (1), 2018).

1.1.2.2. United States of America

The United States has a wide variety of tools and methods for the economic assessment of renewable energy. As mentioned in the introduction, a handbook for conducting an economic assessment of energy efficiency and renewable energy sources was published in the United States as early as 1995 (Walter Short, 1995). A number of economic and financial analysis tools and methods are currently available electronically on the US National Renewable Energy Laboratory's website (The National Renewable Energy Laboratory, n.d.). Two of the proposed models deal with specific technologies – the Community Solar Scenario Tool for the evaluation of solar energy projects and the hydrogen production and distribution model. The Cost of Renewable Energy Spreadsheet Tool (CREST) includes cost and cash flow models designed to assess the project's economy, develop cost-based incentives, and assess the impact of state and federal support structures on renewable energy. CREST is available for solar, wind and geothermal power plants, as well as for biogas production by anaerobic digestion and fuel cells. The website of the National Renewable Energy Laboratory also offers a tool for assessing the impact of the use of renewable energy resources on the labor market and economic development.

The above tools are based on the *MS Excel* spreadsheet, however, the US National Renewable Energy Laboratory has also developed and provides an open access website the System Advisor Model (SAM), a techno-economic computer model that calculates the operational and financial performance of renewable energy projects. Project developers, policy makers, equipment manufacturers and researchers use SAM result infographics and tables to assess financial, technological and support opportunities for renewable energy projects. SAM models the performance of solar PV, concentrated solar energy, solar collectors, wind, geothermal and biomass energy systems and includes a general basic model for comparison with conventional or other types of systems.

1.2. SPATIAL PROFILE OF ENERGY SOURCES

The most used fossil fuels in energy production are natural gas and oil products. However, the share of oil products has decreased and they are being replaced by natural gas and wood (for heat and cogeneration).

Renewable electricity sources include cogeneration plants, biomass plants, biogas plants, wind power plants (WPPs), hydroelectric power plants (HPPs) and solar power plants. In total, Latvia imports 70% of energy consumption, mainly due to dependence on natural gas and energy shortages (Energy Peat Europe, n.d.). The most important renewable energy sources today are water (hydropower) and wood (bioenergy).

In order to assess Latvia's opportunities for the development of renewable energy, it is important to identify the existing energy sources of fossil and renewable resources. Given that the potential of renewable energy sources is affected by spatially changing conditions, it is useful to use a mapping method for this purpose. Therefore, this chapter provides a summary of the spatial distribution of existing energy sources, the fuel consumed, the installed capacity and the energy produced. The information is presented by statistical regions, using the data available in the database of the Central Statistical Bureau of the Republic of Latvia.

1.2.1. Boiler houses

Referring to the data of the Central Statistical Bureau, in 2017 the largest number of boiler houses was in the Pierīga statistical region (178 boiler houses) (Fig. 1.4), in other statistical regions the number of boiler houses was significantly lower. In 2017, there were 64 boiler houses in Riga region.

In recent years, the number of boiler houses in general has had an uneven development trend, especially in the statistical regions of Riga, Pierīga and Kurzeme. More gradual changes in the number of boiler houses are typical in Vidzeme, Zemgale and Latgale regions.

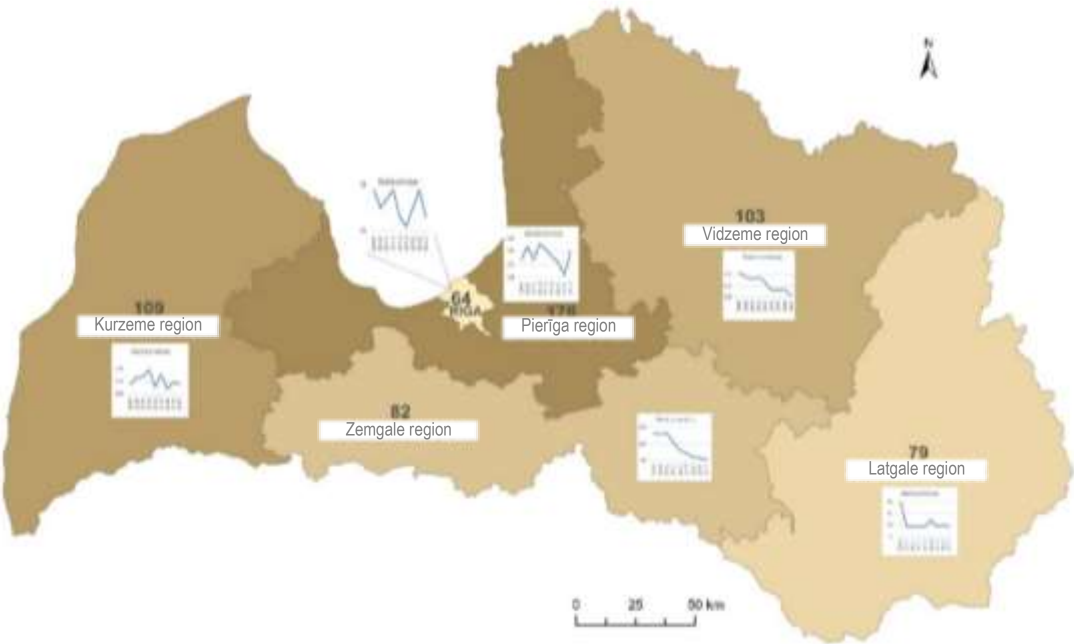

Fig. 1.4. Number of boiler houses in 2017 (GIS layout)

The total number of boiler houses in Latvia in 2017 was 615. In recent years, the number of boiler houses has been decreasing (Fig. 1.5). Compared to 2009, in 2017 there is a decrease of 63 boiler houses or 9.3%.

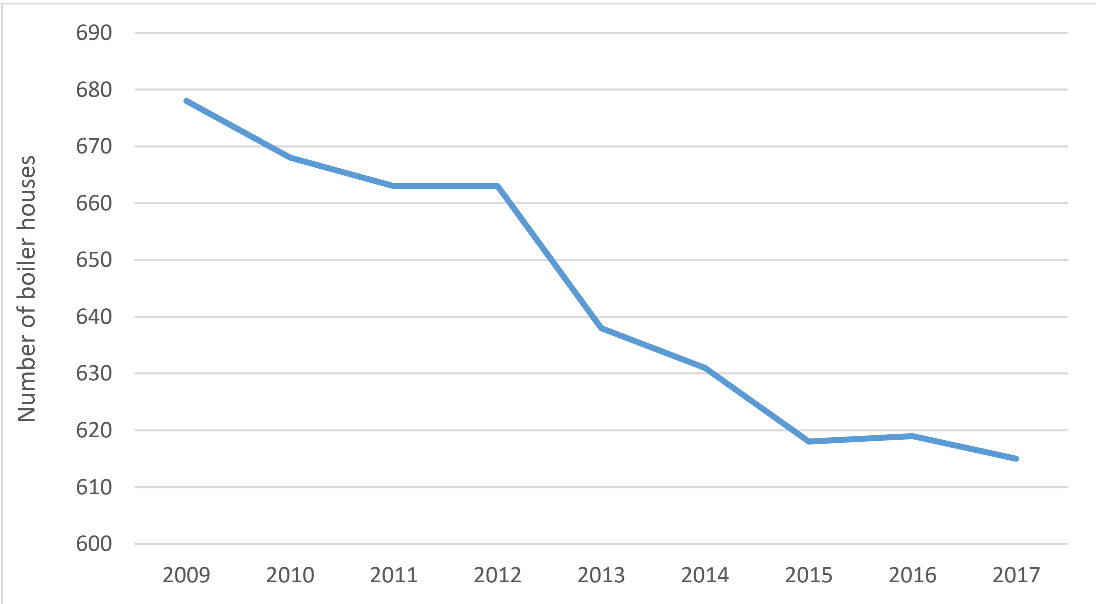

Fig. 1.5. Changes in the number of boiler houses from 2009 to 2017

Like the number of boiler houses, the total installed heat capacity in 2017 was the largest in the statistical region of Pierīga (572 MW) (Fig. 1.6). The lowest installed capacity was in Kurzeme region (256 MW).

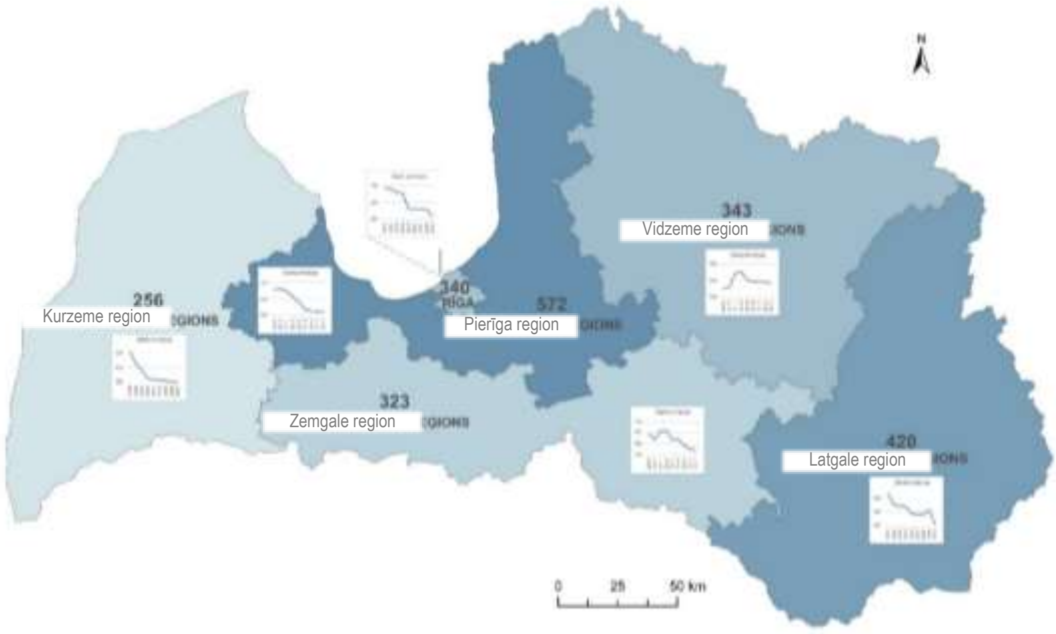

Fig. 1.6. Installed heat capacity of boiler houses in 2017, MW (GIS layout)

The installed heat capacity of boiler houses in Latvia has also been decreasing since 2009 (Fig. 1.7). If in 2009 the total capacity was 3644 MW, then in 2017 it was 2254 MW, marking a significant reduction by 1390 MW or 38%.

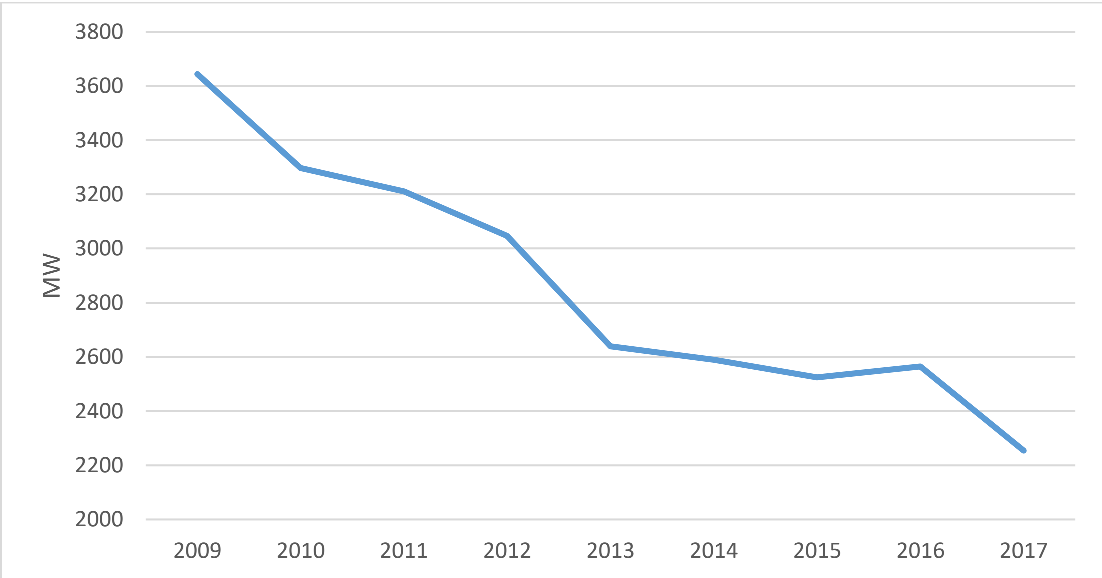

Fig. 1.7. Changes in the installed heat energy capacity of boiler houses from 2009 to 2017

According to the data of 2017, the two main types of fuel used in boiler houses are wood chips and natural gas (Fig. 1.8), which play an almost equal role in terms of installed heat capacity. Natural gas and wood chip boiler houses make up 82% of all boiler houses.

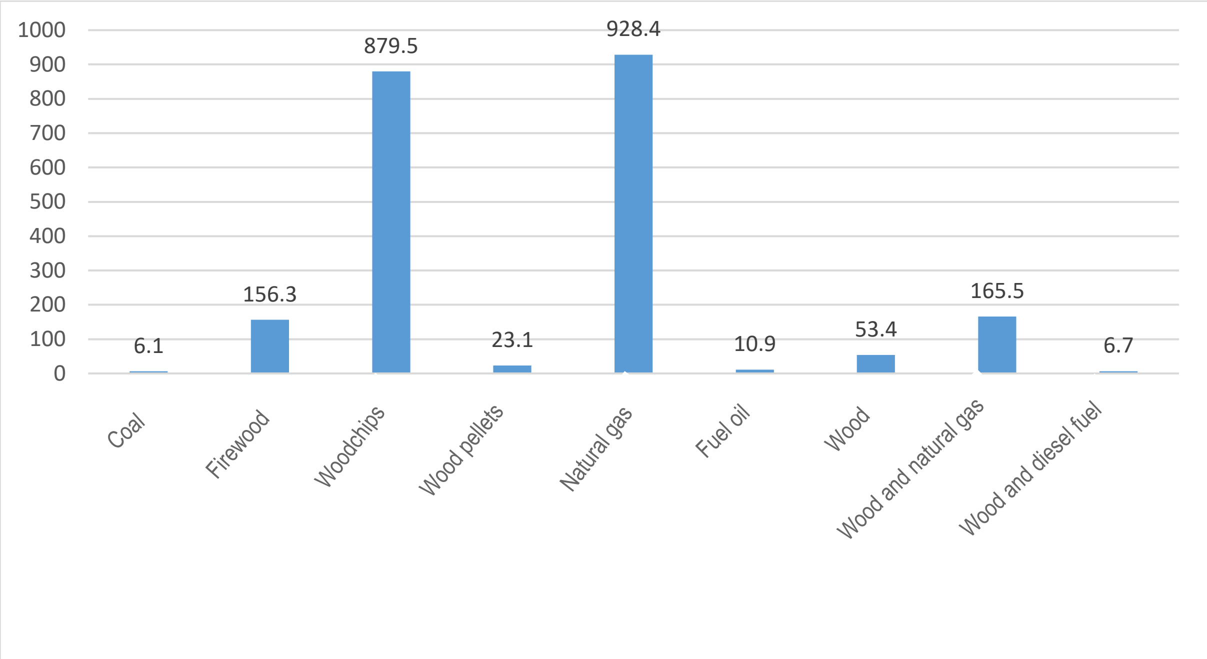

Fig. 1.8. Installed heat energy capacity of boiler houses by type of fuel consumed, MW

Assessing the change in the number of boiler houses over time by the type of fuel used (Fig. 1.9), it can be observed that the number of natural gas boiler houses has been decreasing since 2011. Meanwhile, the number of woodchip boiler houses has increased from 46 boiler houses in 2007 to 136 boiler houses in 2017. The number of wood pellet boiler houses has also increased. In turn, the number of firewood and fuel wood boiler houses is gradually decreasing.

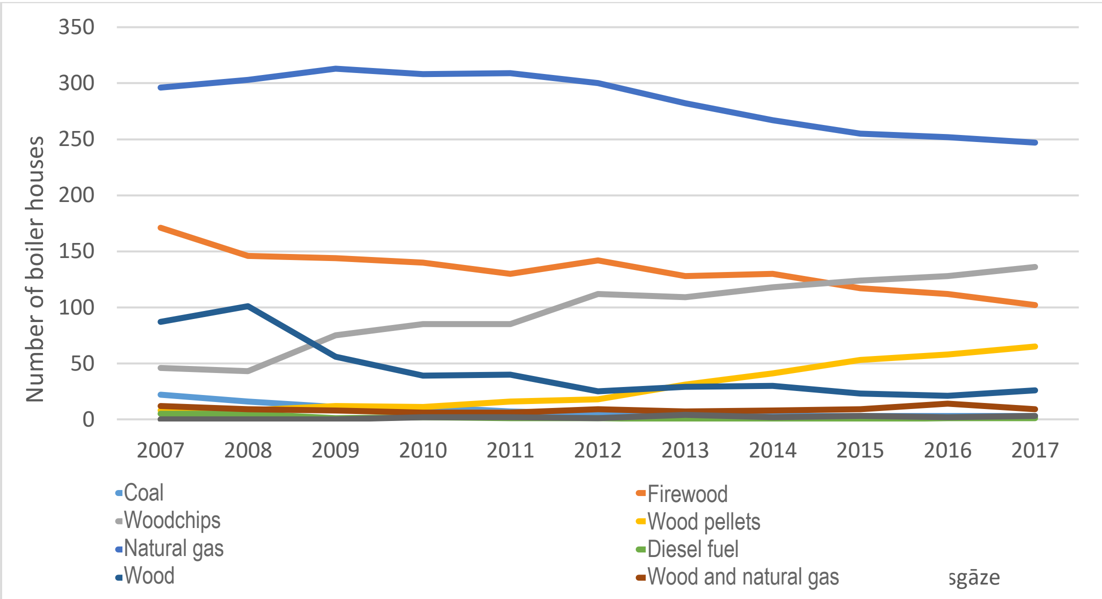

Fig. 1.9. Number of boiler houses by type of fuel from 2007 to 2017

1.2.2. Cogeneration plants

Like the number of boiler houses, the number of cogeneration plants in 2017 was the largest in the Pierīga region (56 stations) (Fig. 1.10). Generally, all regions have experienced a relatively steady increase in the number of cogeneration plants in recent years.

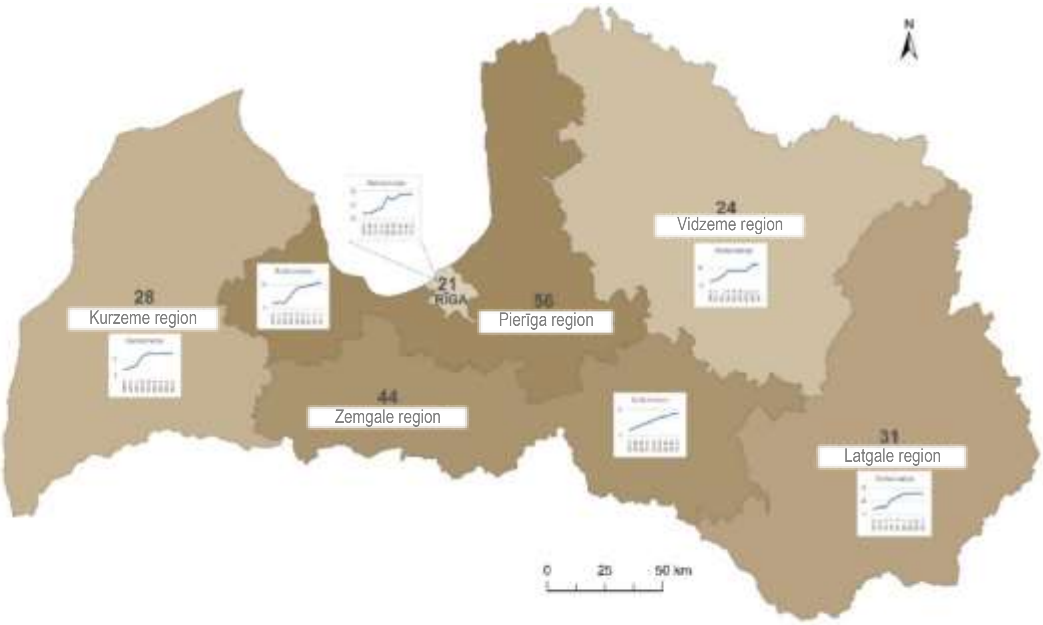

Fig. 1.10. Number of cogeneration plants in 2017 (GIS layout)

In Latvia, the number of cogeneration plants has increased by almost 4 times from 2009 to 2017 (Fig. 1.11), from 56 to 204 stations, respectively.

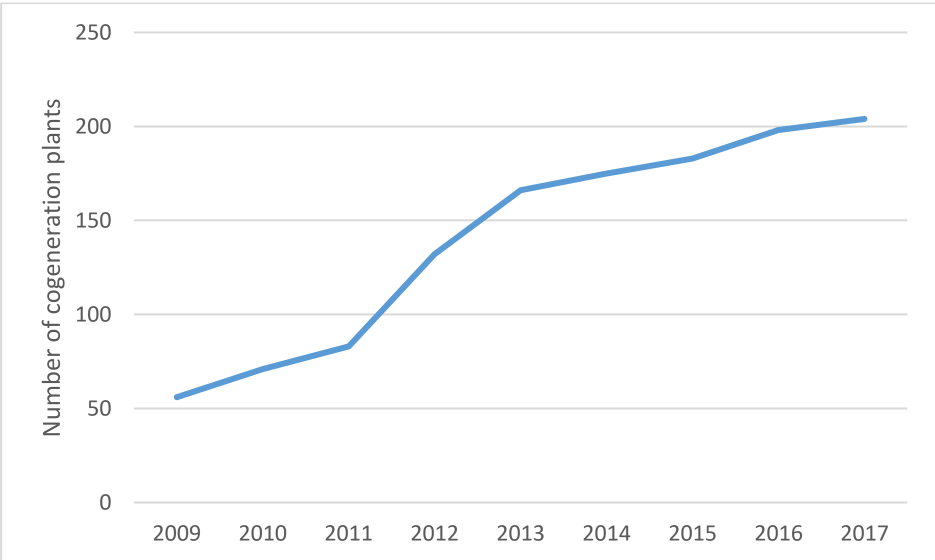

Fig. 1.11. Changes in the number of cogeneration plants from 2009 to 2017

The largest installed electric capacity for cogeneration plants in 2017 was in Riga (1059 MW) and accounted for 82% of the total capacity of cogeneration plants in Latvia (Fig. 1.12). In all statistical regions from 2009 to 2017, there was an increase in the installed capacity of cogeneration plants.

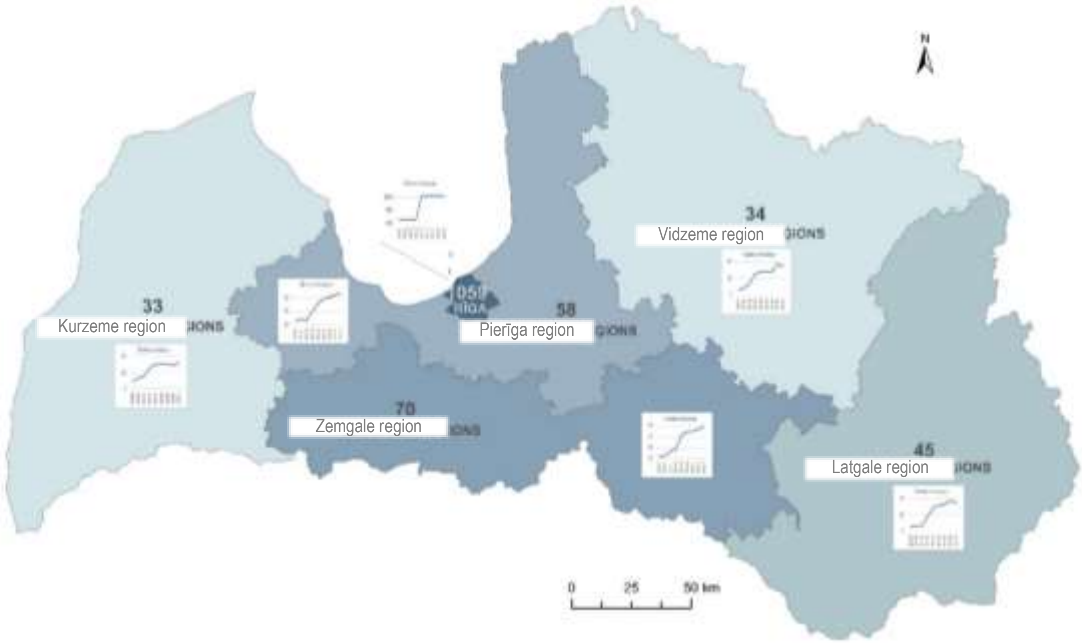

Fig. 1.12. Installed electric capacity of cogeneration plants in 2017, MW (GIS layout)

The total installed electric capacity of cogeneration plants has increased from 934 MW in 2009 to 1299 MW in 2017 (Fig. 1.13). The fastest growth is typical for the period from 2012 to 2013, when the capacity of cogeneration plants increased by 235.5 MW or 23 %.

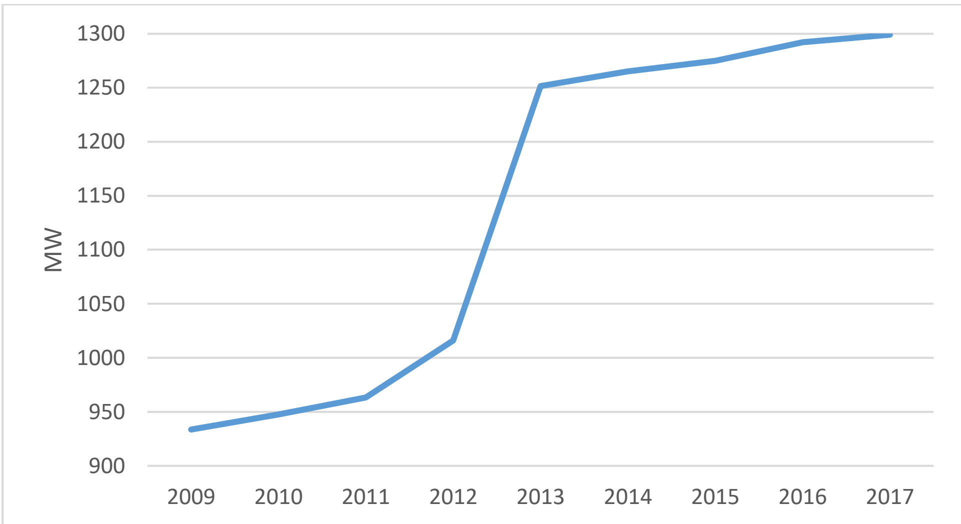

Fig. 1.13. Changes in the installed electrical capacity of cogeneration plants from 2009 to 2017

In total, in 2017, cogeneration plants produced 3000.1 GWh of electricity or 40% of the total amount of electricity produced in Latvia. Meanwhile, hydropower plants (HPPs) and wind power plants (WPPs) generated 4,351 GWh of electricity, of which 97% were generated by HPPs and 3% by WPPs. The share of electricity produced from renewable energy sources in cogeneration plants has been increasing in recent years, and in 2017 it reached 31%. The installed electric capacity of renewable energy cogeneration plants has increased by 15 times since 2008, and in 2017 it was 155 MW (Centrālā statistikas pārvalde (1), 2018).

According to Eurostat and the EBA (European Biogas Associacion, 2018), the number of biogas cogeneration plants increased from 15 to 59 between 2011 and 2016. The data show that energy crops are mainly used (around 75%), while other raw materials are residual and waste mixture. There are currently 59 biogas cogeneration plants with a total capacity of 60.62 MW. Fig. 1.14 shows the distribution of biogas cogeneration plants in Latvia in 2016 (European Biogas Associacion, 2018).

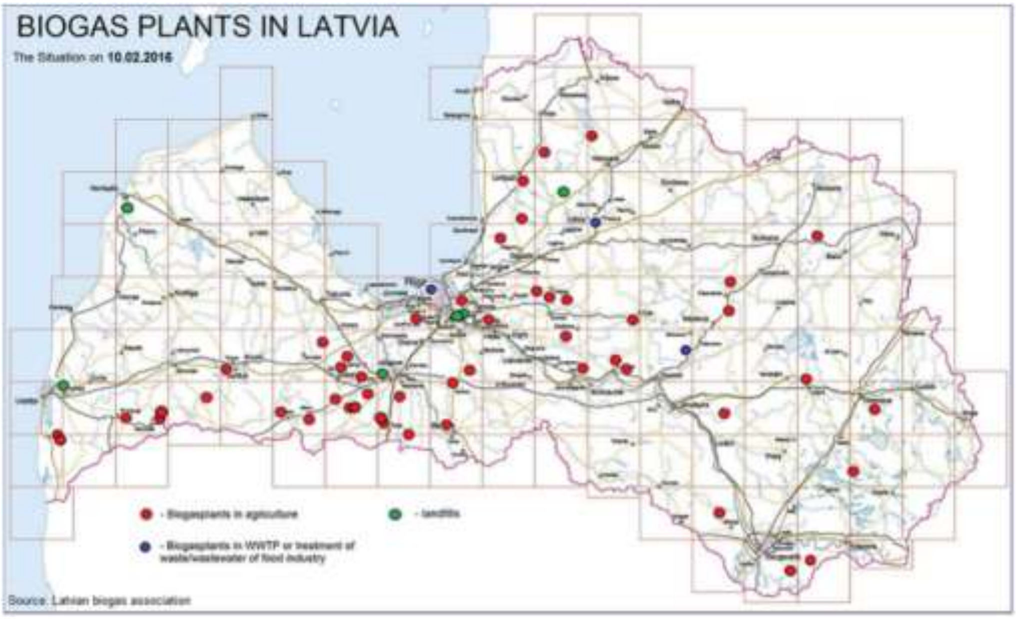

Fig. 1.14. Distribution of biogas cogeneration plants in Latvia (European Biogas Associacion, 2018)

The predominant fuel resource in Latvian cogeneration plants for electricity production in 2017 was natural gas (Fig. 1.15). About 4 times less fuel chips were used, while 5 times less – biogas.

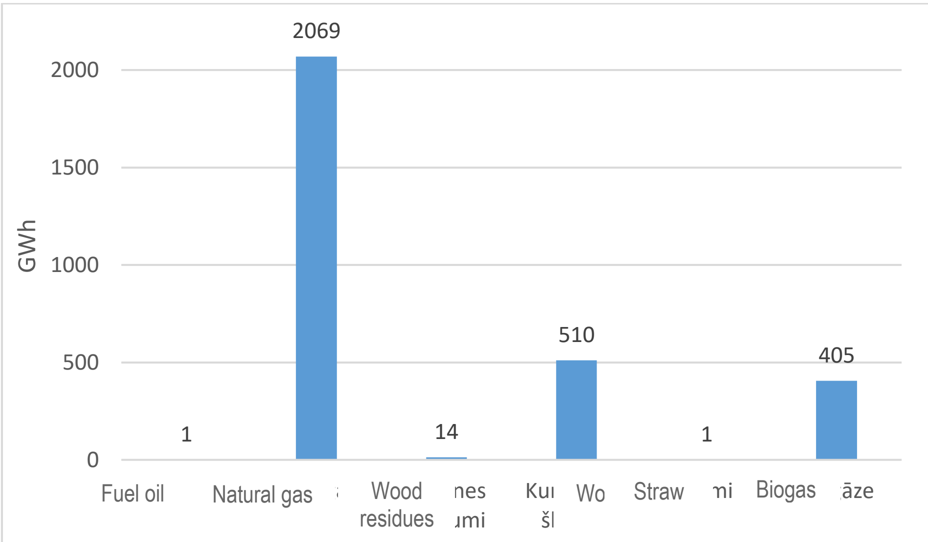

Fig. 1.15. Electricity produced in cogeneration plants in 2017 by type of fuel, GWh

Natural gas was also the main resource for the production of heat in cogeneration plants (Fig. 1.16). About 2 times less fuel chips were used, while biogas also played a much smaller but also an important role.

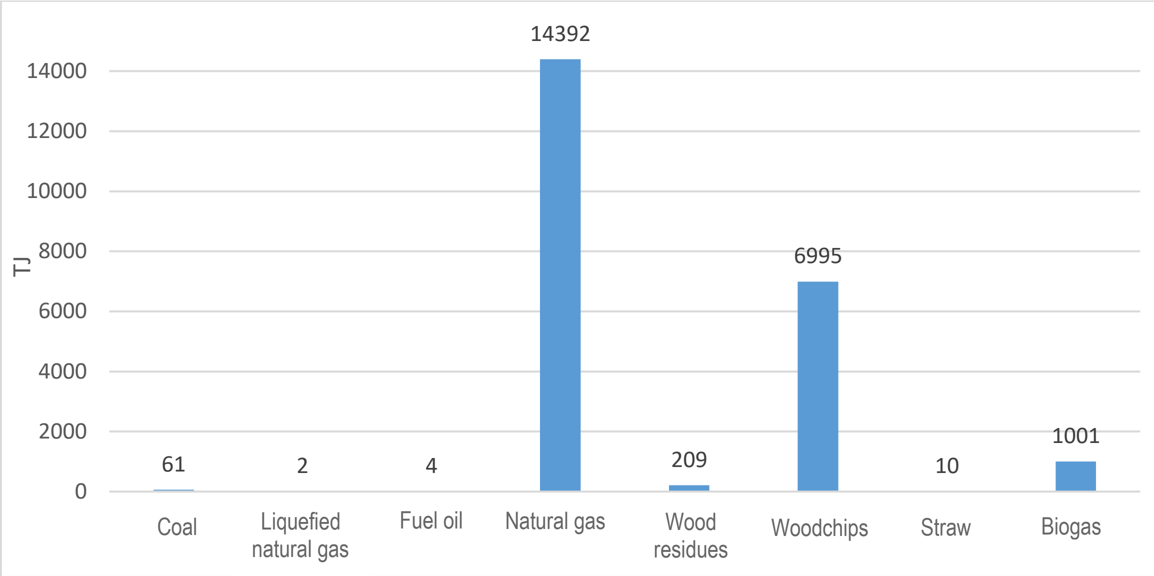

Fig. 1.16. Heat produced in cogeneration plants in 2017 by type of fuel, TJ

The analysis of the amount of fuel consumed in cogeneration plants in recent years (Fig. 1.17), show that the use of natural gas in 2017 compared to 2012 has decreased by approximately 1,500 TJ. Meanwhile, the use of fuel chips has gradually increased between 2012 and 2017.

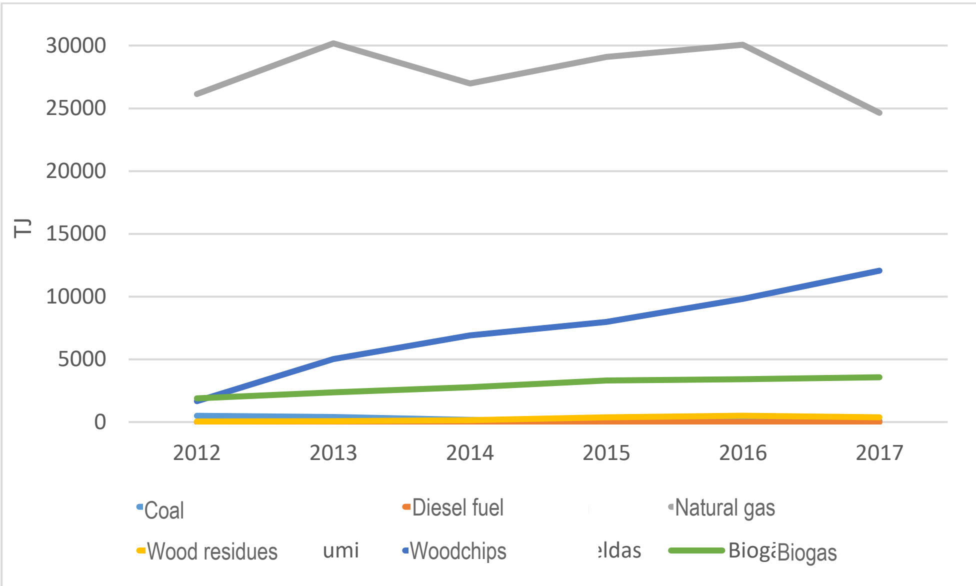

Fig. 1.17. Fuel consumed in cogeneration plants from 2012 to 2017, TJ

When comparing the changes in less used fuels over time (Fig. 1.18), it can be observed that the use of biogas in cogeneration plants has almost doubled from 2012 to 2017, from 1890 TJ to 3570 TJ, respectively. The use of wood residues is also generally increasing, while coal is being used less and less.

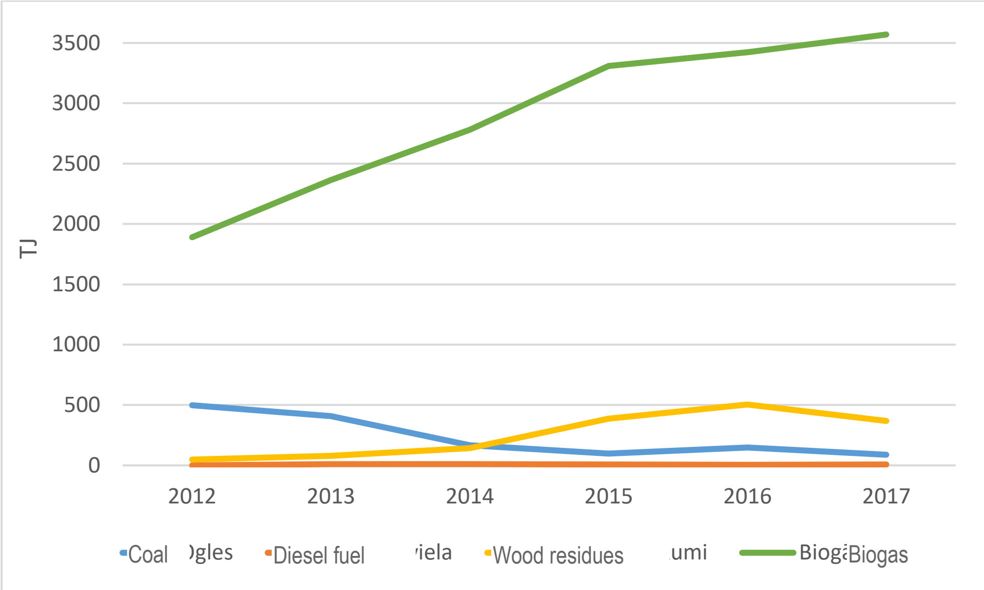

Fig. 1.18. Consumption of less used fuels in cogeneration plants from 2012 to 2017, TJ

Latvia's largest cogeneration plants are concentrated in Riga and their main type of fuel consumed is natural gas. A marked predominance of natural gas use is also characteristic of the Latgale region, while in the rest of Latvia wood chips, firewood and biogas also play an important role.

1.2.3. Hydropower plants

According to the data published by the transmission system operator JSC "Augstsprieguma tīkls", in 2017 the net electricity consumption in Latvia was 7,282,170 MWh, the average electricity exchange price decreased to 34.68 €/MWh and locally generated electricity (7,346,336 MWh) covered the Latvian electricity consumption by 101% (Table 1.2) (JSC "Augstsprieguma tīkls" (1), 2018).

Table 1.2

Electricity produced in Latvia

	HPP	Thermo-electric stations	WPP with trans-mission	Renewable and assisted electricity generators	Total amount of electricity produced in Latvia
2017, MWh	4 246 004	1 499 672	54 023	1 546 637	**7 346 336**
2016, MWh	2 436 885	2 276 264	52 269	1 465 838	**6 231 256**

Due to the amount of electricity generated by the three Daugava HPPs, hydropower is considered to be the leading renewable energy technology in Latvia (Fig. 1.19) (Centrālā statistikas pārvalde (2), 2018).

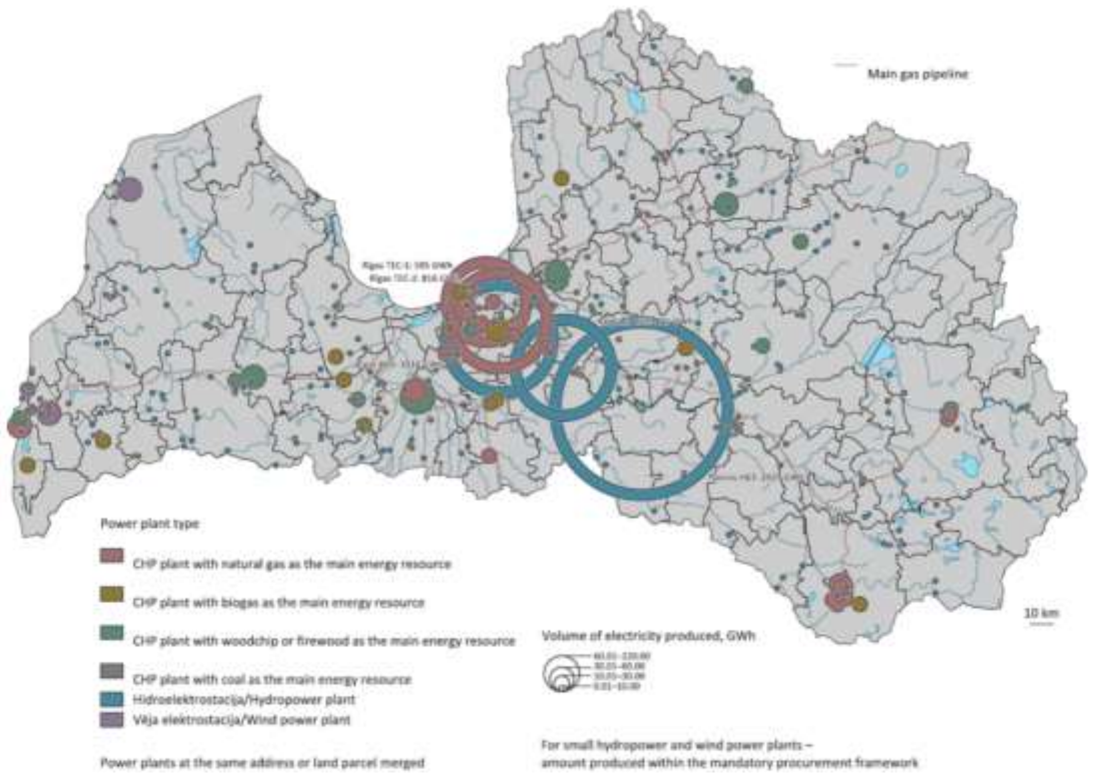

Fig. 1.19. Electricity produced in Latvia (2017)

Fig. 1.19 clearly shows that the most important role in Latvia's renewable electricity generation is HPPs, as HPPs are the largest electricity producers.

1.2.4. Other energy sources

1.2.4.1. Wind power plants

The total installed capacity of wind turbines in Latvia is slightly over 60 MW. This capacity is considered small compared to Estonia, where the installed capacity is more than 300 MW (according to the Estonian Wind Energy Association) and Lithuania, where the installed capacity is more than 500 MW (according to the European Wind Energy Association), where wind energy plays a greater role in the electricity balance.

Wind energy capacity installed in Latvia accounts for approximately 1.8% of electricity consumption (Āboltiņš, Vēja enerģijas izmantošanai Latvijā nākotnē ir labas perspektīvas, n.d.).

Referring to the information provided by JSC “Augstsprieguma tīkls”, in the last quarter of 2018 the share of WPP in electricity generation in Latvia's total electricity balance doubled (JSC "Augstsprieguma tīkls" (2), 2018).

In the last quarter of 2018, the share of wind energy in the total energy balance was 4.3% or 16,381 MWh in September and 4.1% or 15,851 MWh in October. The rapid increase in wind energy production can be explained by the first autumn storms, as well as the decrease in water reserves in the Daugava River, which reduced the energy produced by HPPs and increased the share of wind energy.

1.2.4.2. Solar panel systems

Latvia has almost as many solar energy resources as Germany (1757 h/year). However, the amount of electricity produced by solar panels is not similar. The installed solar energy capacity in Latvia in 2016 was 2 MW (National Meteorological Agencies, 2018).

1.2.5. Heat production

In 2017, the most heat energy was produced in Riga statistical region (4151 GWh) (Fig. 1.20), which accounted for approximately 50% of the heat produced in Latvia. Almost by 4 times less heat energy was produced in the Pierīga region (1118 GWh), but in other statistical regions the amount of heat produced was even smaller and more similar to each other. The amount of heat produced in Pierīga, Zemgale and Vidzeme regions has significantly increased since 2009, while in Kurzeme region it has decreased.

In total, 8328.7 GWh of heat energy was produced in 2017. Of these, 76% or 6301.7 GWh were produced in cogeneration plants, while the remaining 24% or 2027 GWh – in boiler houses (CSB database, n.d.).

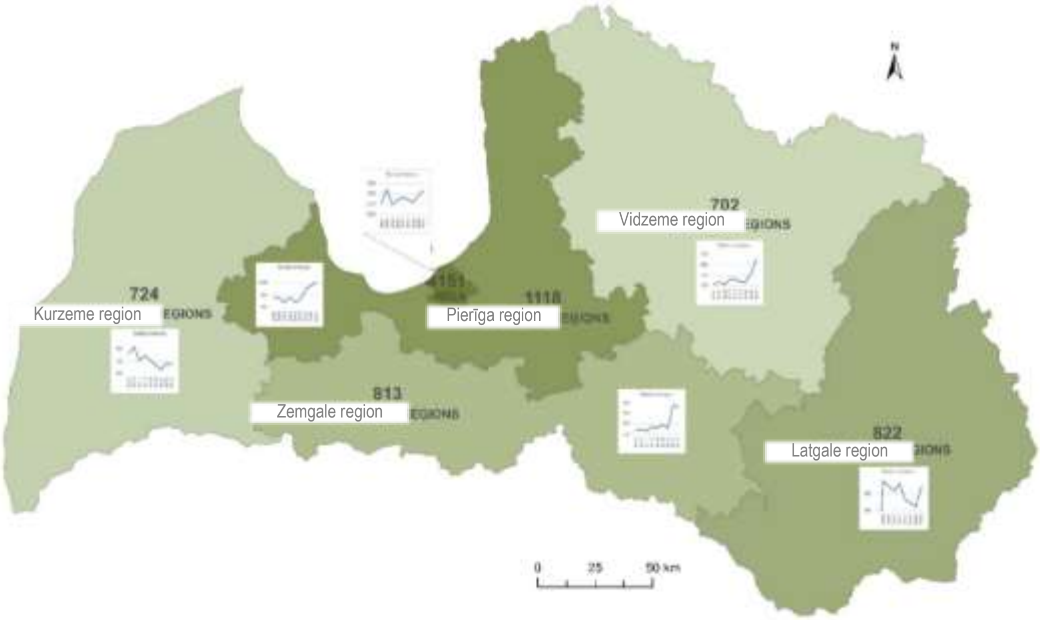

Fig. 1.20. Heat produced in 2017, GWh (GIS layout)

The amount of heat produced in Latvia in recent years varies (Fig. 1.21), however, from 2015 to 2017 it has grown rapidly, from 7072 GWh to 8330 GWh, respectively, which is mainly due to the development of cogeneration plants.

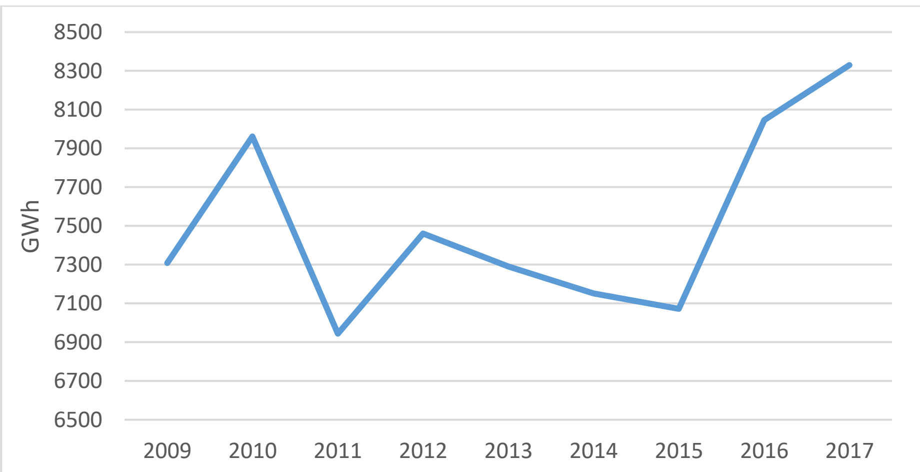

Fig. 1.21. Changes in heat production from 2009 to 2017

1.3. Renewable energy potential in Latvia

1.3.1. Spatial distribution of local and renewable energy sources

In order to plan territorially unified development of renewable energy and, consequently, promote efficient use of resources, it is crucial to explore spatial distribution of resources. This sub-section provides analysis of spatial distribution of the main local and renewable energy sources. It is approached at two levels – municipal level (districts and republican cities) and regional level (statistical regions). Analysis at municipal level allows to evaluate individual possibilities for each municipality to utilize its resources, as well as to estimate the potential opportunities for collaboration with the neighbouring municipalities. Analysis at regional level, in turn, provides a simplified insight into the distribution of resources in Latvia and can be useful in planning development at regional scale. In addition, considering the upcoming regional reform, analysis at regional level will be particularly important.

The main resources for the development of renewable energy considered in this chapter are: solar energy, wind energy, as well as various types of bioresources – sewage sludge, manure, straw and wood. Taking into account the relatively wide distribution of bogs in Latvia, the chapter also considers the distribution of peat as a local energy source. Given that the greatest potential of hydropower is already being realized (Ministry of Economics, 2011), further expansion of hydro energy is not considered in this study. Algae is also a potential resource for energy production, however, taking into account that algae resources are difficult to estimate, as well as considering that algae can be cultivated, this type of resource is not spatially evaluated in this study. Another promising resource for renewable energy is municipal waste. However, given the limited availability of spatial data by type of waste and taking into account the fact that waste to energy is still one of the most expensive types of energy production (Mohammadi & Harjunkoski, 2020), waste resources are not spatially evaluated in this study as well.

1.3.2. Wind resources

Both onshore and offshore winds in Latvia are sufficient to produce wind energy. Latvia is dominated by the west and south-west winds. The geographical location of Latvia, as well as the coast of the Baltic Sea and the Gulf of Riga create suitable conditions for the use of wind energy. Latvia's flat terrain provides an opportunity to produce wind energy not only offshore, but also onshore.

In order to characterize the spatial distribution of wind energy in Latvia, data on the mean wind speed in statistical regions and municipalities have been compiled. Data were obtained from the global Wind Atlas (Technical University of Denmark, World Bank Group, n.d.), which uses wind climatic data for a time period from 2008 to 2017. Taking into account the current tendencies for wind turbine heights, data were obtained for wind speed at 100 m height.

Fig. 1.22 shows that the highest mean wind speed is in Kurzeme region (7.2 m/s), slightly lower speed is typical for Zemgale and Latgale regions (7.1 m/s), while the lowest mean wind speed is in Vidzeme region and in Riga (6.9 m/s).

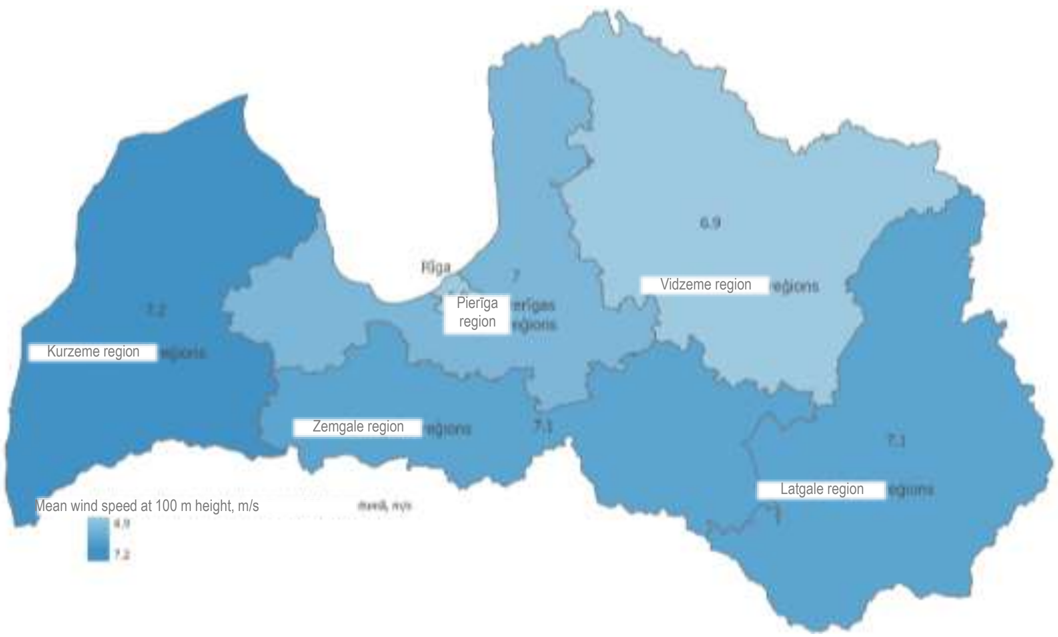

Fig. 1.22. Mean wind speed at 100 m height in statistical regions, m/s (GIS layout, data source: *Global Wind Atlas* (Technical University of Denmark, World Bank Group, n.d.))

At municipal level it can be seen that the highest mean wind speed is in Liepāja (8.2 m/s), followed by Ventspils city (8.0 m/s) and Rauna district (7.8 m/s) (Fig. 1.23). The lowest mean wind speed values are characteristic for municipalities in Pierīga region – Inčukalns district (6.3 m/s), Garkalne district (6.4 m/s) and Ropaži district (6.5 m/s), as well as in Lubāna district (6.5 m/s), which is located in Vidzeme region. Overall, municipalities with higher mean wind speeds are concentrated in Kurzeme, the western part of Zemgale and the central part of Latgale.

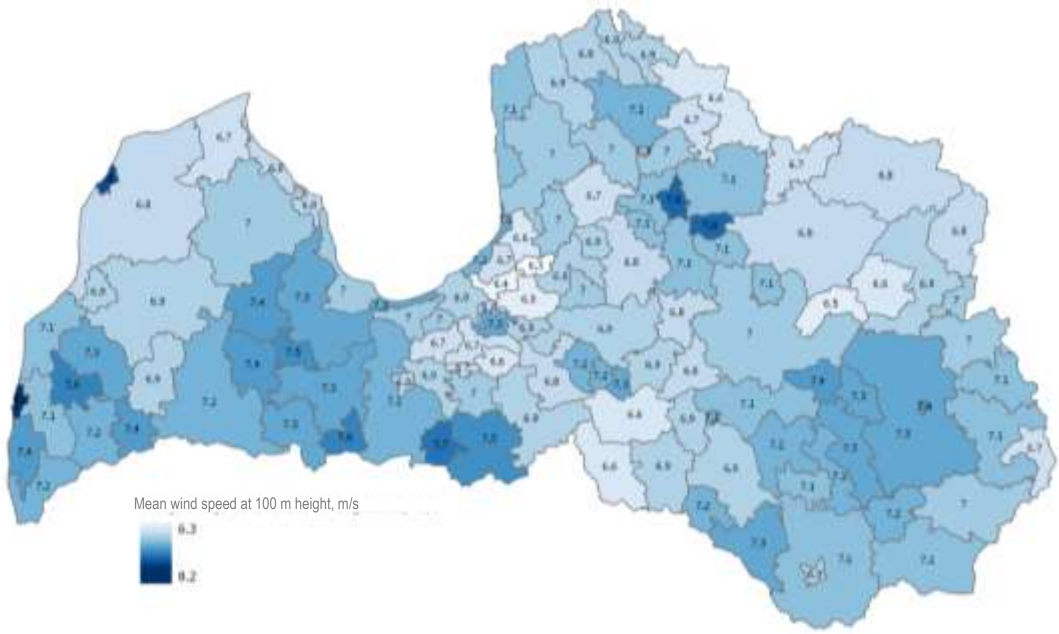

Fig. 1.23. Mean wind speed at 100 m height in municipalities, m/s (GIS layout, data source: *Global Wind Atlas* (Technical University of Denmark, World Bank Group, n.d.))

1.3.3. Solar energy resources

In Latvia, the duration of sunshine is about 1700 – 2000 hours a year (average of 1757 hours). The longest duration of sunshine is in July (approximately 300 hours), while the lowest – in December (approximately 25 hours or less than an hour a day) (LVĢMC, n.d.).

In order to estimate the differences in solar irradiation between regions and municipalities, data from European Commissions' Photovoltaic Geographical Information System was used (European Commission, 2019). Solar energy resources are represented with the data on annual irradiation at 35° slope.

Fig. 1.24 shows that the highest solar irradiation is in Kurzeme region (1180 kWh/m^2/year), while the lowest – in Vidzeme region (1121 kWh/m^2/year).

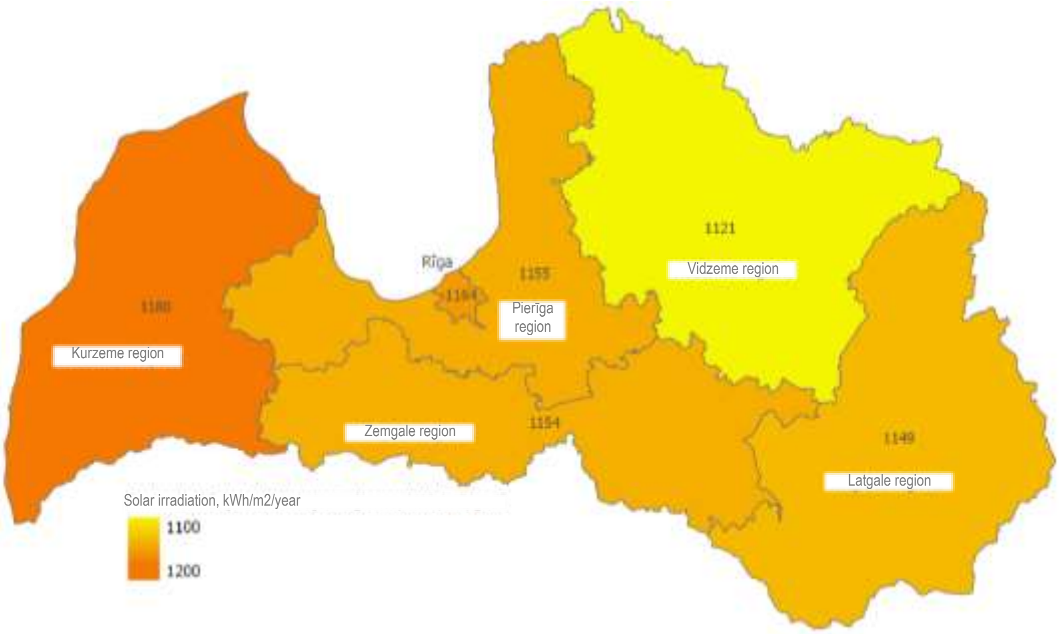

Fig. 1.24. Solar irradiation in statistical regions, kWh/m^2/year (GIS layout, data source: Photovoltaic Geographical Information System (European Commission, 2019))

Visualization of data at municipal level (Fig. 1.25) shows that the highest intensity of solar irradiation is on the coast of Kurzeme – Liepāja city (1268 kWh/m^2/year), Nīca district (1250 kWh/m^2/year), Ventspils city (1235 kWh/m^2/year), Pāvilosta district (1222 kWh/m^2/year), Rucava district (1218 kWh/m^2/year) and Grobiņa district (1212 kWh/m^2/year), as well as in Salacgrīva district (1215 kWh/m^2/year) on the coast of Vidzeme. Municipalities with the lowest intensity of irradiation are concentrated in Vidzeme region. The lowest values are in Valka district (1100 kWh/m^2/year), Cēsu district (1104 kWh/m^2/year), as well as in Līgatne, Priekuļi and Vecpiebalga district (1009 kWh/m^2/year).

Fig. 1.25. Solar irradiation in municipalities, kWh/m^2/year (GIS layout, data source: Photovoltaic Geographical Information System)

1.3.4. Biomass resources

1.3.4.1. Sewage sludge

Most of sewage sludge produced in Latvia is stored and not utilized. However, sludge is a promising renewable energy source. Biogas produced from sewage sludge can be used for heating, in internal combustion engines, as well as for electricity production (Latvijas Biotehnoloģijas asociācija, 2015).

Data on the sewage sludge production were obtained from the Latvian Environment, Geology and Meteorology Centre's summary *2-Ūdens* for a year 2018 (LVĢMC, 2019). The amount of sludge is expressed in dry matter.

Considering that the amount of produced sewage sludge depends on the water consumption, the largest amount of sludge is typical for cities (which is clearly shown in Fig. 1.27 at municipal level). Accordingly, evaluation at regional level shows that significantly large amount of sludge in 2018 was produced in Riga (29.47 t/km^2) (Fig. 1.26). Comparison of other regions shows that Pierīga region is the second largest sewage producer (0.35 t/km^2), while the smallest amount of sludge was produced in Kurzeme region (0.17 t/km^2) and Zemgale region (0.18 t/km^2).

Fig. 1.26. Sewage sludge resources in statistical regions in2018, t dry matter/km2 (GIS layout, data source: Latvijas Vides, ģeoloģijas un meteoroloģijas centrs (LVĢMC, 2019)

Evaluation of sludge resources at municipal level shows that considerably more sludge than in Riga (29.47 t dry matter/km^2) was produced in Valmiera (50.49 t dry matter/km^2) (Fig. 1.27). Riga was followed by Daugavpils (21.55 t dry matter/km^2), Jelgava (20.37 t dry matter/km^2) and Ventspils (18.74 t dry matter/km^2).

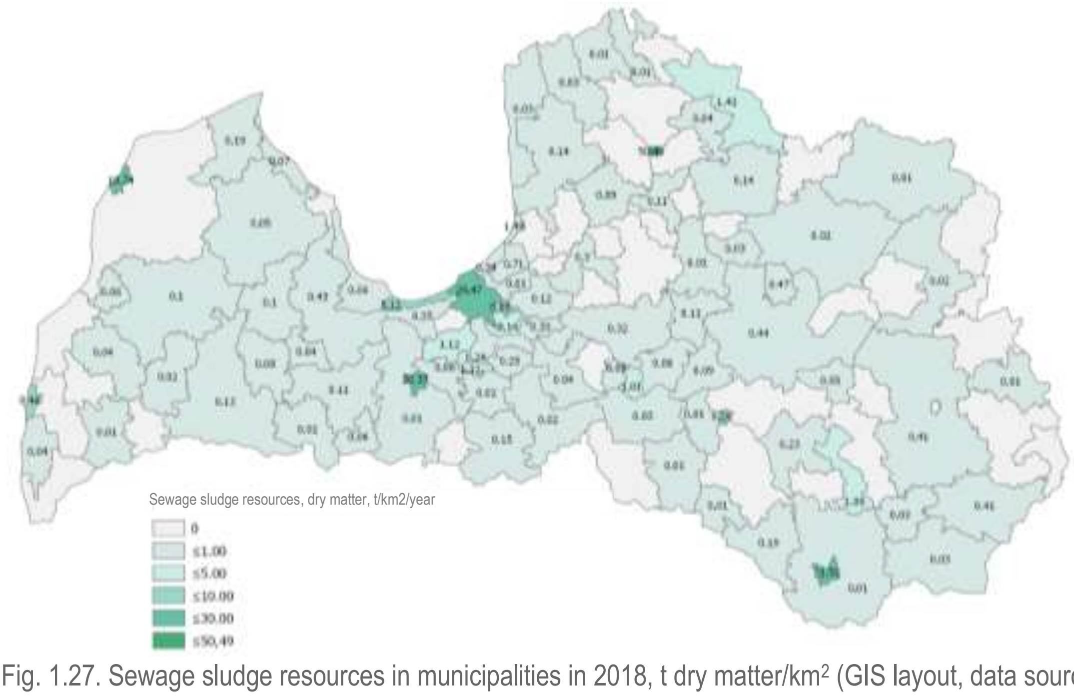

Fig. 1.27. Sewage sludge resources in municipalities in 2018, t dry matter/km^2 (GIS layout, data source: Latvijas Vides, ģeoloģijas un meteoroloģijas centrs (LVĢMC, 2019))

1.3.4.2. Manure

Manure biofermentation is increasingly used technology for bioenergy production worldwide. Theoretically, any type of manure or its organic by-products can be used for fermentation. Often companies operating in this field create a mixture of manure and other agricultural residues. Manure fermentation produces methane (55–65 %) and carbon dioxide (35–40 %)(Asveld, van Est, & Stemerding, 2011). In 2017 a total amount of 451 921 tons of manure was produced in Latvia in companies, which reports with the national statistical report "3–Pārskats par atkritumiem" (LVĢMC, 2018).

Amount of manure production was calculated from the data on the number of animals in municipalities in 2019 obtained from the public database of Agricultural Data Centre of the Republic of Latvia (Agricultural Data Centre, 2020). Calculations are based on data on cattle and pig manure, considering that these are the most common types of manure used for biogas production. To calculate the amount of manure produced, information on manure yield per animal provided in the national standard of the Ministry of Agriculture of the Republic of Latvia "Manure extraction and management" was used (Ministry of Agriculture, 2008). The manure classification given in the above-mentioned document was used to calculate the dry matter. According to this classification, solid litter manure is manure with at least 15 % dry matter content, while liquid manure is any mixture of solid excrement, urine and water with a dry matter content of 3 to 8 %. Calculations are based on the lowest possible values, 15 % and 3 % respectively.

Visualization of the amount of manure produced in 2019 at regional level shows that there was at least twice as much manure in Zemgale as in other regions – 35.4 t dry matter/km^2 (Fig. 1.28). In other regions the amount of manure was somewhat similar to each other, except for Riga, where the approximate amount of manure was only 100 kg dry matter/km^2.

Fig. 1.28. Manure production in statistical regions in 2019, t dry matter/km^2 (GIS layout, data source: Agricultural Data Centre of the Republic of Latvia and national standard "Manure extraction and management" (Agricultural Data Centre, 2020) (Ministry of Agriculture, 2008))

Data visualization at municipal level shows that most manure in 2019 was produced in Tērvete district (482.7 t dry matter/km^2), followed by Stopiņi district (306.7 t dry matter/km^2) (Fig. 1.29). In general, the values for manure production differ greatly between municipalities. According to the data of the Agricultural Data Center, in several municipalities no manure was produced (Saulkrasti district, Garkalne district and Jūrmala city) or the amount produced was insignificant (for example, in several republican cities).

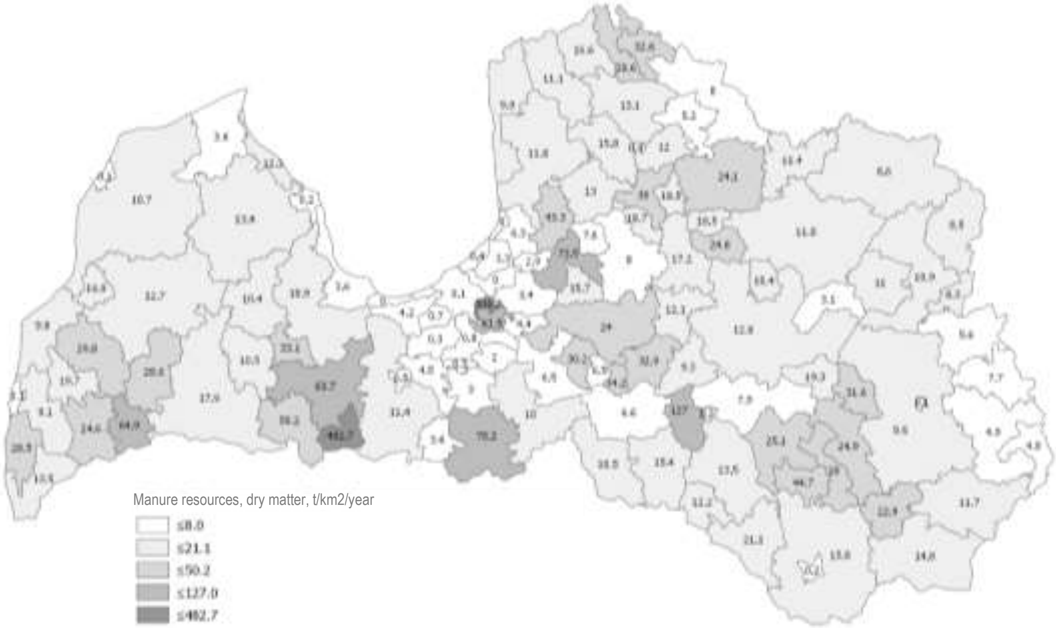

Fig. 1.29. Manure production in municipalities in 2019, t dry matter/km^2 (GIS layout, data source: Agricultural Data Centre of the Republic of Latvia and national standard "Manure extraction and management" (Agricultural Data Centre, 2020) (Ministry of Agriculture, 2008))

1.3.4.3. Straw

By application of various technologies straw can be used to produce electricity and heat, as well as solid, gaseous and liquid biofuels, providing a diverse supply for energy market (Wang, Li, Song, Duan, & Wang, 2018).

Amount of straw production were calculated from Rural Support Service's data on cereal areas in 2018 (Rural Support Service, 2018) and Central Statistical Bureau's data on cereal yield in municipalities in 2018 (CSB database, 2020). Calculations are based on yields of oats, wheat, barley, rye, triticale and buckwheat. Data on grain-straw ratio were obtained from the scientific literature for oats, wheat, barley, rye and triticale (Rozakis, 2013) and for buckwheat (Kara, 2014), while data on moisture content were adopted from Joint Research Center's expert consultation protocol "Cereals Straw Resources for bioenergy in the European Union" (Joint Research Centre, 2007).

Calculations show that in 2018 most straw was produced in Zemgale region (32.2 t dry matter/km^2) (Fig. 1.30), which can be explained by the high agricultural activity in the region. Significantly less straw was produced in Kurzeme region (18.7 t dry matter/km^2).

Fig. 1.30. Straw production in statistical regions in 2018, t dry matter/km^2 (GIS layout, data source: Rural Support Service, Central Statistical Bureau and Joint Research Centre (Rural Support Service, 2018) (CSB database, 2020) (Joint Research Centre, 2007))

Assessment of straw production at municipal level shows that the highest values are concentrated in the western part of Zemgale region (Fig. 1.31). The highest straw productivity in 2018 was in Tērvete district (105.8 t dry matter/km^2), which was followed by Liepāja (96.5 t dry matter/km^2) and Rundāle district (95.5 t dry matter/km^2). Meanwhile, according to Rural Support Service's data in Jūrmala city and in Garkalne and Mērsrags districts there was no or negligible cereal harvest.

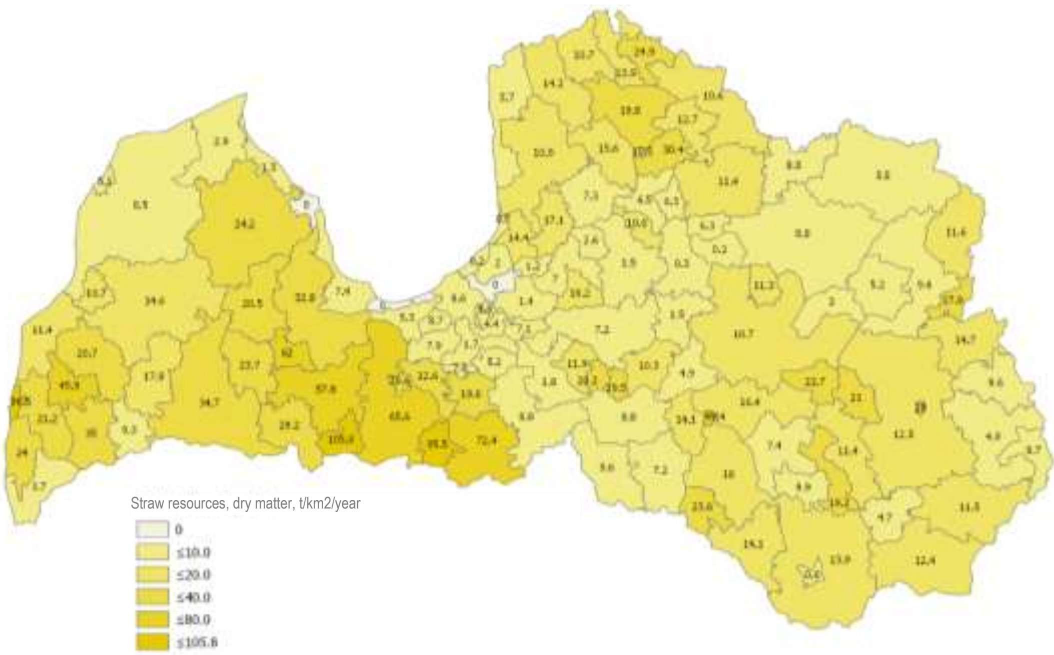

Fig. 1.31. Straw production in municipalities in 2018, t dry matter/km^2 (GIS layout, data source: Rural Support Service, Central Statistical Bureau and Joint Research Centre (Rural Support Service, 2018) (CSB database, 2020) (Joint Research Centre, 2007))

1.3.4.4. Low-quality wood

Considering the increasing demand for wood resources, as well as taking into account the principles of bioeconomy, according to which qualitative wood should be primary used for products with high value-added, for the purposes of this research only low quality wood is considered as energy resource.

Data on wood stock in municipalities were obtained from State Forest Service's of the Republic of Latvia Forest statistics for 2019 (State Forest Service, 2019). According to information provided in literature, it is assumed that low quality wood (branches, bark and foliage) represents 40 % of the total wood stock (Townsend, 2008).

Fig. 1.32 represents low quality wood stock resources per 1 km^2 in 2019. The highest amount of low quality resources is in Kurzeme region (1908 t/km^2), Pierīga region (1905 t/km^2) and Vidzeme region (1895 t/km^2), while the lowest amount is in Riga statistical region (794 t/km^2).

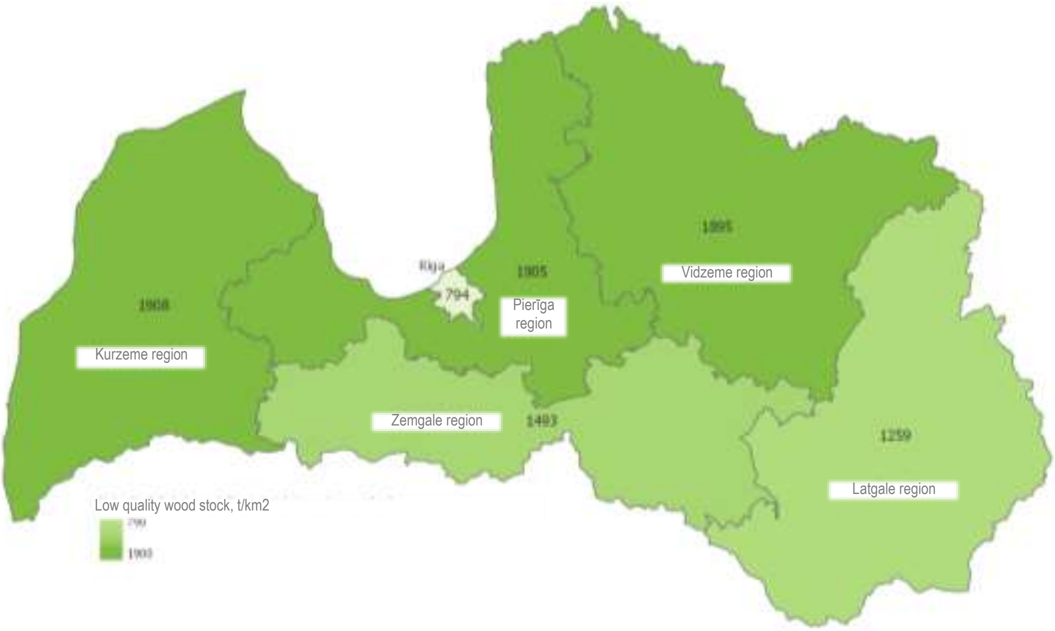

Fig. 1.32. Low quality wood stock in statistical regions in 2019 (GIS layout, data source: State Forest Service's Forest statistics (State Forest Service, 2019))

When evaluating data at municipal level, municipalities with the highest amounts of wood resources are concentrated in Pierīga region and northern part of Kurzeme (Fig. 1.33). According to data from 2019, municipality with the highest amount of low-quality wood resources is Garkalne district (2902 t/km^2), which is followed by Roja district (2783 t/km^2) and Baldone district (2728 t/km^2). Meanwhile, the lowest amount of low-quality wood resources in 2019 was in Rēzekne city (35 t/km^2).

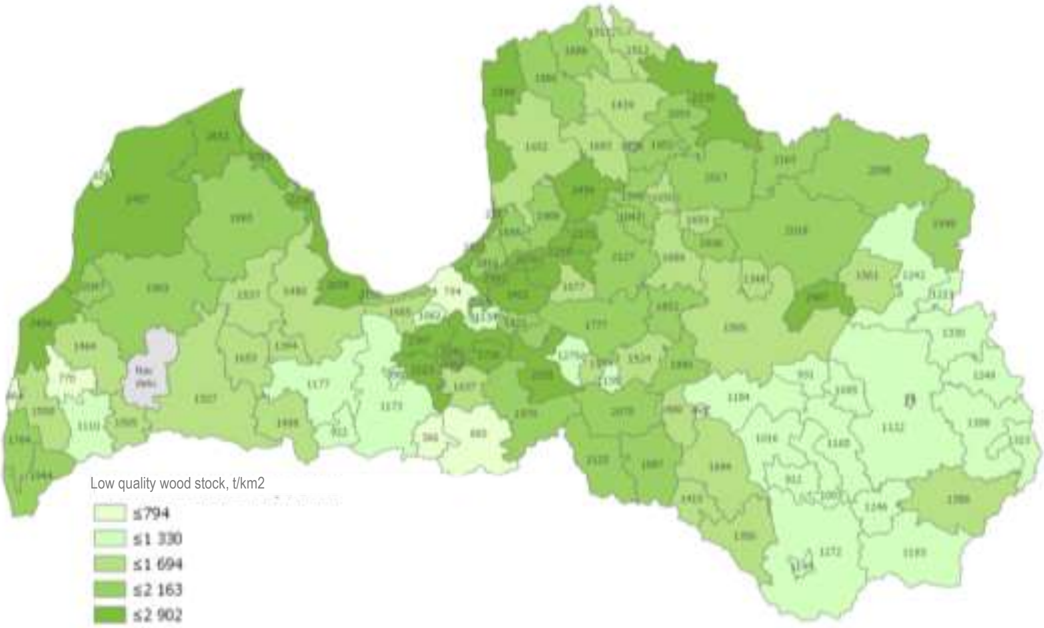

Fig. 1.33. Low quality wood stock in municipalities in 2019 (GIS layout, data source: State Forest Service's Forest statistics (State Forest Service, 2019))

1.3.5. Peat

Another widespread bioresource in Latvia is peat. The Latvian Energy Development Guidelines 2014–2020 highlights the significant potential of peat energy, indicating that there is already 4 000 hectares prepared for peat extraction (Saeima of the Republic of Latvia, 2010). The energy value of peat reserves is 663 TWh (Energy Peat Europe, n.d.), according to the assessment of the European Energy peat Agency.

More than 9600 peat deposits have been researched in Latvia. In Fig. 1.34 it can be seen that almost all districts have at least some areas of bogs.

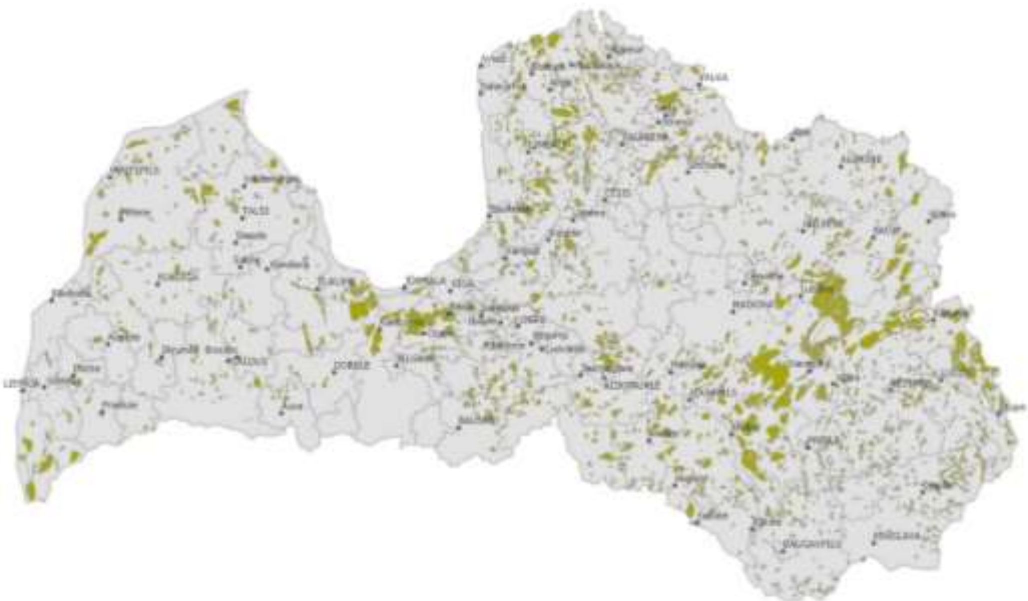

Fig. 1.34. Distribution of bogs in Latvia (GIS layout, data source: GIS Latvija 10.2.)

Considering that bogs are potential peat deposits, they cover 10 % of Latvia's territory. Areas with typical bog vegetation cover 4.9 % of territory, while 10 % have been researched in detail regarding peat resources.

The largest bogs are Teiči, Ķemeri and Cena. Latvian bogs are mainly owned by the JSC "Latvia's State Forests" and local governments.

Around 40 % of bogs have a conservation status – 128 000 ha are included in *Natura 2000* sites. Overall, economic activities in these areas are prohibited. Latvian climatic conditions (rainfall exceeds evaporation) and terrain (much of the flats) create environment favourable for the development of existing swamps and formation of new swamps (Latvijas Kūdras asociācija, n.d.).

1.3.6.1. Renewable energy technologies in Latvia

The world is now at the beginning of the global energy transformation. A long-term vision in the field of renewable energy and cost-effective renewable energy technologies have provided an opportunity for sufficient development in order to reach ambitious climate targets in the EU (Directive 2009/28/EC on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC, 2009).

Synergies between renewable energy sources, which contribute to the deployment of renewable energy technologies, have been identified at the level of many technologies as well as at sectoral level. Renewable energy technologies have evolved steadily over the past decade, so renewables have become competitive enough to meet the demands of the new generation. Moreover, electricity costs from renewable sources continue to fall.

Renewable energy sources are expanding opportunities for industrial development and can boost economic growth and create new jobs. All EU countries, including Latvia, have the potential to use renewable energy resources in a cost-effective way (United Nations, 2015).

This chapter gives an overview of the solar, wind, hydroenergy and bioenergy sectors, focusing mainly on the analysis of existing renewable energy technologies rather than forecasting their expected development. In order to assess the potential of renewable energy resources, it is necessary to identify the strengths and weaknesses of renewable energy and renewable energy technologies. A more extensive analysis of renewable energy sources helps to assess future investments, as well as costs for technology use, adaptation and sustainable use (IRENA (1), 2018).

1.3.6.1. Energy from biomass

Bio-energy power generation technologies are commercially available and have high efficiency. Most mature bio-energy technologies include low-percentage co-firing, municipal solid waste incineration, anaerobic digestion, direct combustion in stoker boilers, landfill gas and CHP. Less mature technologies, such as pyrolysis and atmospheric biomass gasification, are only at the starting point of deployment. Moreover, bio-energy fuels can provide heat at all temperature levels.

Electricity can be generated from a vast variety of biomass feedstock and with a wide range of different combustion technologies. There is also involved a large range of suppliers. The main aspects that must be examined are feedstock (variety of forms, properties' impact on energy generation), conversion (the process when feedstock is transformed into energy) and power generation technology (risks for more innovative technologies).

The most important factor of the economic success of bio-energy projects is the availability of a trusted, secure and sustainable feedstock supply for conversion. Biomass as feedstock has many critical issues – particle size, ash content, density and moisture content. These issues have an impact on the cost of feedstock's transportation, pre-treatment and storage costs. All that can complicate economic viability and planning of biomass-based power plants. Unlike solar, wind and hydropower, the economics of bio-energy power generation depends on the low-cost, long-term, sustainably sourced and predictable feedstock supply. Feedstock accounts for 20–50% of the final costs of electricity production from biomass technologies.

Total investment costs are presented by major categories, like construction, engineering and planning, fuel handling, preparation machinery and other equipment costs. Additional costs correspond to grid connections and infrastructure (transmission lines, roads, etc.). CHP installations have higher capital costs, however, the overall efficiency and possibility to produce heat significantly improves the economics.

Fixed operation and maintenance costs for bio-energy CHP is from 2–6% of total installed costs. These costs include routine component or equipment replacement (for gasifiers, boilers, feedstock handling equipment, etc.), labour, scheduled maintenance, insurance, etc. Variable operation and maintenance costs are usually relatively low. These costs mainly include unplanned maintenance and equipment replacement. In operation and maintenance of existing plants and in the construction of fuel processing facilities fewer jobs are detected, while they are also better-paid. Increased labour productivity, such as ongoing mechanization of feedstock harvesting, keeps lowering the demand for agricultural labourers (IRENA (3), 2017)).

There are many articles on the benefits and costs of the promotion of RES development on a regional, national and even global level. However, the majority of literature discusses the numbers and even technology components differ significantly among the studies. Moreover, a methodology to quantify the costs of RES (or even which costs to include in the RES assessment) is not established (Kreuz, 2018).

In the context of biofuels, it is also important to talk about liquid fuels. Liquid fuels are first, second and third generation biofuels. Biogas is considered a liquid fuel as well.

One of the biggest drawbacks of liquid fuels, is the vast use of the first generation systems, while second and third generation is more sustainable. There is a necessity to refuse first generation biofuel production, for it uses a lot of nutrition full products – corns, grain and other food-based raw materials. A European Strategy for Low-Emission Mobility also states that first generation biofuels should be abandoned and replaced with modern biofuels. For example, biogas must be extracted from all available organic waste.

As to biogas development in Latvia, there is also a need to revise the legislation on the production and marketing of biomethane. In Latvia, biogas production is multidisciplinary field, which combines environmental, agriculture, transportation, energy and economic sectors.

Basically, the evolution of the biogas sector depends on the support schemes. Political backing for electricity production from biogas is currently low. However, the capacity of biogas potential has been achieved. The next step is to make the existing stations more efficient. This requires adequate infrastructure for heat and biomethane from the biogas production process, the application of novel generation technologies, and educating the employees (operators, dispatchers, engineers) of the biogas power plants (Jēkabsone, 2018).

1.3.6.2. Hydropower

Hydropower technology is well developed and reliable and is leading in the generation of renewable electricity. Its main advantage is the rapid technological process – within two minutes of switching on the hydropower units, it starts to produce and transfer electricity to consumers.

It is a favourable renewable energy technology due to the low cost of electricity it produces. When water storage is available, hydropower provides low cost electricity and flexible services to the grid – regulation of frequency or voltage, ability to fit load fluctuations and efficient operation at half loads. HPP contribute to the stability of the electricity system. Moreover, hydropower projects open up opportunities for drought management, municipal water supply, irrigation schemes, flood control services and local social or economic benefits.

HPP sizes and specifications can vary widely. In the construction of HPPs, the type and size of turbines, production profile (seasonal inflows, minimum downstream flow rates, potential reservoir size) and the possibility of improvement of existing schemes (capacity installations) must be evaluated.

The two basic cost components for HPP are the costs related to electro-mechanical equipment and the civil work for the HPP construction (dam, tunnels, canals, storages). Electro-mechanical costs contribute more to the total cost in small-scale projects (less than 10 MW) due to the higher costs per kW of small-scale equipment. Usually, the largest share of HPP installation costs is for civil engineering works. The long term projects (7–9 years) represent investor expenses in the whole project construction time, including the project development costs, feasibility studies, environmental and socio-economic mitigation measures, consultations with local stakeholders and policy makers and land acquisition. Considering that HPP is site-specific technology, HPP projects are designed particularly for a specific location with a given river basin.

In recent years the total installed cost of HPP has increased due to shifting towards HPP projects in less ideal sites, higher project development costs, higher transport and logistical outlay and the boost of the transmission network and grid connection costs.

Operation and maintenance costs are typically stated as a percentage of the investment costs. Usually, the value range from 1–4%. This puts large-scale HPP to a similar position as WPP but not as low as solar PV operation and maintenance costs. HPP operation and maintenance costs can be decreased by centralised control system, dedicated operations team and remote management.

Hydropower employment estimation can be challenging, since activities in construction and supply chain can be informal. In general, the majority of job creation is in the operation and maintenance segment (IRENA (3), 2017).

Hydropower is predictable renewable energy technology, thus, the LCOE is low. The LCOE of small HPP is usually higher than the LCOE of large HPP.

In Latvia, natural conditions are well suited for the development of hydropower, however, it is limited by the contradictory impact of hydropower plants on the environment. There is more and more discussion about the negative impact of hydropower plants on natural processes. The Latvian Energy Strategy 2030 indicates that the greatest potential of hydropower has been exhausted, however, an increase in capacity is expected by reconstructing the existing HPPs and developing small HPPs. At the same time, in accordance with the forecasts on primary energy consumption included in the strategy, a reduction in hydropower consumption is expected from 2020 (Enerģētikas stratēģija 2030 (projekts), 2013).

1.3.6.3. Wind energy

The modern wind power industry has matured and scaled up rapidly. The volume of produced electricity from wind turbines is influenced by capacity, the height of the turbine tower, the quality of the wind resource, the diameter of the rotor and the quality of the operation and maintenance strategy.

Some advantages of wind energy are that it does not need to be imported (unlike natural gas), it does not directly produce CO_2 emissions (CO_2 emissions from the production of wind turbines itself) and particulate matter (unlike solid fuels, including biomass). Moreover, wind energy is relatively stable available and it does not need water or other resources, except wind.

Since 2009, wind power technologies have experienced a revolution: improved technologies (higher hub heights and larger blade areas) have increased capacity for wind resources. Still, there are considerable cost differentials between countries. The cost of wind turbine prices peaked in 2010 due to three factors. Firstly, due to the already mentioned improvement in technologies, more expensive turbines with higher hub height appeared on the market. Secondly, an increase in construction costs, material (steel, cement, copper) labour and civil engineering costs. Thirdly, many countries adopted policies favourable to wind deployment and the demand outstripped supply. Nonetheless, the installed cost reduction shows a range of decline from 30–68%. The drivers of decline since 2010 is falling commodity prices, manufacturing efficiency, process improvements, greater supply chain competition, competition in the global market.

As a result, the shift in wind power deployment in the most competitive countries leads to a larger global weighted average cost reduction. Overall, the costs of wind energy depend on a level of existing infrastructure to enable access to sites, the distance from major grid-interconnection points, the distance from ports or manufacturing hubs, labour costs, etc. All in all, from 2010 to 2016 installed costs of wind power plants have decreased significantly across the regions.

While support for energy production is desirable and advisable for the purpose of faster return of investment, information provided by economic operators shows that, for example, wind parks installed on land are able to exist and operate without additional support on the part of the state. Experience in the use of wind energy in Sweden and Denmark has shown that the market based support systems, such as the so-called green certificate system in Sweden and the auction and premium systems in Denmark, is sufficient to create an interest for operators to invest in wind parks (Āboltiņš, Vēja enerģijas izmantošanai Latvijā nākotnē ir labas perspektīvas, n.d.).

The use of wind in electricity generation depends directly on the weather. Usually the largest volume of electricity produced is between October and January.

In order to increase the wind generated energy, there is a plan to build a wind farm in Dobele and Tukums municipalities by 2022. One of the largest wind farm operators in Sweden enterprise LLC "Eolus" intends to make 250M € investments. The wind farm with 51 turbines should produce 0.7 TWh which is about 10% of Latvia's produced electricity in 2017. The LLC "Eolus" arguments for investing in this project is the growing efficiency of wind turbines, wind as the cheapest renewable energy source and the economic feasibility of wind farm – it is adaptable to renewable energy policy in Latvia.

From a practical point of view, there is a significant drawback due to the vast variety of regulations and limitations for WPP construction. The complexity of suitable area selection for WPP construction and building is shown in Fig. 1.35, 1.36 and 1.37. The layout from GIS programme (Fig. 1.35) demonstrates the buffer zones around residential buildings, cities, villages and major roads. For residential buildings, the restriction is 500 m from the building. Cities have two kinds of buffer zones. For bigger cities distance limitation is 2 km and for smaller ones – 1 km. Accordingly, same distance limitations are for villages, municipalities and districts. After designing and considering all the limitations, regulations and restrictions, there are not many areas and locations for WPP installation, as shown in Fig. 1.35.

Fig. 1.35. Limitation zones for WPP in Latvia (GIS layout)

Fig. 1.35 demonstrates only limitation zones around areas with a significant population. Meanwhile, it is also necessary to take into account limitations in protected areas (Fig. 1.36).

Fig. 1.36. Protected sites in Latvia (GIS layout)

Above all that, it is necessary to consider a proper WPP area according to vegetation in Latvia's territory (Fig. 1.37).

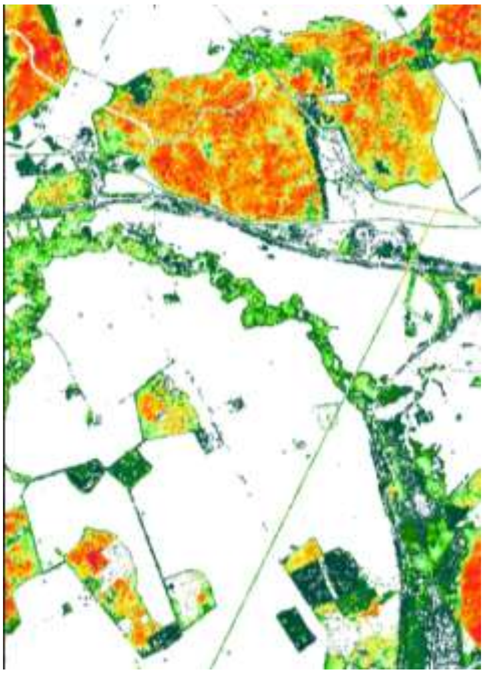

Fig. 1.37. Vegetation surface height in Latvia's territory (GIS layout)

Fig. 1.37 shows the height of the vegetation surface illustrated in GIS programme. White-painted areas are flat areas, while green and red areas denote highly significant vegetation – forests, grasslands, etc.

There are possibilities and solutions for increasing wind energy development. Approximately 500 MW of additional installations are available, however, policy frameworks in Latvia are so complex, that the WPP deployment is under a question even for big companies with big financial capacity.

1.3.6.4. Solar energy

The solar energy sector has a sufficient level of technological development and appropriate economic conditions to achieve a situation where solar panels would pay off in 5-year period or less. Achieving this situation requires political intervention and changes in the legal framework.

According to the energy company "Enefit" data, households in Latvia choose to install solar panels with a total capacity of 3 to 12 kW to cover self-consumption. The project repayment time is approximately 20 years but may also be much shorter. It depends on national policy, as well as from how successfully the electricity tariff is structured and solar-panel system has been established (Eesti energia, 2019).

Solar energy technologies are getting cheaper and more affordable. The cost of technology, when large-size solar PV parks are discussed, is coming to a level that in a few years, solar-produced energy is likely to be able to compete on the market without extra aid and subsidies. However, that tendency would apply only to large-size solar power plants.

The current situation in Latvia is not favourable – the price of solar panel in Latvia is two times higher than in other EU or non-EU countries. Furthermore, the prices for solar panel system are not aligned with the solar panel's efficiency. These circumstances do not encourage local households to invest in solar energy (Rozentale, Lauka, & Blumberga, 2018).

Development of solar panel solutions needs a favourable regulatory environment and a country should have a systemic and consistent approach to stimulate electricity generation through solar energy resources. Unfortunately, the regulatory environment in Latvia is extremely demotivating. Moreover, at the moment, all the common political attitudes towards renewables are damaged.

In the last decade the global trends of solar PV market share have developed rapidly. The solar PV production capacity continues to grow in Asia, where China is the world leader in solar PV production. However, in the EU the yearly installation of new capacities for solar PV did not exceed 8 GW in 2015 and 5 GW in 2016, while in 2011 at least 22 GW of solar PV equipment was installed.

In EU solar PV module prices declined by 83% from 2010 to the end of 2017. The prices plunged rapidly until 2013 and since then have had only moderate cost reductions. The decline in solar PV module costs was made by manufacturers' efforts to maintain solar PV module production in more sustainable levels. Enhancements in the production processes and efficiency improvements associated with modern solar PV cell designs are closely related to solar PV module cost reduction (IRENA (2), 2018).

Still, with the fall in installed and solar PV costs, the share of operation and maintenance costs have risen significantly. Operation and maintenance costs can be low where land values are minimal and no land fees are charged. In contrast, in the case of severe land use restrictions, for example, in densely populated areas, land costs can be a significant barrier.

Increased efficiency and capacity factors and the decline of installed costs have boosted solar PV position in the global economic market of renewables. Of course, all factors depend on specific limits, regulations and legal frameworks of the countries, but the overall trend from 2010 to 2017 shows that the global LCOE of solar PV is declining by 40–75%. The competitiveness of solar panel technologies is affected by regional differences in the local labour market, production costs, the structure of support policies and the level of development of the local market. Countries with a competitive level of installation costs are characterized by a balance of system costs, which accounts for about half of the total installation costs (IRENA (2), 2018).

1.4. Conclusions

1. The economic assessment of energy sources is a complex issue that needs to be addressed in a variety of ways. In order to facilitate such analysis, as well as to obtain the maximum objective result, various evaluation methods are used.
2. LCOE, as well as multi-criteria analysis methods – AHP, ELECTRE and TOPSIS are the most widely used for RES assessment.
3. Which method of multi-criteria analysis is the most appropriate depends on the specifics of the particular analysis. In cases when it is important that the method is transparent and time-efficient and a relatively small number of different alternatives need to be considered, it is recommended to use TOPSIS or a combination of AHP and TOPSIS, where AHP is used to calculate the weights of the criteria.
4. In recent years, the number of boiler houses and their installed heat capacity in Latvia has been rapidly decreasing. In contrast, the number of cogeneration plants and the installed electric capacity are growing.
5. In general, fossil resources in both boiler houses and cogeneration plants are beginning to be replaced by renewable energy resources.
6. From the perspective of resource availability Kurzeme region has the greatest potential for the development of solar and wind energy, while Zemgale region is the most significant in terms of manure and straw production. Cities produce most of the sewage sludge resources, however, overall, cities also have significant solar and wind resources.
7. The spatial evaluation of resources at municipal level shows that there are significant renewable energy resources of at least some type in all municipalities, which indicates opportunities for successful individual development for all municipalities. However, analysis at municipal level also shows the potential cooperation opportunities in resource supply.
8. HPPs are the main electricity producers in Latvia, and hydropower technologies have several advantages both from the economic and technological point of view, however, the potential for further development of HPPs is limited, mainly due to the lack of suitable location and environmental impact of HPP operations.
9. The geographical location, amount of wind energy and relief of the territory of Latvia generally create suitable conditions for wind energy production, however, geographical restrictions (for example, surface and vegetation height) in combination with normative restrictions (WPP construction in relation to populated areas and protected sites) significantly limit WPP development opportunities.
10. Latvia has a sufficiently large potential of photovoltaic energy for solar energy production, however, it is currently at a very low level of development, which is mainly determined by an unsupportive regulatory environment and high costs of solar energy production technologies, which pay off in a relatively long period of time. In order to fulfill the potential of solar energy production in Latvia, significant changes in the regulatory framework and measures supporting the production of solar energy are required.
11. Taking into account that the economic benefits of energy production from biofuels largely depend on the availability of bio-resources, Latvia has a great potential to further develop this type of energy production. However, the choice of efficient and cost-effective technologies is essential in this context, as is the sustainable use of bioresources, which, as far as possible, follows the principle of cascade use of resources.

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2. EVALUATION OF RENEWABLE ENERGY SOURCES FOR VARIOUS SECTORS

The second chapter of report "Mapping of renewable and local energy resources, energy sources and loads, and literature analysis of their potential", the use and possibilities of renewable energy sources are analysed for various sectors:

- Agriculture;
- Industry;
- Service;
- Household;
- Transport.

Analysis includes examples and practises from different countries. Comparison of sectoral renewable energy sources is performed.

2.1. Possibilities for the use of renewable energy in the agricultural sector

According to the Food and Agriculture Organization of the United Nations, greenhouse gas emissions from the agriculture sector account for ~21% of total world emissions and is the second-largest emitter of greenhouse gases. Greenhouse emissions are mainly generated from intensive soil and nutrient intensive management activities, for example, using fossil fuel-based fertilizers, from deforestation or livestock. (Liu, Zhang, & Bae, 2017).

It is estimated that the agricultural sector can noticeably reduce total global emissions by 20-60% by 2030 using relevant measures, such as reducing deforestation, reforestation, and improved agricultural and livestock management.

The main causes of these emissions are related to nitrous oxide and methane as a result of inappropriate soil management and livestock processes, fossil fuels for water pumping, irrigation and nitrogen-rich fertilizers, which together account for 14% to 30% of total greenhouse gas emissions amount. (Waheed, Chang, Sarwar, & Chen, 2018).

The Latvian agricultural sector is in an unenviable position in terms of ecological characteristics, it produces only 4% of GDP, at the same time it is the third-largest greenhouse gas emission producer. According to the 2019 data of the Latvian Ministry of Environmental Protection and Regional Development, the agricultural sector is responsible for 23,6% of Latvia's GHG emissions. It places the agriculture sector in a precarious position, because of its low economic importance can lead to a lack of political attention and thus hinder its development, including slower innovation and a slower transition to more sustainable working methods. Thus, in the ideal scenario for the future development of agriculture, the economic value of the agricultural sector would increase simultaneously, and emissions would decrease. Both of the above can be achieved by promoting more sustainable use of agricultural resources. In this way, it is not only possible to contribute to reducing emissions and meeting climate targets, but also to increase the economic value of the agricultural industry by producing products with higher added value. The use of agricultural residues can give significant benefits at the sectoral level, in addition to its potential to make a substantial contribution to increasing the use of renewable energy at the national level. Statistics show that in 2018, 4,5 million tonnes of cereals were produced (Central Statistical Bureau of Latvia, 2019).

(Scarlat, Fahl, Lugato, Monforti-Ferrario, & Dallemand, 2019) calculations show that it would be possible to obtain 189 tons of grain residues in dry matter from cereals produced in Latvia during the year in a sustainable way. That is a significant amount of raw material, and valuable and potentially usable residues or by-products are not only obtained from cereals. Potentially valuable residues also arise from livestock (for example, manure), forestry (for example, wood residues, wood biomass), aquaculture (for example, fish waste), agricultural processing (by-products). The low level of use of these residues not only means wasting resources but also harms the environment.

Finnish researchers have estimated that producing only 5% of the world's potential electricity generation from biomass, solar energy, wind energy and energy from waste could provide electricity for 55,4 million portable container-type agricultural production module, by 2050. This amount of such agricultural production modules would be able to provide the recommended amount of vegetables in the diet for 24,4% of the world population.

Latvia also has significant potential for the use of renewable energy in the agriculture sector, which could become a driving force for increasing GDP in the agriculture sector, at the same time helping Latvia to achieve climate change mitigation goals (Farfan, Lohrmann, & Breyer, 2019).

This report summarizes the opportunities and technologies with examples from international experience, as well as a brief review of Latvia's planning documents.

2.1.1. Smart agriculture

In the agricultural sector, drying processes are one of the largest consumers of energy, therefore new solutions are being sought to reduce energy consumption, including using new technologies and renewable energy sources. The study evaluates the design of smart agriculture to provide a drying process using a selective solar absorber as an energy source, which assessed as cost-effective. The system is based on a heating flat plate and a solar absorber (Çiftçioğlu, Kadırgan, Kadırgan, & Kaynak, 2020).

The first step is that solar energy is converted into internal energy and that way solar collectors can be considered as heat exchangers. Energy conversion implemented as an absorption process where solar radiation is absorbed by the collector surface and converted into heat.

The heat absorbed by the collector is transmitted to the transport fluid, which is usually air, water or oil.

2.1.1.1. Smart Agriculture Monitoring via the Internet of Things (IoT)

Wireless sensor networks (WSNs) are more and more being used to implement the Internet of Things (IoT) in smart agriculture processes. Wireless sensor networks (WSNs) used as one of the solutions for limited energy availability by using and storing ambient solar energy in WSN nodes to charge batteries. Concerning solar energy production and storage, there are several challenges, such as interruptions in solar energy production due to inappropriate weather conditions, such as cloud cover, solar energy forecasting, also issues related to the efficiency of solar panel conversion. The advantages of smart agriculture linked to increased productivity, higher quality of cultivated crops and efficiently managed and controlled agricultural system, that way increasing the income of the population. (Sharma, Haque, & Jaffery, 2019).

The Internet of Things can be defined as a network of wireless sensor networks (WSNs) and is widely used for monitoring and controlling temperature, light, gas, smart agriculture and smart cities. The disadvantages of the WSN design are such that the battery power of the sensor unit is limited and consumed maximum only for few days (short period), so as a solution to increase the life of the sensor network, for example, solar PV panels can be used.

One of the advantages of using and storing solar energy in wireless sensor network nodes is that solar energy is flexible and can be used for different power equipment. Other advantages are related to that solar energy is free and does not cause atmospheric pollution, solar energy systems serve for several years.

2.1.1.2. Precise agriculture

If the Internet of Things (IoT) and wireless sensor networks (WSN) are used in the agriculture sector, then advanced agricultural methods, for example, precise agriculture (PA) can be used. Using precise agriculture method, it is possible to have more control over the crop production process and livestock production. The use of crop monitoring technologies can increase crop efficiency and reduce costs, because of using this method, it is possible to determine the doses of pesticides much more precisely. (Sharma et al., 2019).

Internet of Things (IoT) devices can be used in monitoring systems which consist of nodes that interact with the environment and use sensors to collect information at a specified time and transmit it to the control room for further processing. In precise agriculture, sensors outdoor are operating using batteries, as the sensor nodes are located outdoors, rechargeable batteries, and because of that energy storage devices can be used.

By combining low-cost energy production and storage methods with low-capacity IoT devices, precision agriculture methods can be implemented. It is estimated that the use of battery-powered sensor combined with traditional agricultural methods can be a solution for higher efficiency and lower overall costs.

According to the research made in 2017., scientists designed a system based on open-access IoT devices to monitor nitrate concentrations in groundwater.

Another example of smart agricultural monitoring is the use of wireless sensor networks (WSNs) to equip a cotton field with an automatic irrigation system to control soil moisture (Sharma et al., 2019).

2.1.1.3. Smart agriculture monitoring using the Internet of Things in rural areas

In the recent years, smart agriculture systems are used as a solution mostly for rural areas. Smart agriculture or in other words farming methods are often used to measure moisture in the soil or in the crops themselves. The sensors detect and measure moisture levels in the crop or soil, and the wireless data i transmitted to the Internet of Things (IoT) cloud, which is then transferred to a GSM mobile phone or Wifi router.

The users are being able to control the measured data using a monitoring and control application running on a mobile phone or personal computer. At the same time, the energy required to operate the IoT Internet sensor unit is extracted and stored from solar PV panels and can be used directly to charge the sensor unit. The obtained solar energy can also be stored in the battery, so that the Internet of Things (IoT) node can be operated at night as well (Lingayat, Chandramohan, Raju, & Meda, 2020).

The solar energy storage device required to operate the WSN sensor unit consists of a solar panel, a rechargeable battery with a DC converter, as well as an energy management scheme. (Fig. 2.1).

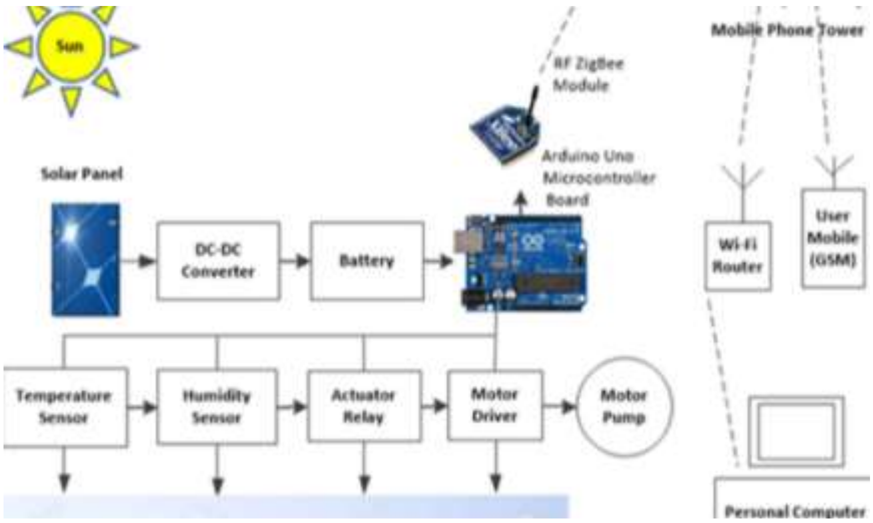

Fig. 2.1 Smart agriculture soil moisture and temperature monitoring

2.1.2. Possibilities of using solar energy in the agriculture sector

2.1.2.1. Use of solar photovoltaic (PV) panels in agriculture sector

Semiconductor materials that convert sunlight into direct current energy are called photovoltaic (PV) panels. Typically, the main components of a PV system are PV solar block collectors, energy conditioners, an energy storage system, and solar inverters. PV panels can be used as an energy source, either as stand-alone or grid-connected systems.

Solar PV panels can be used to meet the needs of different users, such as water pumping, battery charging, household energy storage, street lighting, refrigeration, mining, swimming pool heating systems, as well as the hydrogen production process (Ganiyu, Martínez-Huitle, & Rodrigo, 2020).

Use of solar PV panels in soil treatment

Solar photovoltaic panels have been evaluated as an alternative source of electricity in the treatment of electrochemical wastewater and contaminated soil. Electrokinetic soil treatment (ECSR), which uses solar PV panels as an energy source, has been studied in both laboratories and pilot studies for the removal of heavy metals from contaminated soils and the treatment of herbicide-contaminated soils.

(Ganiyu, Martínez-Huitle, & Rodrigo, 2020) research on the use of EKSR for soil removal from herbicides (2.4 D) estimated that after 15 days of treatment, 73.6% soil removal efficiency was achieved.

Solar energy PV-EKSR - a method for cleaning contaminated soil

In the case viewed in situ EKSR methods was used, which based on a powered electric field obtained from electricity produced by solar PV. The study evaluated the possibility of separating cadmium and lead from contaminated soil in a two-chamber MFC equipped with granular graphite as an anode and carbon felt as a cathode using a graphite rod for electrical contact and a proton exchange membrane as a separator.

An anode chamber containing electrochemically active microorganisms were injected daily with 396 ml of synthetic nutrient solution. At the same time, the cathode chamber was filled with 230 grams of sieved dried contaminated soil and also flooded with 200 millilitres of deionized water and irrigated with deionized water every two days. In case, it was estimated that the removal efficiency of heavy metals (cadmium and lead) after 143 days was 31%, while only after 108 days - 44.1%. (Fig. 2.2) (Ganiyu, Martínez-Huitle, & Rodrigo, 2020).

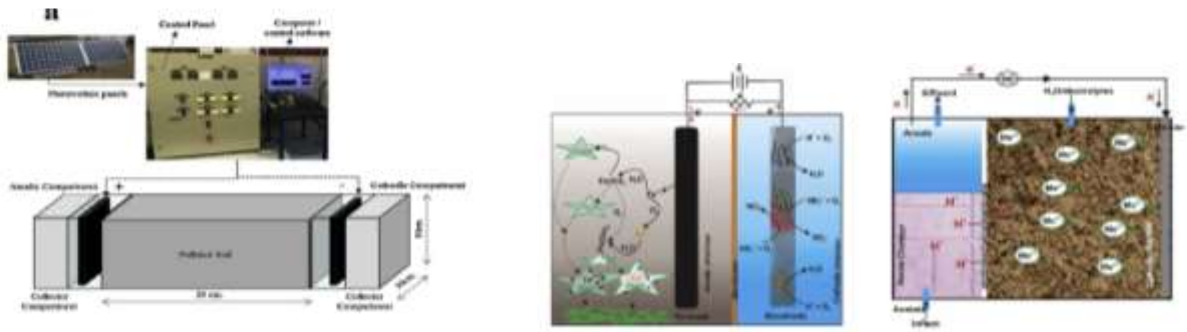

Fig. 1.2 MFC electrocoagulation and MFC electrokinetic soil treatment system

2.1.2.2. The concept of renewable batteries and energy storage options for converting agricultural waste into bio-coal using friction pyrolysis

The idea of renewable batteries in agriculture offers opportunities for renewable and cleaner fuel. Renewable energy storage capacity has been one of the main barriers to increasing the share of renewable energy. (Vakalis, Moustakas, Heimann, & Loizidou, 2019).

Friction pyrolysis technology envisages that electricity from renewable energy sources, where agricultural residues have been used as raw material, can be used to convert biomass into bio-coal. Friction pyrolysis can be defined as a process where mechanical energy is used - the effect of pressure and friction without introducing external heat. In the study, lignocellulosic biomass was pyrolyzed using friction and pressure. Friction pyrolysis is one of the alternative methods for obtaining char-coal from lignocellulosic biomass residues, using only mechanical energy instead of thermochemical transformation processes.

The first step is that surplus energy from usable renewable energy sources (such as solar or wind energy) is transferred through the grids to an energy conversion plant, a friction pyrolysis plant. In the case of California, surplus energy from solar energy was used, while in the case of Denmark it was surplus from wind energy and Norway - from hydropower.

The energy obtained, in the case of a specific example, from solar energy surpluses, was used to power an electric motor, which provided the mechanical energy required for the process.

Unprocessed agricultural residues are used as feedstock in the friction pyrolysis process. During the friction pyrolysis process, solid carbon fuel with increased heat of combustion and better combustion properties is obtained. (Fig. 2.3).

Fig. 2.3. Renewable battery concept using friction pyrolysis

In the viewed study case, three types of lignocellulose residues were processed - oak, corn foliage, pine residues using the above-mentioned technology. Corn residues were estimated to perform best. By converting agricultural residues (such as maize residues) into biofuels using friction pyrolysis, excess energy from renewable energy sources can be used to convert raw materials into high-carbon products, approximately 80% of the moisture was separated during the process mentioned before, and the total energy in the range of 78.6% to 86.8% relative to the initial input.

2.1.2.3. Solar energy systems for drying agricultural raw materials or products

Mexico

Studies have shown that artificial drying is more effective than other drying methods. The use of heating systems based on solar energy can improve product quality, reduce waste and reduce the use of fossil resources.

Mexico is one of the largest producers of agricultural products, so the issues of reducing energy consumption in the drying process and solutions for the use of alternative energy sources are becoming increasingly crucial. According to a study in Mexico, hybrid thermal solar monitoring equipment for food drying was successfully installed in Zacatecas. The heat energy was provided by an air heating system with 48 solar collectors and a water heating system with 40 solar collectors. It was estimated that the energy efficiency of air heaters was 39.49% with a maximum capacity of 46,14 kW.

A device was developed and installed for drying agricultural products, which uses solar energy systems - air heaters and plates for water heating. Still, conventional propane gas was also used for drying the products. It is proved that split-type forced convection dryers are the most efficient among solar-powered dryers in terms of their drying speed and quality. A split-type forced convection hybrid drying system using solar energy as an energy source consists of a drying chamber, a direct and indirect air heating system and conventional system (García-Valladares, Ortiz, Pilatowsky, & Menchaca, 2020).

Direct and indirect drying systems

The main advantages of dryers for solar products or raw materials are that this type of drying equipment does not emit carbon monoxide, carbon dioxide, nitrogen oxides and other substances that are traditionally released during combustion processes and therefore do not contribute pollution. Solar dryers of various sizes, capacities and designs are available in the agriculture sector. Solar-powered drying systems are divided into direct and indirect systems (Lingayat et al., 2020).

In direct drying systems, the relevant raw materials or products placed in a container covered with transparent plastic or glass, and the drying process takes place using solar energy which is absorbed through the lid. Indirect type of solar energy dryers (ITSDs) are among the most widely used dryers and stand out for their unique performance (Lamidi, Jiang, Pathare, Wang, & Roskilly, 2019) (Lamidi, Jiang, Pathare, Wang, & Roskilly, 2019).

In the indirect drying process, the air heated by solar energy and then used for drying or mixed drying, which means drying in solar radiation in combination with hot air. It has been studied that among the different types of dryers, indirect type sun dryers (ITSD) achieve higher product quality and are more efficient in making a large amount of material to be treated compared to direct type sun dryers. Indirect dryers can provide the required temperature, carry out more precise drying control, preserve the natural colour of the product, do not affect the quality of the product or raw material during the process and are suitable for drying sensitive crops such as lemons, cucumbers or papayas.

Compared to direct drying plants, in the case of indirect drying, the process takes less time, for example, in the case of bitter gourd, the drying process with a direct dryer takes 8 hours, but in the case of an indirect dryer - 4 hours. The most crucial parameters in controlling the drying process are the air temperature drying time and airflow rate. It is proved that indirect drying systems can prevent product losses.

Hybrid drying systems

The drying process can be assessed as sustainable if solar energy systems, biomass, geothermal systems, as well as heat recovered from waste recovery are used as an energy source, or several systems - hybrid drying systems - are combined to ensure the process. Such systems often use solar energy in combination with other technologies, including biomass drying systems, heat pumps and solar thermal storage systems designed to address the shortcomings of the drying system. (Lingayat et al., 2020).

The most significant disadvantage of the drying system is related to the loss of product quality during solar energy interruptions, including due to the effects of the weather. Using hybrid solar energy systems based on the use of additional heat energy sources or heat storage (TES) can improve the quality of end products (Lingayat et al., 2020).

For hybrid drying systems, their efficiency studied using four different energy sources, including a combination of the energy sources used in the drying systems - solar energy and liquefied petroleum gas. The results showed that with this system, 45% efficiency achieved in 15 hours and the drying time reduced from 20,75 hours to 15,75 hours. Solar photovoltaic panels (PV) and solar collectors were combined with heat and electricity storage equipment to compensate for the lack of solar energy during the drying process.

The study developed solar photoelectric and thermal (PV/T) systems in which a spherical material was filled with paraffin wax. According to the research viewed solar photoelectric and thermal (PV/T) systems in which a spherical material was filled with paraffin wax. The spherical material was then placed on a box containing a fan and a gel battery (electricity storage location). The box, in turn, was placed on the roof of the greenhouse. The heat generated by the solar concentrator was used in the drying process - to heat the hot air, as well as it was stored in paraffin wax.

The electrical energy produced by the solar PV cells was used in the drying process to transfer the drying air, while part of the obtained electricity stored in the gel battery. A drying air recirculation system has also been identified as an effective solution to reduce the impact of solar interruptions on some crops.

As part of the study case viewed, an innovative combined solar, and biomass dryer was built for drying corn. Air circulation was provided by a solar-powered (PV panels) fan. In another study, a wind turbine was placed above the drying chamber to improve air circulation in the dryer.

Similarly, a hybrid electric heater - a solar dryer equipped with a water storage system - has been studied. The system was mainly powered by solar energy, but the electric heater was used only after sunset or in unsuitable weather conditions, and even the use of water storage ensured continuous drying after sunset. In the water storage mode, if the air temperature required for the drying process was not sufficient to ensure the intended temperature gradient, an additional electric heater was used, as well as to improve the system efficiency, 65% of the drying process air was recirculated. Table 2.1 is given information on the hybrid drying system.

Table 2.1

The efficiency of hybrid drying systems

Drying method	Agro-product	Research findings
Solar with latent heat storage	Mint leaves	Drying continues 5-6 h after sunset
		Payback period is less than two years
Solar-LPG	Pineapple	Drying times are reduced from 8.0-8.8 h to 6.0-6.8 h
Solar-LPG	Tomato	Drying times of 15 h, 28 h and 18 h are noted for LPG, solar and hybrid mode respectively
Solar-desiccant-electric heater	Kenaf core fibre	Drying time is reduced by 24%
Solar PV/T with TES systems	Spinach leaves	Drying continues several hours after sunset
		Paraffin wax ensures the reduced temperature rise of PV units
Biomass-solar	Cashew nut	Drying is completed in 7 h with forced hybrid system with system efficiency with 5.08%

		Drying time 9 h with 3.17% is recorded with natural convection
Solar-water storage	Tomato	Time savings of 56.25% is for the hybrid solar dryer when compared to sun-drying
		Compared with commercially available dried tomato available in the market, better quality is obtained especially in terms of ascorbic acid, lycopene and flavonoids contents
Solar-electric heater	Tomato	Use of solar energy results in 6.6-12.5% energy savings
		Non-enzymatic browning, Maillard reaction and lycopene degradation are observed in the dried tomato
Solar-biomass	Yam chips	Drying rate of 0.0142 kgh-1 is recorded for the hybrid mode when compared with 0.00732 kgh-1 noted for single mode
Solar-biomass	Okra, groundnut and yam	The efficiency of the dryer varies with crops dried
	Chips	Energy efficiency varies from 0.23% to 16.04% for okra, groundnut and cassava chips
Solar dryer with air recirculation	Pistachio nuts	Air recirculation produces better product quality; Drying time is reduced by 19%
Heat recovery from a hybrid solar-biomass convective dryer	Red chilly	Drying efficiency is from 9.9 to 12.9%
Solar-biomass hybrid dryer	Maize	It can dry 12, 923 bags of maize per year for two years payback period
Solar-biomass wind turbine hybrid dryer with partial tracking	Turmeric	55-60 ^{o}C is observed inside the drying chamber; Moisture content is reduced from 831.09% (d.b.) to 6.68% in 14 h against 25 h observed for the open sun drying
Electric heater-solar dryer with air recirculation	Banana	Moisture content is reduced from 82% to 18% (w.b.) in 8 h when compared to 62% moisture content for open sun drying

Phase change materials used in product drying

A heat storage system (TES) can be a solution for storing energy on cloudy days. TES can be divided into sensible heat, latent heat, thermochemical reaction, which accumulates heat in well-insulated liquids or solids as a change in internal energy.

Influence of different drying methods on the quality of agricultural products

The study evaluated the functional changes of tomatoes using a hybrid sun-drying system, direct sun drying and drying in the open sun. The use of heat recovered from biomass to dry agricultural products was assessed as an effective solution. With using a hybrid dryer, tomatoes had relatively better quality, and tomato drying time was reduced by 56,25% compared to other dryers.

Another study evaluated the effects of four different drying systems on the texture and colour of ginger and turmeric. The study showed that the ginger and turmeric treated in the integrated sun dryer had both minimal colour loss and crush resistance, which found that the hybrid dryer was more efficient compared to other drying systems.

The main advantages of hybrid drying systems are 1) the ability to reduce the effects of solar interruptions; 2) biomass is readily available in local regions; 3) biomass fuelwood is currently one of the primary sources of heat supply; 4) Solar biomass drying equipment is more cost-effective compared to other systems (Lingayat et al., 2020).

2.1.2.4. Possibilities of using solar energy in greenhouses

Several renewable energy sources can be used in greenhouses as a heat source to provide the required temperature, such as biomass energy, solar energy, or geothermal energy (Gourdo et al., 2019).

In greenhouses, solar energy is most often used to ensure the appropriate temperatures. Among the systems for raising the air temperature in greenhouses, such as a water storage system, a rock-bed storage system and a ground air collector have been recognized as effective solutions.

<u>Morocco</u>

A Moroccan study evaluated the effectiveness of a bed-rock storage system in the use of greenhouses. The study used a PVC cylindrical tube, which was placed and buried under the greenhouse, filled with 225 kg of spherical stones with specific heat and thermal conductivity of 20 °C of 652 J / (kg.K) and 5 W/(m.K). The shape of the spherical stones was evaluated as an essential factor because due to the spherical shape, which creates free space between the rocks, air circulation in the reservoir facilitated, as well as a large exchange surface between the rocks and air, so the stones heat up quickly.

During the day, when the temperatures in the greenhouse exceeded 25 °C (from 12 to 16 hours), the hot greenhouse air brought into the storage system of the formed stone bed using a fan. The cold air was accumulated during the night and used during the day to cool the greenhouse air. Rock-bed storage is considered to be an economical heat storage material, and its advantages are related, for example, with a large heat transfer surface, fast heat transfer, high storage capacity, high thermal conductivity, low cost and long service life.

The results of experimental measurements of climatic parameters showed that the air temperature in the greenhouse under which the stone bed storage system was installed is on average 3 °C higher at night than in other greenhouses, but 1,9 °C lower during the day than in other greenhouses. The average minimum growing temperature for tomato seedlings was about 10oC. It was estimated that the optimum temperature was from 22 °C to 26 °C during the day and from 13 to 18 °C at night, with the optimal temperature during the day from 21 °C to 25 °C.

It was estimated that the rock bottom system had a positive effect on the tomato yield, which had improved by 22% compared to conventional greenhouses.

2.1.2.5. Possibilities of using solar energy in irrigation systems

To use solar energy (PV panels) in large irrigation systems, the issues associated with solar power interruptions, like adverse weather conditions, must first be addressed, and solar panels should be better adapted to the needs of irrigation systems. It has estimated that in order to prevent solar energy interruptions, it is necessary to use an additional energy source or build an energy storage system (for example, batteries, accumulators).

<u>Spain</u>

In Alicante, Spain, a case study developed a prototype into well to provide community irrigation using solar PV generated electricity to run the pump. Irrigation prototype was installed in 2013 in the Alto Vinalopó community "Candela" using 20 kWh capacity PV generator for running the pump (Fig. 2.4). Innovative solutions were included in this prototype. Control algorithms were introduced in the frequency converter to avoid solar energy interruptions. Control algorithms were developed and implemented in the frequency converter to ensure stability during solar power interruptions. The control algorithms consisted of the following steps: Step 1 - to determine the solar irradiation fluctuations in the shortest possible time by monitoring the DC voltage in the internal frequency converter. When clouds appear, the DC voltage drops sharply, and standard frequency converters offer feedback signals about the internal DC voltage that is excessive to respond to irradiation fluctuations. In the proposed prototype, a direct and fast DC voltage sensor is connected to the frequency converter. Step 2 - As soon as a decrease in irradiation is detected, the PID controller was deactivated, and the output frequency was reduced to gain power for regeneration in the centrifugal pump to keep the DC voltage in the frequency converter stable. Step 3 - If the clouds pass, the PID controller was restored to its original parameters for normal operation. If the cloud did not pass, then a soft, controlled stop was done.

The results showed that the volume of water pumped using this system reached 258,562 m^3, which reflected the average daily amount of pumped water – 236,13 m^3.

Economic analysis has shown that using solar PV panel irrigation systems in agriculture can save up to 60% of electricity costs. The efficiency of the system largely depends on the geographical location, water availability, as well as user habits (Narvarte et al., 2018).

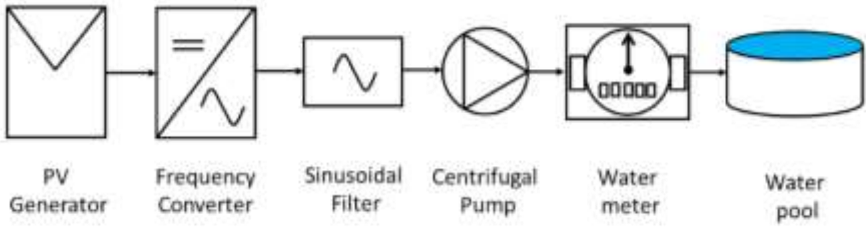

Fig. 2.4. Irrigation system scheme as a source of energy for run the pump using electricity from solar PV panels

2.1.3. Possibilities of using wind energy in the agriculture sector

2.1.3.1. Combined systems. Possibilities of using biomass together with wind energy

Use of wind generators with biomass energy

Several studies have been conducted to evaluate the efficiency of biomass combined systems. It has been studied that the use of biomass as an additional energy source is an effective solution to prevent solar energy interruptions. In one of the study evaluated the use of solar PV-wind-biomass combined systems in seven different locations in Australia. One study assessed the use of PV-wind-biomass combined systems in seven different areas in Australia. Studies have shown that the efficiency of the hybrid system has increased from 3 to 10% (Tajeddin & Roohi, 2019). (Tajeddin & Roohi, 2019).

Iran

The feasibility of using a wind-biomass system in Iran was examined in a study focusing on the economic and technical assessment of a combined operation - a wind farm and a biomass gasifier. According to the study, the renewable energy system consisted of wind turbines and biomass energy reserves; the total installed wind-biomass capacity of the hybrid system was 1.5 MW. Given that in Iran, the largest share of biomass is agricultural residues, most often wheat and barley residues, the biomass used in the study consisted directly of these agricultural residues. In the biomass gasifier, agricultural residues were processed into gaseous fuel, which was used to generate electricity.

Calculations show that the number of agricultural residues required for energy production per year was about 892.3 thousand tons, which makes biomass a suitable resource in case of wind energy deficit.

In the study, it was estimated that the combined system with an installed capacity of 1.5 MW was able to operate without restrictions, and the obtained electricity can be transmitted in centralized networks (Fig. 2.5).

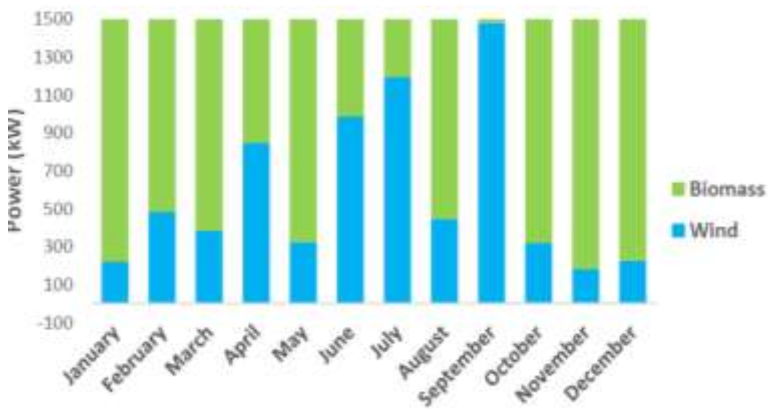

Fig. 2.5. Wind and biomass energy production potential in Iran on an annual basis

Use of wind energy in water pumping systems

Wind energy is also used as an energy source in water pumping systems. Separate small turbines with a capacity of less than 100 kW are often used for pumping water (Ganiyu et al., 2020).

2.1.3.2. Possibilities of electrochemical soil treatment using wind energy as an energy source

Studies have shown that wind energy can be used as an effective additional solution for the treatment of polluted wastewater and soil. It is estimated that wind turbines can be used as an energy source for electrochemical treatment of soils contaminated with herbicides (2,4-D). According to the results of the study, 53,9% of the contaminated soil was cleaned within 15 days, however, at the same time, 90,2% reduction of soil pollution was achieved using conventional methods.

In Finland, to promote the use of wind energy in agriculture, it is recommended to create joint wind farms and communities by forming cluster systems. (Rikkonen, Tapio, & Rintamäki, 2019).

2.1.4. Possibilities of using geothermal energy in the agriculture sector

2.1.4.1. Drying of agricultural products using geothermal energy

Geothermal energy in agriculture can be used, for example, to generate electricity, cool and dry crops. The efficiency of the use of geothermal energy highly depends on its thermal properties. It is estimated that high enthalpy energy (T> 150 °C) is mainly used for electricity generation, medium enthalpy energy (100-150 °C) is primarily used for electricity generation using ORC technologies. In contrast, low enthalpy energy (T <100 °C) is used for direct use (Ambriz-Díaz et al., 2017).

Drying of products with cascade type geothermal energy

The geothermal energy cascade system is recognized as one of the most efficient drying systems for agricultural products or raw materials. The study evaluates a cascade system consisting of three levels. The first level consists of electricity generation, the second level includes cooling, and the third level consists of the drying of agricultural products or raw materials. The results of the study showed that the inclusion of the drying system in the geothermal energy cascade system is economically advantageous, higher energy efficiency was achieved. Based on the results of the study, using a three-level cascade system with a capacity of 110 kWe, the amount of greenhouse gas emissions decreased by 537.7 tons during the year. In order to estimate the emitted CO_2 emissions, it was assumed that the cascade system emits one-sixth of CO_2 when generating electricity using geothermal energy compared to plants burning natural gas. In general, the use of geothermal energy cascade technologies is associated with more favourable energy use and lower emissions (Ambriz-Díaz et al., 2017).

2.1.4.2. Possibilities of using geothermal energy in aquaculture

Iran

In the study case of Iran, the use of geothermal energy was evaluated in a particular trout farm, assessing the compliance of temperature with trout growth conditions with and without the use of geothermal energy. Geothermal energy was used as a heating source in a trout farm during one year in eight cold months.

The pressure and temperature created by the geothermal fluid can be used to provide heat and hot water. As the geothermal fluid moves, the heat transfer of the fluid occurs. In the study, based on the heat factors and the obtained geothermal fluid potential, heat load indices, heat resistance, as well as the time required to ensure optimal temperature conditions for trout growth in the fish farm were calculated. The study analysed the direct use of geothermal fluid in the eight cold months of the year in a trout farm and the impact on thermal factors with and without the use of geothermal fluid.

The optimum temperatures for the growth and development of rainbow trout range from 12 to 17 °C. Thus, the minimum optimum temperature required for trout growth was 12 °C, which was taken into account in all months when calculating the heat factors. Heat factors were calculated and determined using mathematical models. In the study, geothermal fluid was used for trout farming, providing a minimum temperature for optimal growing conditions (11.53–12.03 °C, with an average temperature of 11.92 °C).

As the ambient temperature is colder, the heat dissipation also increases, but at higher average temperatures, the heat dissipation decreases. In the study, the addition of geothermal fluid reduced heat dissipation. The study estimated that the time required for cooling or reaching the minimum growth temperature using geothermal fluid was almost identical in all months - 4.5 times higher compared to the system without geothermal fluid. It was concluded that the use of geothermal fluid creates stable conditions regardless of the month (Asl & Gilandeh, 2019).

2.1.5. Possibilities of using biomass in the agriculture sector

Biomass can be converted into chemical products to produce electricity, heat and fuel. Approximately 3,7-5,1 billion tonnes of lignocellulosic biomass is produced in agriculture each year. Thus, the use of agricultural residues for energy production is essential, and a strategy is needed to achieve renewable energy targets (Lamidi et al., 2019), (Wang et al., 2019).

Agricultural residues can be divided into primary residues from the harvesting process, like rice straw, cotton stalks or secondary residues from the post-harvest processing of crops, such as shredding or extraction of oil (Gojiya, Deb, & Iyer, 2019).

2.1.5.1. Methods and technologies for the use of agricultural residues (thermochemical transformation, biochemical transformation, synthesis gas)

Agricultural residues usually contain cellulose, lignin, hemicellulose, components that can be converted into sustainable energy using gasification technology (Samadi, Ghobadian, & Nosrati, 2020).

Iran

In Iran, about 30% of agricultural output is agricultural waste. Agricultural residues are generated at various stages of processing and can be used as sources of green energy, such as biodiesel and bioethanol. Despite the large production of sugar cane in Iran, in the southern province of Khuzestan, and the adequate availability of water, the resulting agricultural residues are not used for bioethanol production.

The first four types of agricultural residues for which their energy production potential was assessed were wheat straw, sorghum stalks, sugar cane pulp. It is estimated that using sugar cane pulp and gasification technology as a raw material for energy production has a higher quality in terms of total biomass (Safieddin Ardebili & Khademalrasoul, 2018).

Biomass conversion technologies for agricultural residues

Combustion and co-incineration, as well as biogas production through anaerobic digestion, are considered to be the most common technologies for the conversion of biomass for further energy (Samadi et al., 2020). The moisture content of certain types of agricultural residues significantly affects their energy recovery potential. Other sources consider biomass compaction, pyrolysis and gasification to be the most common and efficient biomass conversion technologies (Akkoli, Gangavati, Ingalagi, & Chitgopkar, 2018).

Conversion of agricultural residues to synthesis gas

Biomass residues from agriculture or forestry can be converted into synthesis gas to produce electricity or heat or chemicals. Bain (2007) compared different technologies for converting biomass to liquid biofuels using different renewable feedstocks. Another alternative to the conversion of biomass residues is the transformation of residues into chemicals (Lozano & Lozano, 2018).

(Mendoza et al., 2015) in a study on biogas used biomass residues for gasification evaluating pecan shells. The study assessed that the residues could be used to mix synthesis gas with nitrogen. Although the gas produced contains high concentrations of nitrogen, it can be used as a fuel. Another alternative is the high-temperature gasification of wood using steam, which produces synthesis gas not diluted with nitrogen.

1. Biomass residue (pecan shell) gasified with sub-stoichiometric air forms a gas stream containing CO, H_2, CH_4, nitrogen when cooled generates superheated steam, which produces electricity. The cooled gas then is pressurized and burned in a turbine to produce more power, the combustion gases produce superheated steam which generates even more power, while the low-pressure exhaust steam is used to provide cooling in the absorption cooling system in combination with ammonia-water (Fig. 2.6).

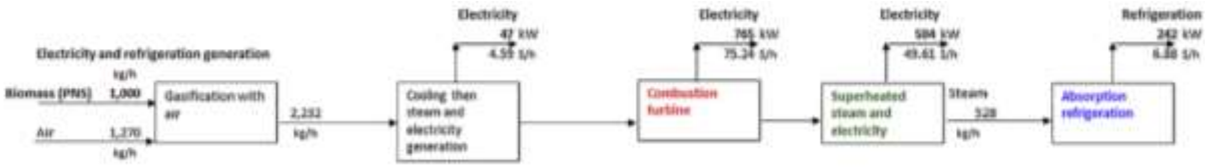

Fig. 2.2. Electricity and refrigeration processes

2. As in the first case, the biomass residue (pecan shell) was gasified with sub-stoichiometric air, but in this case, the gas stream was still treated to obtain a gas mixture containing mainly nitrogen and hydrogen. (Fig. 2.7).

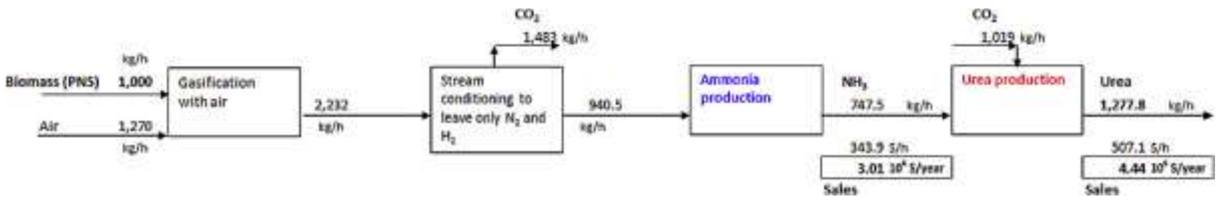

Fig. 2.7. Gas flow treatment to obtain a gas mixture with nitrogen and hydrogen

2.1.5.2. Use of agricultural residues for energy production

The use of crop residues for animal feed is considered an inefficient use of biomass, as most agricultural residues have the potential for energy production. (Go, Conag, Igdon, Toledo, & Malila, 2019).

Agricultural residues such as cereal straw, rice husk, animal manure are produced at different stages of agriculture and can be used in energy production processes. Lignocellulosic biomass, consisting of lignin and cellulose, respectively, has been estimated to have a high potential for energy production, and the use of agricultural residues is not affected by competition with food production (Samadi et al., 2020).

Residues from agriculture can be used as an energy source, for example, orange peel from crop production can be used as an energy source for electricity generation or as a fuel element in technology. It has been estimated that the use of agricultural residues has the potential to improve the overall CO2 balance (Bedoić, Ćosić, & Duić, 2019).

Cotton stalks and peanut shells with high nutrient content are not considered to be cost-effective for electricity generation. In contrast, the use of rice and wheat residues for energy production is considered profitable if biomass conversion technologies are used (Gojiya et al., 2019). It is also estimated that wheat straw, maize residue, barley and rapeseed straw have the highest potential for agricultural residues in the European Union. It has been studied that in India it is possible to obtain 686 Mt of cereal residues per year with a projected energy potential of 4.15 EJ, which is about 17% of India's total primary energy consumption (Vakalis et al., 2019).

Agricultural residues or by-products also can be used to process low-quality materials into higher-quality materials. For example, agricultural by-products can be recycled into environmentally friendly and sustainable materials and nanofibers derived from mycelial fungus composites, used as a cosmetic ingredient, in pharmaceuticals, and water treatment. Agricultural by-products derived from cotton, flax, hemp, rice, sorghum, and wheat are often used only as fillers in composite materials (Jones et al., 2019).

Energy products that can be obtained from biomass and its residues are biogas, synthesis gas hydrogen, biomethane, bioethanol, as well as biodiesel (Lozano & Lozano, 2018).

Sweden and Denmark

The Swedish International Renewable Energy Agency has estimated that by 2030, 13-30 EJ y - 1 of agricultural residues should be used for energy production to reach energy target of doubling the global share of renewable energy. The study estimates the current global theoretical potential of primary agricultural residues - cereals and sugar cane – 3,7 Pg of dry matter per year, which corresponds to 65 EJ y-1. Therefore, it can be concluded that by using the mentioned agricultural residues, it is possible to achieve the goals set for 2030 in terms of increasing the share of renewable energy.

In Denmark and Sweden, agricultural residues traditionally used for energy purposes are residues from wheat and barley, as well as residues from rapeseed cultivation and processing.

Expensive fossil fuels can be replaced by agricultural straw. Ethanol can be used in vehicle internal combustion engines, while gaseous fuels can be used instead of natural gas, either through district networks or in the operation of cogeneration plants (Bentsen, Nilsson, & Larsen, 2018).

Bolivia, South America

Bolivia is dependent on fossil fuels, especially natural gas, and renewable energy accounts for only 5.4% of total energy resources. To reduce dependence on fossil resources, the Bolivian government has pursued a strategic policy to replace existing imported and indigenous fossil fuels with renewable energy sources. It is estimated that in 2025, electricity generated from hydropower will account for 74% of the total volume, while the overall share of other renewable energy sources in the total amount of electricity generated will account for only 4%.

The use of agricultural residues has the potential to generate clean and sustainable energy if suitable biomass is converted. One of Bolivia's cities, Santa Cruz, is rated as one of the main sites in Bolivia with high availability of agricultural biomass residues - 3.3 M s. t / year and the potential amount of energy produced 4.5 TWh/ year. It is estimated that the amount of energy produced from agricultural residues would correspond to 722 MW, which is 34% of the total installed capacity in Bolivia (Morato, Vaezi, & Kumar, 2019).

India, Karnataka

The use of biomass residues from agriculture for energy production is suitable precisely for securing energy supply in rural areas. Karnataka is the fifth largest agricultural waste-producing state in south-western India. The most abundant agricultural residues are chilli peppers, pigeon pea stalks (*Cajanus cajan*) and soybean stalks. These agricultural residues have a moisture content of 4 to 7%, which corresponds to the range of the gasification process, and carbon of 46 to 49%, which generally contributes to higher energy potential. Agricultural residues are considered to be a better source of energy compared to others, and their use for energy will lead to the economic management of residues (Akkoli et al., 2018).

2.1.5.3. Use of agricultural residues in electricity and heat supply (CHP - cogeneration plants)

Southern Italy, Calabria region

In the Calabria region of southern Italy, renewable energy sources are mainly hydropower (1.404 TWh/year) and wind energy (1.866 TWh/year), with around 10% of the hydropower produced being exported to other regions, while wind energy is fully consumed locally. On average, 615 GWh of solar energy is produced annually, and 977 GWh of biofuel is used, which is less than needed to provide adequate electricity in the region (1010 and 6490 GWh/year).

To assess the energy potential associated with the use of agricultural residues, it was first necessary to calculate the amount of biomass available, given that the theoretical potential of residues is limited due to the use of other alternative residues. To identify the actual potential of available biomass residues for further energy production, the availability factor was determined (Algieri, Andiloro, Tamburino, & Zema, 2019).

In Calabria, agricultural land covers 703,931 h, which is 46.4% of the region's total area. Thus, the use of agricultural residues is one of the possible solutions to reduce independence from the use of traditional fossil resources, as well as to reduce the environmental pressures associated with the management of agricultural residues (Venturini, Pizarro-Alonso, & Münster, 2019).

A study in the Calabria region of Italy estimates that the area understudy in the study area is about 820,000 tonnes of biomass per year, which can be used as an energy source in small-scale cogeneration plants to provide electricity and heat to the population locally and regionally. Based on the analysis performed in the study, it is estimated that the amount of available biomass residues could provide approximately 116,000 households with heat supply and approximately 178,000 households with electricity (Venturini et al., 2019).

According to the results, the use of biomass residues (per capita) can provide electricity and heat supply of 288,0 kWh (electricity) and 587,6 kWh (heat), providing heat supply to 128,000 households and electricity to 215,000 households, based on the average local consumption in southern Italy (2616 kWh (electricity) and 9029 kW (heat).

In the study, it was estimated that potential dry lignocellulosic residues in the Calabria region amount to approximately 290 kilotonnes per year. In turn, the largest amount of biomass is made up of residues from olive groves with a volume of 230 kilotonnes. Olive oil mills produce the largest amount of processing residues due to the widespread use of olive groves (85% of the region's total agricultural area). Citrus tree residues reach 40 kilotonnes per year, while grape biomass is less than 14 kilotonnes. The study estimates that one of the solutions for the efficient use of agricultural residues for further energy production is to mix organic residues from olive oil mills, citrus processing plants, wineries with other substrates, often straw or animal manure. Poultry manure has been assessed as the most suitable substrate for biochemical energy conversion processes, and it can also be mixed with other substrates, such as agro-food residues, to balance the carbon to nitrogen ratio and raise pH (Venturini et al., 2019).

Thermochemical conversion based on combustion processes is considered to be the most suitable for processing of lignocellulose residues for further energy. For the other agricultural residues viewed under study (cereals, agro-food industry), biochemical transformation based on anaerobic digestion as an appropriate solution for biogas production and use in internal combustion engines were identified as suitable for energy production (Venturini et al., 2019).

2.1.5.4. Use of straw for energy production

Denmark and Sweden

Demonstration plants for ethanol production have been operating in Denmark since 2009, using straw as a raw material. There are nine large-scale district heating plants in Denmark, as well as several smaller-scale decentralized cogeneration plants using agricultural straw as a raw material. In Sweden, on the other hand, at least four district heating plants use a straw to produce heat. The total installed capacity of the equipment is about 12 MW, and the total demand for straw is about 12 Gg y-1. In Sweden, the number of medium-capacity farms selling heat is around 40, while the number of small-capacity plants (~ 0,5 MW) using straw as raw material is 100, and the total estimated amount of straw for energy production is 50 Gg y− 1.

In Denmark, about 50% of agricultural straw is collected, and 45-50% of this is used as a raw material for further energy production. In Denmark, the total amount of agricultural residues generated during the year is estimated at around 6 Tg of cereal straw, accounting for more than 90% of the total. The remaining part consists of rapeseed straw with a small part of legume (pea) residue (0,1 – 0,3%).

Analysing several scenarios related to the potential for biomass and higher energy production, it is estimated that the amount of straw needed for biorefining or energy production should be increased to 2,9-3,5 Tg / year. According to with Danish policy, to achieve the set targets for the use of straw for energy purposes, it was determined that it is necessary to increase the amount of collected straw intended for further energy production by 1 PJ (69 Gg^{-1}) by 2020.

In Sweden, the most crucial consumer of bioenergy is the forest sector, mainly the wood pulp industry, which mostly uses its biomass residues internally. Compared to other uses of biomass for energy, the use of agricultural residues is small. Unlike Denmark, Swedish policy does not provide for specific incentives to increase the use of straw, nor does it set particular targets for the management of agricultural residues. It is estimated that the total straw mass that can be used for further fuel production could be 0,8-0,9 Tg/year, which corresponds to about 13 PJ / year.

The technology-neutral green certificate system in Sweden and the specifics of the technology in Denmark are the reasons for the different use of straw (Bentsen et al., 2018).

2.1.5.5. Use of grain residues in heat supply and electricity generation

Denmark

In recent years, agricultural residues as an energy source have attracted a great deal of interest, as the use of agricultural residues is seen as beneficial in reducing greenhouse gas emissions and its consumption for energy is considered to be less harmful to the environment than other biomass resources. The assessment of the sustainable use of Danish straw for the production of heat and electricity until 2020 states that installations for the supply of heat and electricity where straw is used as a raw material are exempt from energy and CO2 tax. The use of straw for electricity supply in decentralized cogeneration plants is supported through a feed-in tariff.

In Denmark, straw is mainly used to provide heat and electricity with the aim of reducing greenhouse gas emissions. In Denmark's view, the use of straw for energy production has also contributed to the security of energy supply (Bentsen, Jørgensen, Stupak, Jørgensen, & Taghizadeh-Toosi, 2019).

In Denmark, straw from wheat and barley and other cereals is estimated at around 49,000 t / DM per year, equivalent to 68 PJ. It is estimated that about 50% remain in the field, 23% for further energy and 27% for other uses. In turn, animal manure corresponds to 6200 t DM per year, and 4% of the total amount used for energy production, and 96% left in the field. It is estimated that the remaining biomass of agricultural residues per year forms the energy potential in the range of 105–145 PJ, which corresponds to 14–19% of Denmark's total primary energy consumption in 2015 (Venturini et al., 2019).

2.1.5.6. Biogas production and digestate extraction

Mixing of straw, manure, and other raw materials for biogas is one way to obtain digestate and use it to restore the soil's carbon and nutrients.

2.1.5.7. Use of by-products from the bioethanol production process

The fermentation process of obtaining second-generation bioethanol also generates valuable by-products, like feed, as well as lignin, which can be reused for energy and heat (Zhu, Curtis, & Clancy, 2019).

2.1.5.8. Possibilities of high quality biogas and biomethane production using agricultural residues

In recent years, more attention has been paid to biogas and its quality improvement as an alternative to fossil fuel. For example, the production of ethanol by biorefining of lignocellulosic feedstocks and the production of gaseous fuels using anaerobic digestion or thermal gasification methods (Akkoli et al., 2018).

Biogas consists of about 60% methane (CH4), 40% carbon dioxide (CO2). Biogas can be used in cogeneration plants or burned in boilers to produce heat (Zhu et al., 2019).

Europe can be defined as one of the leaders in biogas production, producing more than half of world production, followed by Asia with 30% (Valenti et al., 2018). Germany is considered to be the leading European country in biogas production, and manure and agricultural residues are mainly used as feedstock for biogas (Weide, Baquero, Schomaker, Brügging, & Wetter, 2020).

Britain and Italy are also among the leading biogas producers and mainly use landfill gas and agricultural residues as production. It is estimated that biogas production increased by 700% between 2000 and 2017, reaching 16.7 million tonnes (Mtoe). German biogas production in 2017 reached 7,845 ktoe of biogas, which is more than twice the amount produced in the United Kingdom. In Sweden, on the other hand, biogas sales have increased fivefold since 2006. This has made Sweden a leader in the production of biofuels for transport (Valenti et al., 2018).

In European Union, 75.6 % of produced biogas is used for production of heat and electricity. For example, biogas is used for district heating and power generation in Denmark and the Netherland. Almost all biogas produced in Italy is used to produce power and heat, and small part is used for biomethane production.

Italy

In Italy, the biogas industry continues to grow, with more than 1,300 biogas plants with a capacity of 8 GWh/year on farms over the last twenty years, making Italy the world's third-largest biogas producer after China and Germany.

Anaerobic coagulation of various organic residues is a widely studied method to increase biogas production and reduce solid part to improve the digestion process. In the classical case, the primary raw material for co-digestion (e.g. animal manure or sewage sludge) is mixed with a small amount of secondary raw materials (e.g. cereal residues, silage and food waste) and fed to a bioreactor (Valenti et al., 2018).

Muradin and Foltynowicz (2014) studied the economic operation of a commercial biogas plant using nine types of organic residues (corn silage, potato pulp, used grape waste, fruit and vegetable pulp, cereals, broad-leaved vegetable waste, household waste) for biogas production. These studies showed a sample for successful biogas production from different types of organic residues. More and more biogas plants are planning to use more types of feedstocks to improve their recycling potential. There is a growing demand for laboratory-level tests to determine the likelihood of such actions (Muradin & Foltynowicz, 2014).

Bangladesh

The digestate of the biogas plant can be used as a fertilizer - bio-fertilizer. Bio-fertilizer is high in nutrients and is excellent for agriculture. By controlling all aspects of the digestion process, it is possible to obtain a quality digestate that can be used as a biofuel impurity. Biomass electricity generation is attractive in developing countries such as Bangladesh, which is rich in biodegradable waste and other bioenergy sources. The calorific value of biogas is variable and depends on the methane content of the gas. It was estimated that the total amount of biomass residues in 2017 was 42.86 million tons. Biomass is used for heating, cooking and other household activities. IDCOL (a company established by the Government of Bangladesh) has invested 238.65 million in Bangladeshi Taka (BDT) biomass technologies, which include biogas-based power plants, biomass power plants and biomass gasification plants. Biomass and biogas power plants produce about 2 MW of electricity (Hasan & Ammenberg, 2019).

Biomass pyrolysis is used to produce biofuels, biochar and gas products. Pyrolysis of different biomass components yields a different product. For example, pyrolysis of lignin results in higher yields of hydrogen and methane compared to cellulose and hemicellulose, while higher yields of CO and CO_2 are obtained from cellulose and hemicellulose.

The study case was also related to methane production using a two-stage pyrolysis-catalytic hydrogenation reactor system from cellulose, hemicellulose and lignin, as well as from four different agricultural biomass wastes. Catalytic hydrogenation of cellulose, hemicellulose (xylan) and lignin pyrolysis in the presence of 10% by weight Ni/Al_2O_3 catalyst were performed in a two-stage fixed bed reactor. The results showed that the highest amount of coal was obtained from rice straw in the amount of 28% by weight, while the lowest amount of coal was obtained using willow and sugar cane residues with 23% by weight. The highest amount of liquid component was obtained with sugar cane biscuit 32% by weight, but the lowest - rice straw with 18% by weight. Differences in the volume composition of methane gas in different biomass samples were similar to ∼70% CH4 (Jaffar, Nahil, & Williams, 2020).

2.1.5.9. Use of agricultural residues for biomethane production

Due to the high potential of biomethane, maize residues are the most popular feedstock for anaerobic digestion. In this study, mono-digestion (maize silage, pineapple silage) and co-digestion (maize silage + inoculum, pineapple silage + inoculum) were performed under mesophilic and thermophilic conditions to investigate which activities may significantly affect the potential of biomethane and anomethane. The experiment was performed in mono- and co-digestion modes to investigate the biomethane process of pineapple and maize residues under mesophilic (38 °C) and thermophilic (50 °C) conditions. It was estimated that temperature control had a more significant effect on biomethane potential and anaerobic digestion performance. Also assessed that temperature-controlled co-digestation might be most appropriate for the use of pineapple residues due to the high potential of biomethane and the stable digestion process.

A study in Denmark aimed at optimizing the use of biomass residues, straw, concluded that biogas production is not a cost-effective way to use a straw. In the synthesis of Fischer-Tropsch (FT) gases, various synthetic fuels, such as methanol or DME (dimethyl ether), could be obtained from straw gasification, which can replace fossil fuels for combustion in vehicles with minor engine modifications. The main advantages of this process are the flexibility of the final fuel products and the ability to store excess electricity in fuels obtained by electrolysis of carbon dioxide and water (using hydrogen), promoting the production of liquid or gaseous fuels.

The no-bioenergy (NO-IMP) scenario of the study predicted that almost all biogas produced in 2050 (33 PJ) from the co-digestion of manure, grass, organic waste and energy crops would be upgraded to for the quality of natural gas using methanization with hydrogen, which allows increasing the production of methane (Fig. 2.8).

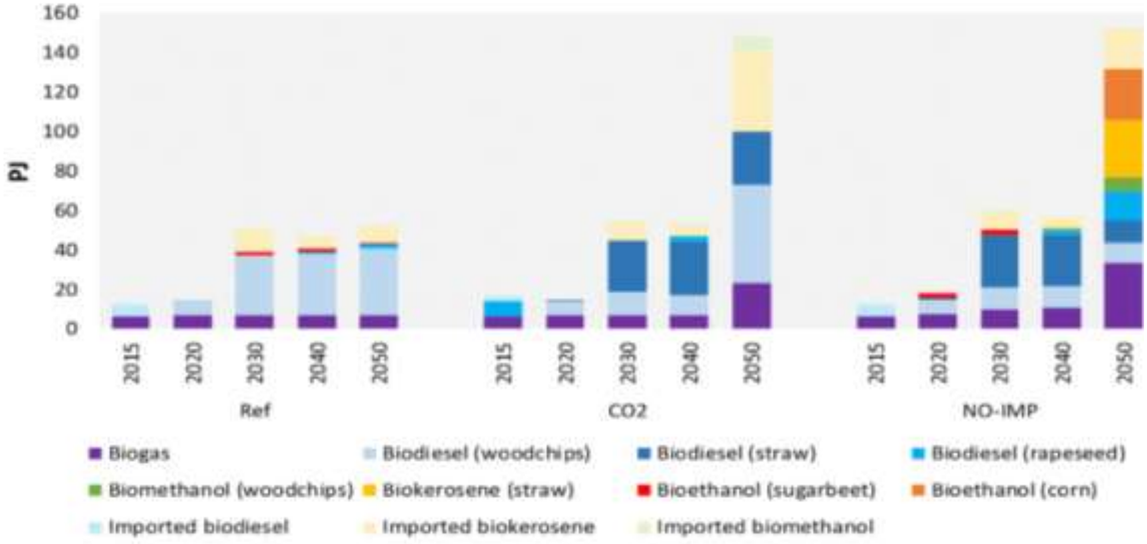

Fig. 2.8. Biofuel and biogas development scenarios

Among the possible technological improvements, the gas amount can be further optimized by raising the gasification temperature. The possibility of increasing the production of biofuels by thermal gasification with syngas hydrogenation has also been highlighted in other studies, assuming that the availability of biomass is limited. Straw burning for heat and power cogeneration is mentioned as the preferred alternative, as it excludes heat and power generation from coal and natural gas by 2030. In contrast, coagulation of manure and straw for biogas production is preferable to second-generation bioethanol (produced from agricultural residues).

Biogas production is not a cost-optimal alternative to straw, as the high lignin content requires an expensive pre-treatment process. The use of straw in bioethanol production is not a priority in the long term, as bioethanol is mostly used in light vehicles that can be electrified (Venturini et al., 2019).

2.1.5.10. Use of biomethane

The leading countries in biomethane production in Europe are Germany, Great Britain, Sweden, Switzerland, France, the Netherlands and Denmark, as well as Ireland. Under the *FiT flat-rate* scheme, energy producers receive a fixed amount per unit of electricity produced or biomethane injected, regardless of production costs or market prices. In Sweden, biogas electricity producers receive electricity certificates and sell them under the Norwegian and Swedish green certificate scheme for renewable energy. Biofuel quota schemes also exist in Germany, the United Kingdom, France, the Netherlands and Denmark. According to current cultivation practices, energy crops can only make up 30% of the raw material, with the rest being manure. The use of specific energy crops for biogas production is also limited in Germany, Austria and Denmark.

Gas with a methane content of more than 97% (biomethane) is the only biofuel whose properties surpass those of fossil fuels. Therefore, biomethane is a promising alternative to fossil fuels. Biogas, enhanced by reducing the composition of CO_2 and other impurities to biomethane, has the same chemical properties as fossil fuels and can be fed directly into an existing gas distribution network or sold at retail service stations as a fuel for cars (Qyyum et al., 2020).

<u>Denmark</u>

The Green Growth Pact, launched in 2009, set a target in Denmark of using 50% of green energy from livestock manure by 2020. For achieving this target, specific policy support is being implemented. The existence of district heating systems and cooperation of farmers in small communities also contribute to the achievement of the goal. Most centralized biogas plants in rural areas process manure along with food waste and other raw materials (Zhu et al., 2019).

Sweden

In Sweden the following target has set for the transport sector: 3,5% of modern biofuels must be produced from certain raw materials listed in regulatory legislation - manure and sewage sludge, household and industrial bio-waste, agricultural and forestry residues, algae and energy crops. Biomethane production is affected by the composition of biogas, which depends on the raw materials and the process used to obtain them.

According to EBA (EBA, 2017) data, in 2016, there were 513 biomethane plants in Europe with an estimated production volume of 17,264 GWh. Current biogas production is estimated to be only 3.3% of the total potential available in the EU (Bentsen et al., 2018).

2.1.5.11. Possibilities of biomethane production with high methane content

Scientific research has looked at various strategies for increasing the methane content of the final product. One option is the use of *oleaginous* microalgae. These microalgae can reduce the amount of CO_2 by converting it into lipids. This process not only cleans biogas from CO_2 but also produces biofuels from microalgae. Using this method, the methane content in biogas increased from 60% to> 90%, and the lipid productivity reached 88,57 mg L_1 day_1. Maximum CO_2 removal occurred at a gas flow rate of 0.15 L/h per 1 L microalgae culture, with an initial cell concentration of 107 cells/mL, 0.65 g/L KNO3, and a light intensity of 5,28 lux. Under these conditions, 99.33% of the CO_2 in the gas was removed.

2.1.5.12. Processing of agricultural residues in Latvia

2.1.6.1. Processing of agricultural residues in Latvia within the framework of policy planning documents

Latvian policy planning documents and regulations regarding the use and production of RES are integrated from the European Union regulatory framework. The main policy documents binding for the use and production of RES in the agriculture sector in EU and Latvia are shown in Fig. 2.9.

Fig. 2.9. Agricultural policy planning documents regarding RES

Sustainable Development Strategy of Latvia until 2030 (Latvija2030) states that innovations and use of RES are one of the long-term priority lines of action towards safe and renewable energy. The document suggests that the abandoned agricultural lands can be used for growing energy crops suitable for biofuel production. At the same time, it is underlined that the development of biofuels should be related to the transfer of innovations and best practice. Moreover, the production of biomass as RES should be planned in areas less favourable for food production.

Latvija2030 identifies the promotion of biofuels in public transport and agriculture as one of the solutions towards the development of RES use and innovation, however, it does not set specific objectives in this respect. One of the targets set in LIAS 2030 is the use and innovation of RES (indicator: RES share in gross domestic energy consumption in 2030 > 50%), still, there are no targets for RES production.

Energy Strategy 2030 sets several directions beneficial to the use of agricultural residues:

- Support for the development of second-generation biofuel production, through preparing contest conditions for the creation of BTL (biomass-to-liquids) synthetic biofuel production plant with capacity at least 100 million liters per year, which would significantly contribute to the use of local biomass in the transport sector, ensuring the demand for wood, peat and agricultural waste of 1,5 million m^3 per year;
- Energy should be produced from animal-based by-products and derived products, as well as gas from waste disposal facilities and wastewater treatment.
- The power capacity and produced power in biomass power stations should increase multiple times from 2010 to 2020 and should continue to increase significantly in 2030. (Latvijas Republikas Saeima, 2010).

National Development Plan of Latvia for 2014-2020 (NAP 2014-2020) states that it is necessary to support the deployment of new technologies and rational use of resources, thereby reducing pollutant emissions in energy, industrial, transport, agricultural and household sectors. The aim is to prevent exceeding the level of pollution and greenhouse gas emissions at which sustainable development can be ensured (by reducing the emissions and waste from energy, industry, transport, agriculture, fisheries and households).

In relation to agricultural land, NAP 2014-2020 has identified the need to stimulate the use of agricultural land by supporting the production and provision of services. At the same time, it is underlined that the use of land must be both intensive and sustainable.

According to NAP 2014-2020, there is an intention to support energy production from RES, however, in this respect, no specific relation to the agriculture sector has been made Cross-Sectoral Coordination Centre, 2012).

2.1.6. RES target evaluation in the agriculture sector policy planning of Latvia

The evaluation of agricultural sector policy documents regarding RES consisted of five steps – three steps of 3-dimension evaluation adopted from European Climate Foundation (European Climate Foundation, 2019) and two steps to make conclusions and determine opportunities for RES development

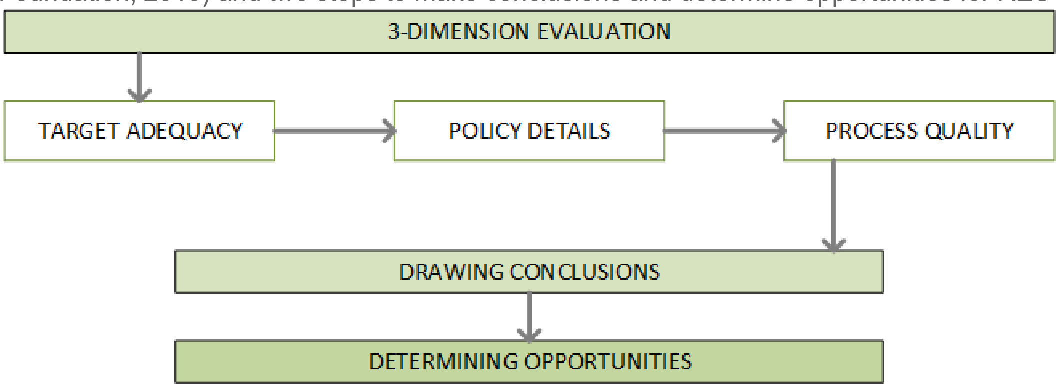

Fig. 2.3 (a).

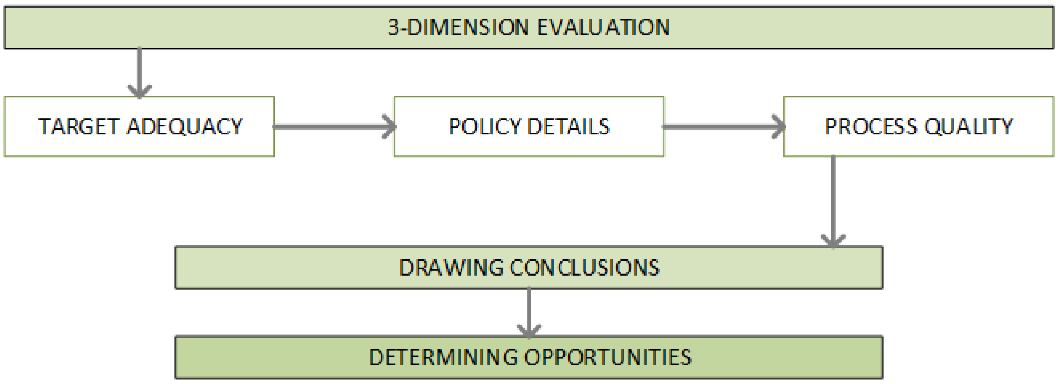

Fig. 2.3. (a) an Evaluation of agricultural policy planning documents in relation to RES

European Climate foundation used the method of 3-dimension evaluation to assess the successfulness of National Energy and Climate Plans (European Climate Foundation, 2019). They defined several qualitative indicators for each dimension and expressed each score numerically. In this study the same dimensions have been used, however, dimensions were not divided into indicators, due to the difference in document objectives and target areas. Therefore, the evaluation is not expressed numerically and is limited to a qualitative assessment. The 3-dimensions were evaluated through the criteria presented in Fig. 2.10 (b).

Fig. 2.10. (b) Evaluation criteria of policy planning documents in relation to RES

The evaluation of agricultural sector policy planning documents in relation to RES is given in Table 2.2

Table 2.2.

The evaluation of agricultural sector policy planning documents in relation to RES

	Latvian Bioeconomy Strategy 2030	
3-dimension evaluation	Target adequacy	No targets for the production or utilization of RES in the agriculture sector are set.
	Policy details	The strategy does not provide the identification of specific measures, responsible actors or sources of funding.
	Process quality	The strategy was prepared by the Ministry of Agriculture in cooperation with Latvia University of Life Sciences and Technologies. Associations of related sectors, scientific institutions, as well as representatives from the Ministry of Economics, Ministry of Environmental Protection and Regional Development, Ministry of Welfare and Cross-Sectoral Coordination Centre were also involved. During the preparation process seminars and international conferences were organized in order to promote the transfer of best practices to bioeconomy from the North. A public consultation was being held.
Conclusions		Although the targets set in Strategy could promote the production and utilization of RES in the agriculture sector, from a political perspective document does not promote that, because relevant targets and measures have not been identified.
Opportunities		RES utilization for the production of products with high value-added. RES production from agricultural residues and manufacturing by-products.
	Rural Development Programme 2014-2020 (LAP 2014-2020)	
3-dimension evaluation	Target adequacy	Although the promotion of RES utilization along with the reduction of GHG emissions is set as one of the three main necessities for the development of agriculture sector, no specific targets concerning RES are set. The planned direction of RES development is in line with the direction set at the EU level, however, at national level priorities are too ambiguous and no achievable goals or performable actions are identified.
	Policy details	As an *ex-ante* condition applicable at the national level for the RES LAP 2014-2020 states that "measures have been taken to promote the production and distribution of renewable energy sources", as a criterion "transparent support schemes, priority access to the grid or guaranteed access and priority in the distribution, as well as publicly announced standard rules on the taking-up and distribution of technical adjustment costs" is set. Performance assessment states that there should be "an annual increase in the number of new projects starting power generation from renewable energy sources, receiving support in the form of feed-in tariffs". According to NAP 2014-2020, it is expected that several such projects should continue to increase in the next period as well. At the same time mandatory purchase component of electricity, which is currently being revised to make it more flexible and economically justified, taking into account the risks it poses to end-users, is not the only support mechanism implemented in Latvia for energy production from RES. There is an intention to support farmers who use residues from their farm for energy production for their farming purposes. The total investment target for renewable energy production for 2023 is EUR 40 000 000. The investment is intended to support 25 actions.

	Process quality	LAP 2014-2020 was prepared by the Ministry of Agriculture. *Ex-ante* evaluation, including strategic environmental assessment, has been made. A public consultation has been held.
Conclusions		In general LAP 2014-2020 supports the utilization of RES, which is evidenced by the accordingly defined necessity. Although the promotion of RES utilization is set as one of the main priorities, policy planning in this respect cannot be considered successful because of the lack of targets and clear action plan, as well as because only one political instrument – the financial support in the form of investments – is selected. It should be noted that the LAP 2014-2020 document is voluminous, however, at the same time, the information often repeats itself. The structure of the document (integrated comments) makes it chaotic and opaque.
Opportunities		Utilization and production of RES.
3-dimension evaluation	Common Agricultural Policy until 2020	
	Target adequacy	No targets for RES production and utilization in the agriculture sector are set.
	Policy details	No specific actions for the promotion of RES production and utilization in the agriculture sector are planned.
	Process quality	The document was prepared by the Ministry of Agriculture.
Conclusions		The document only mentions RES, so it does not refer to RES directly.
Opportunities		RES utilization for the production of products with high value-added. RES production from agricultural residues and manufacturing by-products.

From the evaluation of agricultural sector policy planning documents, it can be seen that the promotion of RES utilization is considered as one of the priorities in relation to agricultural development. Nevertheless, the political quality of these documents suggests that the development of RES in the agriculture sector will lead its own way because of the lack of targets and clear action plans.

Yet, there is a high potential for the agriculture sector to develop the utilization of RES not just on a sector level, but on a national level as well. In the following section, the methodology for the ranking of RES utilization options with multi-criteria analysis is presented.

2.1.7. Analysis of agricultural waste utilization opportunities

The algorithm of the evaluation process for RES utilization opportunities is shown in Fig. 2.11.

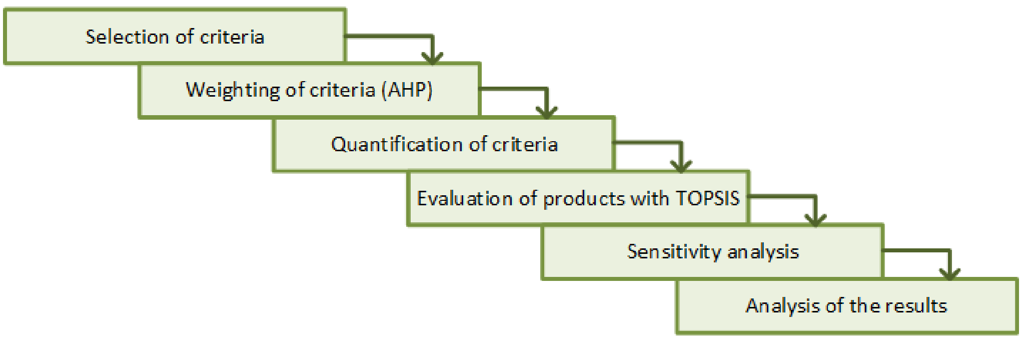

Fig. 4. The algorithm of the evaluation process with MCDA

2.1.7.1. Selection of agricultural residue utilization options

Five types of options for agricultural residue utilization were selected. Biogas and modern biofuel were chosen as the most desirable products considering the need for the development towards climate neutrality. Agricultural residues for the production of building material (as an additive) was selected as one of the competitive products to biofuel/biogas production. Material for combustion was chosen as the less efficient option for resource utilization. Meanwhile, reuse in agriculture (use of resources in future agricultural activities, such as composting of waste for soil fertilization, crop residues for fodder, etc.) was chosen as a relatively easy solution from a technological point of view and more dependent on the individual activities of farmers.

Selection of criteria

(Xu, Wei, Ji, Wang, & Gao, 2019) have developed a review of renewable energy development research and identified renewable energy assessment indicators such as economic, technical, political and social. Similar criteria were used in this study. However, given the purpose of this study, environmental and climate factors have also been added. Description of each criterion is given below.

Technological factor determines the level of technology development suitable for the production of a certain product, as well as the efficiency of the production process.

Economic factor determines the economic viability of the production of a certain product. The evaluation includes current costs related to the manufacturing process, installation and maintenance of equipment, extraction and pre-treatment of resources etc., as well as tax payments, opportunities to receive financial support, opportunities to attract investors etc.

Environmental factor determines the environmental impact of the production process. The evaluation includes the types and intensity of pollution that will arise in the production process (e.g. wastewater, air pollution with solid dispersed particles etc.).

Climate factor determines how the production of a given product will impact climate from GHG perspective. The evaluation includes the amount of GHG emissions generated in the production process, as well as the importance of product utilization in reaching the climate goals.

Social factor determines the public readiness to produce and/or utilize a given product, considering the risks and disadvantages related to the production and utilization of this product. The evaluation includes the favourability of manufacturers and consumers' attitude towards the production and utilization of the given product.

Political factor determines the favourability of the political environment for the production and utilization of a given product. The evaluation includes the existing policy planning goals and priorities, policy instruments (financial support, research project contests, advantages etc.), as well as the regulatory environment.

All criteria were evaluated in the context of agricultural residues.

Determining criteria weights with AHP

In order to get a realistic assumption of the importance of each selected criterion, their weight was determined with a pairwise comparison (PC) method. PC method is used to determine the relative importance of weights of the alternatives and criteria with respect to each criterion in the decision process (Bertuzzi Leonelli, 2012). The process involves the evaluation of two criteria at a time by choosing which one is more important than the other and indicating the intensity of this importance with a scale from 1 to 9 (1 meaning that both criteria are of equal importance, 9 meaning that one criterion is extremely more important than the other).

Criteria weights, as well as attribute values, were determined by the expert judgment method. The obtained criterion weights are average values calculated according to expert judgments. The specified criteria weights are given in Table 2.4.

After comparing the importance of criteria, the AHP pairwise comparison matrix was created (Table 2.3). The normalized pairwise comparison matrix was created according to the formula:

$$X_{ij} = \frac{C_{ij}}{\sum_{i=1}^{n} C_{ij}}, \qquad (2.1)$$

where
X_{ij} – normalized pairwise value;
C_{ij} – pairwise comparison value for each element;
$\sum C_{ij}$ – the sum of the pairwise comparison column.

Table 2.3

Creation of AHP comparison matrix

		i_1 Technological	i_2 Economic	i_3 Environmental	i_4 Climate	i_5 Social	i_6 Political
i_1	**Technological**	1	0.5	4	3	1	0.33
i_2	**Economic**	2	1	7	6	2	1
i_3	**Environmental**	0.25	0.14	1	0.2	0.34	0.25
i_4	**Climate**	0.34	0.17	5	1	0.5	0.34
i_5	**Social**	1	0.5	3	2	1	0.33
i_6	**Political**	3	0.25	4	3	3	1

Priority vector for each criteria was calculated according to the following formula:

$$W_{ij} = \frac{\sum_{j=1}^{n} X_{ij}}{n}, \qquad (2.2)$$

where
$\sum_{j=1}^{n} X_{ij}$ – the sum of normalized pairwise column;
n – number of criteria.

Calculated criteria weights are shown in Table 2.4.

Table 2.4

Criteria weights calculated from expert judgement

Criteria	**Criteria weight**	**Criteria weight in percentage**
Technological i_1	0.15	15 %
Economic i_2	0.32	32 %
Environmental i_3	0.04	4 %
Climate i_4	0.09	9 %
Social i_5	0.14	14 %
Political i_6	0.26	26 %

Evaluation of products with TOPSIS

With TOPSIS (Technique of Order Preference Similarity to Ideal Solution) the distance to the ideal and anti-ideal solution is calculated for each possible solution. The best possible solution is the one which is at the shortest distance from the ideal solution and the furthest distance from the anti-ideal solution. The main advantages of TOPSIS include: (1) unlimited number of criteria and performance attributes can be selected; (2) the opportunity to compare alternatives to understand their similarities and differences; (3) comparatively simple calculation process and no need for special software. The main disadvantage of TOPSIS is that it provides no correlation between the attributes. TOPSIS was chosen for this study mainly because of the opportunity to compare different alternatives (Ishizaka & Nemery, 2013).

The first step in the evaluation process with TOPSIS was to create a decision matrix by giving each attribute value (Table 2.5). All values are the mean scores calculated from the expert judgements. In the evaluation process, the favourability of each factor (criterion) for the production of selected products was evaluated according to the current situation. The quantification of the qualitative evaluation is shown in Table 2.6. For example, the development of technology can be considered favourable for the production of biogas, building material, material for combustion, as well as for agricultural reuse (value 5), while technologies are well developed for only some types of modern biofuel production and therefore the favourability of technology is considered neutral in this case (value 3).

Table 2.5

Creation of decision-making matrix

	Product	Biogas	Modern biofuel	Building material	Material for combustion	Agricultural reuse
	Criteria	x_1	x_2	x_3	x_4	x_5
i_1	Technological	5	3	5	5	5
i_2	Economic	5	3	3	1	3
i_3	Environmental	3	4	5	1	4
i_4	Climate	4	4	5	4	2
i_5	Social	4	5	5	4	5
i_6	Political	2	2	3	3	2

Table 2.6

Quantification of qualitative evaluation

Value	**Factor favourability**
1	**Factor favourability**
2	factor is unfavourable
3	factor is rather unfavourable
4	factor is neutral
5	factor is rather favourable

After a value was given to each attribute, they were normalized with distributive normalization method according to formula:

$$r_{ai} = \frac{x_{ai}}{\sqrt{\sum_{a=1}^{n} x_{ai}^2}}, \tag{2.3}$$

where
r_{ai} – normalized value;
a – alternative;
i – criterion.

After a normalized decision matrix was made, the values were recalculated with the determined weights according to formula:

$$v_{ai} = w_i * r_{ia}, \tag{2.4}$$

where

v_{ai} – weighted value;
w_i – weight.

In the next step, the ideal and anti-ideal solution was calculated. Each weighted value was compared with the maximal and minimal value of the corresponding criterion. The sum of squares of each alternative's difference from the maximum value was used to determine the total distance of alternative to the ideal solution. The distance to the ideal solution was calculated with the following formula:

$$d_a^+ = \sqrt{\sum_{j=1}^{n}(v_i^+ - v_{ai})^2}, \tag{2.5}$$

where
d_a^+ - distance to the ideal solution.

The distance to the anti-ideal solution is calculated with the following formula:

$$d_a^- = \sqrt{\sum_{j=1}^{n}(v_i^- - v_{ai})^2}, \tag{2.6}$$

where
d_a^- - distance to the anti-ideal solution.

The final step was to calculate the relative closeness of each alternative to the ideal solution. This was done with the following formula:

$$C_a = \frac{d_a^-}{d_a^+ + d_a^-}, \tag{2.7}$$

where
C_a – relative closeness to the ideal solution.

Each alternative gave a value ranging from 0 to 1. The best alternative is the closest to 1.

Sensitivity analysis

In the sensitivity analysis, input data is modified in order to observe the impact on the results. In the sensitivity analysis, different scenarios are generated by varying the weight of criteria and observing the impact on the global alternative priority. It allows to determine whether the results are sensitive or *robust* (Ishizaka A., 2013). If the ranking does not change, the results are considered to be *robust*.

The steps of performing sensitivity analysis was as follows:

(1) All criteria were given the same initial weight according to formula:

$$w' = \frac{1}{n}, \tag{2.8}$$

where
w' – initial weight of criterion;
n – number of criteria.

(2) Each criterion was exposed to different unitary variation ratios – 0.1, 0.5, 1, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0 and 4.5. Similar unitary variation ratios were selected as in Li et al. evaluation of sensitivity to the parameter weights in water quality assessment (Li, 2013). However, ratios of 0.01, 0.02, 0.05 and 0.2 were not included, due to unlikely sensitivity at such minor variations.

(3) After designing the unitary variation ratios, the weights of criteria were recalculated and the attributes in matrix were calculated under the new weights.

An example of criteria weighting under different unitary variation ratios for technological criteria is given in Table 2.7.

Table 2.7

Weights under different unitary variation ratios for technological criteria

	Weights					
Unitary variation ratio (β_k)	**0.01**	**0.5**	**1**	**1.5**	**2**	**3**
Technological	0.002	0.083	0.167	0.250	0.333	0.500
Economic	0.200	0.183	0.167	0.150	0.133	0.100
Environmental	0.200	0.183	0.167	0.150	0.133	0.100
Climate	0.200	0.183	0.167	0.150	0.133	0.100
Social	0.200	0.183	0.167	0.150	0.133	0.100
Political	0.200	0.183	0.167	0.150	0.133	0.100

Evaluation of opportunities for RES utilization

Results of the multi-criteria analysis show that the best possible utilization option of agricultural residues is biogas production, which has a relative closeness coefficient to the ideal solution of 0.66 (Fig. 2.12). The second best option from the selected alternatives is shown by building material, which has a relative closeness result of 0.63. The production of modern biofuel and agricultural reuse shows a similar score – 0.51 and 0.50, respectively. Results suggest that the material for combustion is the least favourable utilization option for agricultural residues.

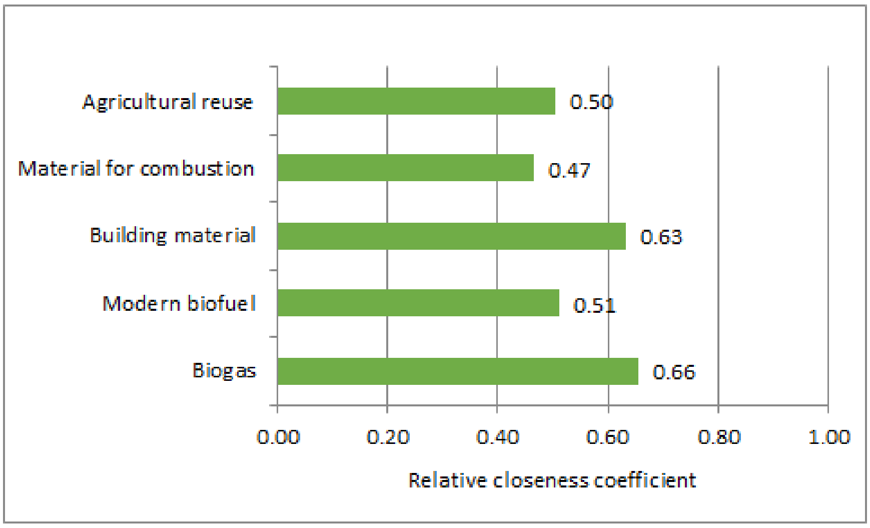

Fig. 2.12. Result with the realistic weights

In order to conduct how results would change within specific policy goals and what changes would appear in the field of development of RES, various possible scenarios were analysed based on variable weight of criteria. Four scenarios were analysed – equal-weights, economic, climate, and policy scenarios.

(1) Equal-weights scenario

The equal-weights (base) scenario was selected to test the ranking of utilization options in a situation where all factors are equally important. Basically, this test represents the ranking made by attribute values only.

The weights were calculated according to the formula:

$$w_i = \frac{1}{\mathrm{n}}, \tag{2.9}$$

where
w_i – new criterion weight;
n – the number of factors.

In the base scenario, the ranking of utilization options is somewhat similar to the ranking with the realistic weights, however, in the base scenario, the production of biogas is switched with the building material (Fig. 2.13). Building material takes the top priority with the highest relative closeness score of 0.71, while biogas is left the second best. The ranking of all the other options matches the realistic scenario.

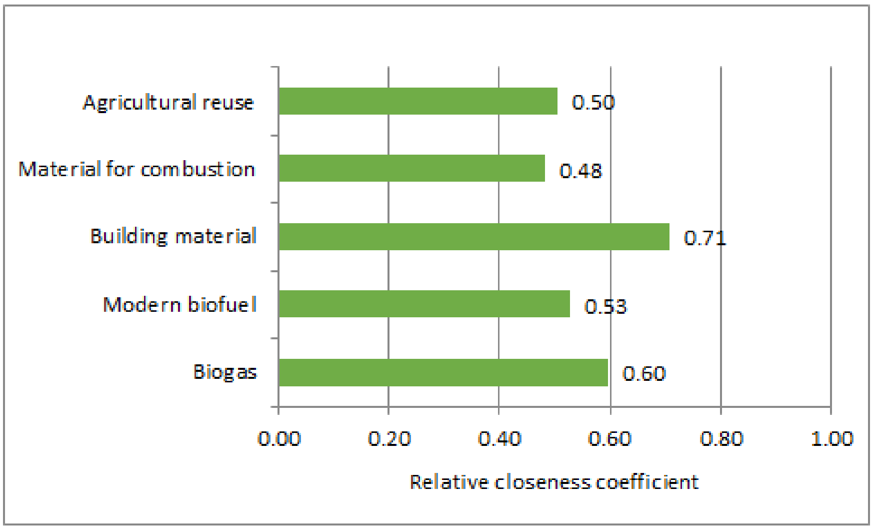

Fig. 2.13. Result of the base scenario with all weights being equal

(2) Economic scenario

The economic scenario was selected to test how the ranking would change if the importance of the economic factor was even more pronounced. The weight of economic factor was increased to 50 %, and the weights of all the other factors were calculated proportionally to the realistic weights according to the following formula:

$$w_i = \frac{1 - W_k}{(\sum W' - W_k') \cdot W_i'}, \tag{2.10}$$

where
w_i – new criterion weight;
w_k – new economic weight, 0.5;
$\sum w_i$ – the initial sum of weights, 1;
W_k' – initial economic weight, 0.32;
w_i' – initial criterion weight.

Ranking in the economic scenario is somewhat similar to the ranking in the realistic scenario as well (Fig. 2.14). Nevertheless, the bottom priority (material for combustion) is explicitly less favourable with the relative closeness score of 0.40, and the top priority (biogas) is explicitly more favourable with the score of 0.72. This represents the variety in values assigned to the utilization options in relation to economic criteria.

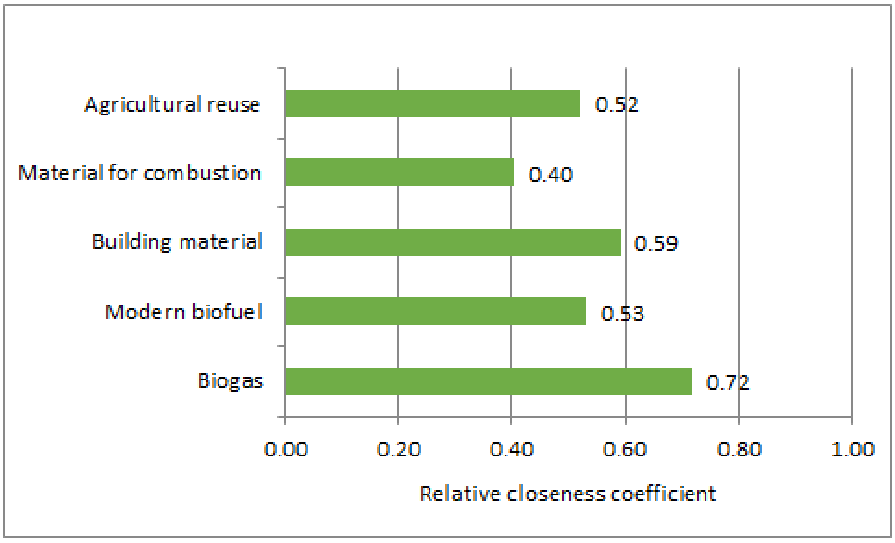

Fig. 2.14. Result of the economic scenario with the weight of the economic factor being 50 %

(3) Climate scenario

Taking into account the possible increase of significance for the climate factor through growing political targets, the ranking of alternatives was tested with a 50 % weight of climate factor.

Results of the climate test give a different result than the test with realistic weights (Fig. 2.15). When the weight of the climate factor is increased to 50 %, the building material is the most preferred utilization option with a relative closeness coefficient of 0.70. It is followed by biogas, modern biofuel, material for combustion and agricultural reuse.

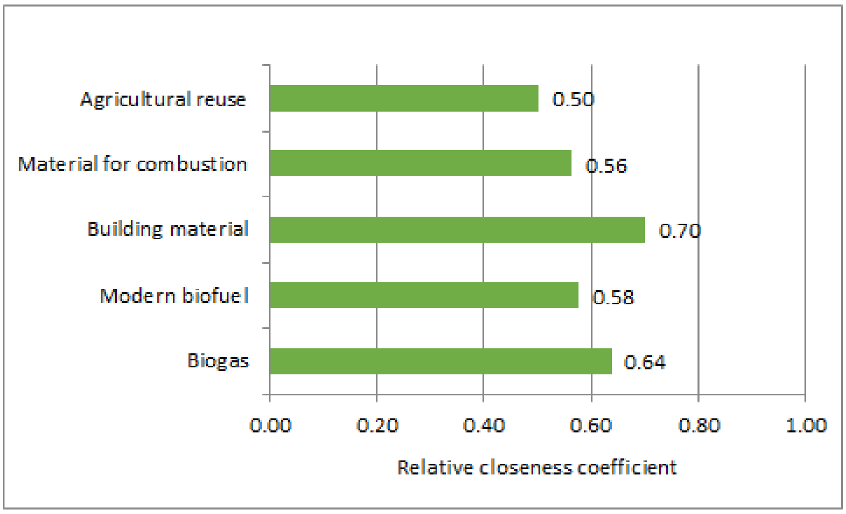

Fig. 2.15. Result of the climate scenario with the weight of climate factor being 50 %

(4) Political scenario

This test allows to determine the influence of the existing policy and shows how the ranking of favourability for different types of residue utilization would change if a policy were equally favourable to all utilization options. The influence of the political factor was tested by giving the highest attribute value to all products (Table 2.8) and increasing the weight of political factor to 50 %. This test differs from the previous ones, for along with the changed criteria weight, attribute values have also been changed. It is assumed that the values determined by the political factor can be affected more easily, while the values of other factors are a combination of several aspects, which can be more difficult to influence.

Table 2.8

Modification of attribute values for the political factor

	Product	Biogas	Modern biofuel	Building material	Material for combustion	Agricultural reuse
	Criteria	x1	x2	x3	x4	x5
i_1	Technologic	5	3	5	5	5
i_2	Economic	5	3	3	1	3
i_3	Environmental	3	4	5	1	4
i_4	Climate	4	4	5	4	2
i_5	Social	4	5	5	4	5
i_6	**Political**	**5**	**5**	**5**	**5**	**5**

When the political factor is of the highest favourability for all utilization options and the weight of political factor is increased to 50 % the potential successfulness for biogas production is even more expressed with the relative closeness coefficient of 0.75 (Fig. 2.16). As with the realistic values and weights, the production of building material is the second-best option. Meanwhile, the suitability of agricultural reuse and the production of modern biofuel are equal and indicate a relative closeness score of 0.56. Material for combustion is even less desirable option than with the realistic values and weights. The test shows that political factor has no significant influence on the ranking of the selected options for residue utilization. Nevertheless, a political factor is particularly significant, because it has the power to impact all the other factors.

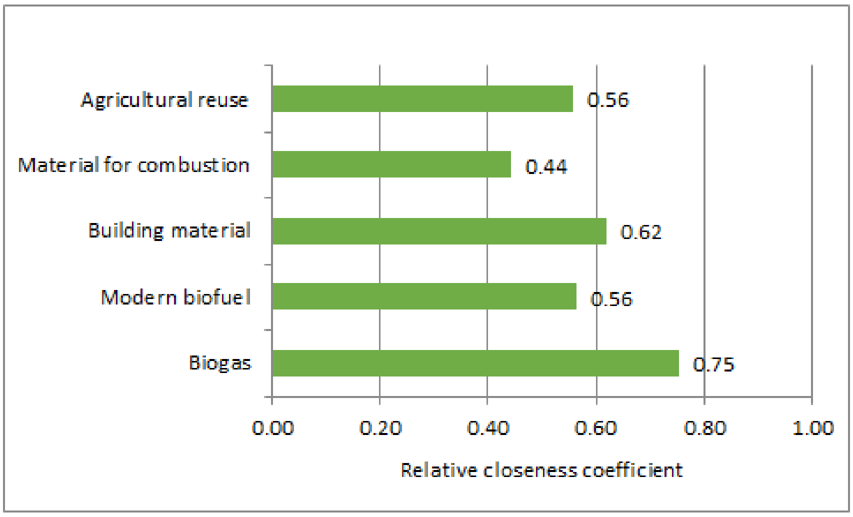

Fig. 2.16. Result of the political scenario with the weight of political factor being 50 % and highest favourability values

Considering that biogas, according to the results with the realistic weights, holds a high potential for agricultural residue utilization, as well as it can contribute significantly to the replacement of fossil fuels, results for favourability for biogas production from all the tested scenarios are represented unitedly in Fig. 2.17.

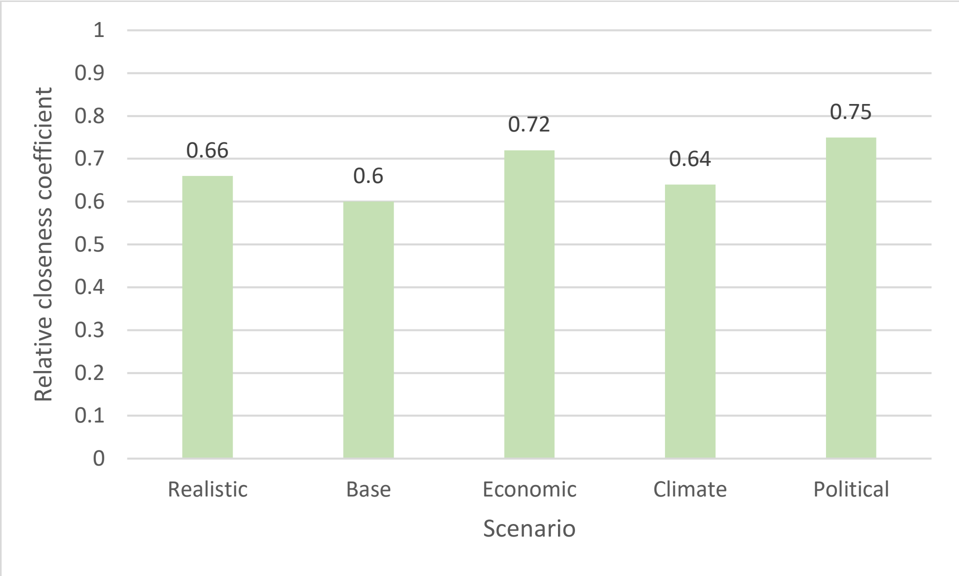

Fig. 2.17. Favourability for biogas production from agricultural residues according to different scenarios

It can be seen that the highest potential for biogas production might be from realizing the political scenario and increasing the favourability and importance of the political factor by setting respective goals and implementing political instruments. The economic scenario shows the second-best option for biogas production with a slightly lower score than in the political scenario. This shows that the promotion of economic importance can facilitate biogas production.

Results show that, according to the present situation (realistic attribute values and factor weights), the ranking of potential successfulness of residue utilization options is as follows: production of biogas > production of building material > production of modern biofuel > agricultural reuse > material for combustion. This highlights the need to move towards a cascaded use of resources because while incineration and agricultural reuse might be the easiest options, production of biogas can give major benefits to economics and climate by utilizing resources more efficiently, as well as contributing to the replacement of fossil fuels. Furthermore, politics has the potential to increase the favourability of factors which are not that favourable to the production of biogas at the moment to increase its potential even more.

2.1.8. Conclusions

The agricultural sector is the second-largest emitter of GHG gas, so the fight against climate change will inevitably affect agriculture. The use of solar, wind, geothermal and other renewable energy sources in agriculture can not only make it more environmentally friendly but also can reduce production costs and improve productivity. Besides, the agricultural sector itself generates large amounts of residues that can become a renewable energy source or a valuable resource. The use of solar and wind energy in agriculture and the processing of agricultural products has a history of thousands of years. The latest technology improvement makes it possible today, using these technologies with much greater efficiency.

Solar energy is used to heat greenhouses, dry agricultural products, pump water, charge batteries, street lighting, refrigeration, mining, in swimming pool heating systems, for the hydrogen production process and even soil purification. Wind energy is almost as widely used. Examples of geothermal energy applications from different countries can also be found in the literature.

Agricultural residues can also be used as a renewable energy resource. They can be used as material to be burned for heat and electricity generation, digestion for biogas or biomethane production and other means.

Performing a multi-criteria analysis of several deliberately selected alternatives for the use of agricultural residues, it was concluded that the use of agricultural residues by incineration in Latvia is the least desirable alternative to the use of residues in almost all examined scenarios.

This was to be expected as this alternative was chosen as a less efficient option. Although increasing the incineration of agricultural residues for energy would facilitate the transition to carbon neutrality, it is not the best solution for resource use. Agricultural resources, including agricultural residues, can be used much more widely to reap significant economic and environmental benefits. Therefore, promoting the use of agricultural residues in energy should not be a political goal.

The analysis highlighted the two best uses of biomass residues - biogas and construction materials. However, it is essential to note that the alternatives (use options) were not compared with each other during the evaluation process. The use of agricultural residues for the production of construction materials has gained the highest value according to the climate criterion, however, it cannot help to achieve climate goals to the same extent as biogas can. This suggests that it would have been useful to divide the climate factor into two factors: emissions to air and the contribution to climate goals. It is concluded that as the importance of the economic factor increases, the benefits of biogas production also increase.

Locally produced biogas can also be used as an energy source in agriculture.

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2.2. POSSIBILITIES FOR THE USE OF RENEWABLE ENERGY IN THE INDUSTRIAL SECTOR

Studies have estimated that the industrial sector uses more non-renewable energy and less renewable energy resources, but the share of renewable energy in the industrial sector is also increasing, and it is recognized that there is a high potential for the use of renewable energy resources in the industrial sector (Salha et al., 2018).

In recent years, China has seen a significant shift from fossil fuels to cleaner energy sources, including wind turbines and solar PV panels in manufacturing industries. China is one of the leading countries in the production of electric cars, wind turbines and solar PV panels. Several of the large fuel companies are beginning to switch, at least in part, to the use of renewable energy. Large-scale oil companies such as Shell, British Petroleum are investing heavily in renewable energy as well as charging electric cars (Edomah, 2019).

In South Asia, a several of developing countries, like India, Pakistan, Sri Lanka, Bhutan, Nepal, Afghanistan and the Maldives, are increasingly seeking access to renewable energy sources such as solar, wind, hydropower and biomass. Nepal alone has a huge hydropower potential - 83,000 MW (Shukla et al., 2017).

Based on 2017 data, the energy consumption of the EU industrial sector was 10929 PJ, corresponding to 23% of the total final energy consumption in that year. The share of the use of renewable energy sources in the industry in the respective year is estimated to be small - 9% and the most used solid biomass from renewable energy sources - 93% (Malico et al., 2019).

It is estimated that the provision of heat energy processes in industry accounts for the largest share of the amount of energy required in the sector. It is estimated that 28.84% of the heat needed for production processes in the 28 EU Member States are used in the five most energy-intensive industries: in the iron and steel industry, the chemical and petrochemical industries, the pulp, paper and printing industry, the food, beverage and tobacco industry, and the production of non-metallic minerals such as cement (Malico et al., 2019).

2.2.1. Possibilities of using solar energy in the industry sector

In Europe, about a third of the total energy demand in the industrial sector corresponds to industrial processes that require temperatures below 100 °C and can, therefore, solar energy can be used as an energy source. Although solar energy technologies are widely used in the household sector in Europe, the actual use of solar energy technologies in the industrial sector is relatively low. In Europe, about 27% of total energy demand is consumed in the industrial sector, of which about 30% corresponds to low-temperature processes below 100 °C and 27% to medium-temperature processes between 100 and 400 °C.

The temperatures required for industrial processes up to 200 ° C are achieved by using extremely high vacuum plate collectors and vacuum tube collectors with concentrators. Parabolic or Fresner solar concentrators, on the other hand, can generate pressurized steam at temperatures up to 400 ° C.

It is estimated that using the technical potential of solar energy could provide about 15 EJ of solar thermal energy by 2030, and in this period the share of solar thermal energy in the industry could reach 33%, however, at European level, there is a relatively small number of solar collectors exceeding 1000 m_2 (Kylili et al., 2018).

In recent decades, solar energy technologies have been increasingly used and developed to support industrial processes. China is rated as the largest consumer of energy, and its industrial sector accounts for almost 70% of total energy consumption and continues to grow, with energy and cost reduction issues becoming increasingly important. It is estimated that production processes at low and medium-low temperatures account for about 45% of the total heat required by production processes, which covers about 50-70% of the total energy consumption generated by industry. This creates favourable conditions for the use of solar energy in industrial processes. In China, the industrial sector is divided into the energy, manufacturing and mining sub-sectors. Manufacturing accounts for the dominant share - 82.1%, while energy and mining account for 8.2% and 8.2%, respectively (Jia et al., 2018).

In order to improve market competitiveness, reduce fuel costs and environmental pollution, companies are increasingly using renewable energy in their industrial systems, focusing on the most potentially cost-effective deployment of solar energy systems in the industry. By the end of 2014, the installed capacity of solar collectors worldwide was estimated at 410.2 GWth, with China accounting for the largest share - 70.6% (i.e. 289.5 GWth). Industrial solar energy systems (SHIP) have been in operation in China since 2010. The systems are based on the use of solar energy in various industrial production processes in different industries (Jia et al., 2018).

2.2.1.1. Solar energy industrial systems

Solar collectors

The technological equipment of solar energy industrial systems (SHIP) can consist of different types of collectors. The most common of these are flat plate collectors (FPCs) and parabolic trough collectors (PTCs). Flat plate collectors and tubular collectors (ETCs) are suitable for use in low-temperature processes, while parabolic collectors can be used in production processes that require higher temperature conditions. With using parabolic collectors, it is possible to reach temperatures above 250 °C (Table 2.9) (Jia et al., 2018).

Modern designs have been developed recently for flat plate collectors (FPCs) and pipe collectors (ETCs). For example, flat plate collectors are equipped with transparent insulation material to ensure high-temperature conditions up to 150 °C. For flat plate collectors it is also possible to use multiple glazing to reach and maintain temperatures up to 110 °C, as well as to use an inert gas or an extremely high vacuum to maintain temperatures up to 150 °C (Jia et al., 2018).

Industrial processes usually require the use of medium-temperature thermal energy systems like the above-mentioned trough-type parabolic collectors (PTCs) and linear Fresnel collectors (LFRs). Depending on the absorber and the effective concentration factor, these high-concentration collectors can reach temperatures up to 400 °C and are an essential part of the solar energy industrial system (Jia et al., 2018).

Table 2.9

Types of solar collectors

Motion	Collector type	Absorber type	Concentration ratio	Indicative temperature range (°C)
Stationary	Flat plate collector (FPC)	Flat	1	30–80
	Evacuated tube collector (ETC)	Flat	1	50–200
	Compound parabolic collector (CPC)	Tubular	1–5	60–240
Single-axis tracking	Fresnel lens collector (FLC)	Tubular	10–40	60–250
	Parabolic trough collector (PTC)	Tubular	15–45	60–300
	Cylindrical trough collector (CTC)	Tubular	10–50	60–300
Two-axes tracking	Parabolic dish reflector (PDR)	Point	100–1000	100–500
	Heliostat field collector (HFC)	Point	100–1500	150–2000

It is estimated that in solar energy projects, solar industrial system equipment accounts for 50–70% of the total cost, while the rest is accounted for by installation and integration of systems into the overall system (Jia et al., 2018).

Depending on the processes and temperatures involved, different modes are possible for solar energy industrial systems:

- Use of solar energy to provide water in production processes. Hot water systems require temperatures above 80 °C (in some cases 100-250 °C);
- Use of solar energy for steam generation. Industrial steam is mainly used for pre-treatment, sterilization processes and high-temperature dehumidification;

- Another SHIP mode is dry drying. Drying is performed using direct or indirect solar energy systems (greenhouse type, collector type, combined greenhouse and collector type drying systems);
- Desalination of seawater using solar energy. The solar water desalination system can operate independently, is not constrained by steam or electricity, and can be operated cleanly without the use of fossil fuels (Jia et al., 2018).

Solar energy industrial systems can be integrated into the overall production system by combining low-temperature requirements with existing processes for heat supply (Jia et al., 2018).

2.2.1.2. Use of solar energy for hot water in the industrial sector

The use of solar thermal energy systems for hot water production is most suitable for those industries where the water temperature required for the processes is in the range of 40 ° C to 80 ° C. Examples of such industries are the food industry, the agro-industry, the textile industry, the chemical industry and the beverage industry. One of the scientific studies estimated that, due to low costs and simple constructions, the textile plant had built-in water heating equipment that combined plate collectors and water storage tanks in one system. It is estimated that solar energy for hot water preparation, in addition to the already mentioned industries, can also be used in milk processing processes, cheese production and purification processes (Jia et al., 2018).

2.2.1.3. Global characterization of solar energy use possibilities and potential

The study conducted in Australia analyzed the current potential and future potential of ten countries in the industrial sector using solar energy as an energy source. The industries with the highest potential for solar energy were estimated to be, for example, motor vehicles, textiles, printing, metal products, paper, rubber and plastics, chemicals, food and beverages, and electrical energy, manufacture of machinery equipment. The study identified that the main design specifications to consider when installing solar collectors are the type of collector, location, dimensions of the bridge switches and the load for the application. The study identified that lower countries in the industrial sector had introduced the use of solar energy in production processes in specific industries (Farjana et al., 2018).

<u>India</u>

India's industrial energy consumption is currently estimated at 150 million tonnes of oil equivalent, accounting for 38% of the country's energy consumption. India accounts for an estimated 1,2% of the total solar water system capacity for hot water, with the food industry and agriculture leading the way in the use of industrial solar energy systems.

India has a significant number of high-capacity plants using solar-powered technological equipment as a source of energy - solar collectors designed and implemented to provide the necessary power in sectors such as metal processing, electrical equipment, motor vehicle manufacturing, tobacco manufacturing, manufacture of paper, and manufacturing of transport equipment.

Fish processing and fruit drying have also been assessed with a high potential for the use of solar energy. One study estimated that air heaters in combination with solar-powered recirculating dryers could be used to dry, for example, mangoes, pineapples and bananas. It is also recognized that large-scale research currently focuses on solar drying equipment for agriculture and the food sector.

<u>Austria</u>

It is estimated that more than 1 million m2 of solar collectors were installed in one of the regions of Austria. Austria is considered to be a leading country in a number of industries where solar energy systems are used as an energy source, including in the production of food and beverages, leather, chemicals and metal products. In turn, the largest areas of solar energy collectors with the largest technological equipment capacities were installed to ensure processes in the metal industry and the furniture industry.

Germany

In Germany, thanks to the current policies and support programs for the promotion of renewable energy, more solar-powered plants have been installed compared to other countries. The energy obtained from solar thermal energy is used to ensure the processes of agriculture, beverage production and production of metal products.

United States of America

In the United States, natural gas is most widely used in industries like the chemical, food, paper and petroleum industries. Nevertheless, solar energy is also increasingly used as a primary energy source in the food and beverage industry, where plants are already equipped with large-scale solar thermal systems to support production processes.

France

In France, solar thermal installations are used in the food and beverage and metalworking industries, mainly using plate collectors and pipe collector technologies. The obtained solar thermal energy is used in the production of beverages, for example, in the processing of beverage bottles to ensure the required temperature, as well as in cooling.

Greece

In the Greek industrial sector, most solar thermal equipment is used in food production, and a significant number of solar-powered equipment is installed to provide processes in the beverage, textile, pharmaceutical, and leather industries.

(Table 2.10) represents those industrial sectors which are dominant but lack renewable energy system integration (Farjana et al., 2018).

Table 2.10

Industrial sectors using SHIP and industrial sectors which are dominant but lack renewable energy system integration

India	Agriculture, food, tobacco, textile, wearing apparel, leather, paper, chemical, metals, electrical equipment, transport equipment	pharmaceuticals, steel, mining
Austria	Food, beverages, leather, chemicals, metals, furniture	Electrics and Electronics industry and Wood, Pulp and Paper industry
Germany	Agriculture, food, beverages, textiles, chemicals, metals	automobiles, electrical equipment,
USA	Agriculture, food, beverages, textiles,	steel, motor vehicles, aerospace, chemicals, electronics, mining
Spain	Agriculture, food, textiles, wood, metals, motor vehicle	chemicals, pharmaceuticals, shipbuilding, automobiles,
China	Agriculture, food, beverages, textiles, chemicals, leather	mining and ore processing; iron and steel; aluminum; coal; machinery; cement; automobiles, ships
South Africa	Mining, food, beverages, machinery, motor vehicles	Automotive, electronics
Mexico	Agriculture, food	Aerospace, electronics, tobacco, chemicals, iron and steel, mining, textiles, clothing, motor vehicles
France	food and beverages, metals	automobile manufacturing, aircraft production, chemicals, electronics
Greece	food, beverages, textiles, Pharmaceuticals, leather	Shipping, chemicals, metal products; mining

Australia

An Australian study estimated that, given its geographical location and solar intensity, Australia has significant potential to use heat in industrial processes as well. In Australia, the primary industry is mining, where processes require high-temperature conditions that are not so easy to provide and lower costs for coal, so less attention is paid to the potential use of solar energy (Farjana et al., 2018).

2.2.1.3. Actual use of solar energy in different industries

Motor vehicle industry

South Africa, India and Spain are increasingly using solar energy as an energy source in their mechanical manufacturing systems. The obtained hot water is used for car painting and paint application, washing of engine components, as well as body pre-treatment lines. Various types of solar collectors are used in the production processes of motor vehicles, which can reach a maximum temperature of 120 ° C (Farjana et al., 2018).

Breweries

Solar heat energy in beer production can be used in such processes as steam generation, malt production process, stopping grain germination, air cooling, canning using hot air, to provide operations in ovens. The temperatures required for beer production processes are low to medium and therefore, suitable for the use of solar energy equipment.

Several European countries, China, South Africa and the United States, are estimated to make a significant contribution to reducing CO2 emissions from breweries' production processes using solar energy as an energy source. The washing and cleaning processes use a maximum temperature of 120 ° C, which also corresponds to the temperature that can be obtained using solar energy technology equipment. Air collectors or flat-plate collectors with a maximum temperature of 60 ° C are used for pre-treatment and heating of the bottles. For increasing energy efficiency, the integration of solar thermal energy using collectors is considered a viable alternative to meet the low-temperature requirements required for beer production (Farjana et al., 2018).

Food industry

The food industry is rated as the dominant industry where solar thermal systems are used. Many European, North American, South American and Asian countries use solar energy systems as heat sources in the food industry, and Mexico, the United States, Greece, India, Spain and Austria are considered to be the dominant countries. Solar energy is used as an energy source in food industry processes such as hot water supply, pre-treatment, pasteurization, preheating, drying and cooking. It has been estimated that flat-plate collectors and parallel rail collectors are mainly used in the food industry as solar energy systems (Farjana et al., 2018).

Turkey processing industry

In 2012, one of the largest solar-powered plants in North Carolina, equipped with flat plate collectors, was installed in the United States and used to supply hot water to a turkey processing plant (Jia, 2018).

Cheese production

In Italian city Sardinia, solar collectors are being used to generate steam for cheese production in the milk processing company *Fresnela.* It was estimated that to payback time for invested costs in the solar collectors was around four years (Jia, 2018).

Dairy industry

India

The dairy industry in India accounts for 13% of total finished milk production, and it is estimated that solar energy systems can provide 0.49 PJ of heat. It is estimated that the use of solar installations could save 12,9 kilotonnes of diesel per year and reduce greenhouse gas emissions by 41 kilotonnes. Flat plate and tubular collectors can be used in milk processing (Suresh & Rao, 2017).

Paper manufacturing

India

It is estimated that the Indian paper industry produces about 2.6% of the world's total paper production (Ferjana et al., 2018). India's paper industry is estimated to be one of the most energy-intensive industries and has a paper production capacity of over 10 million tonnes. Studies estimate that the total annual energy consumption of Indian paper production is around 52 million Gcal, which is equivalent to about USD 220 million. Processes in which solar energy technologies can be integrated are peeling, pulp production, bleaching, paper production. The study estimates that the total energy potential that can be obtained using solar energy systems - in this case, parabolic collectors - is 25.2 PJ per year (Suresh & Rao, 2017). One of the studies estimates that one of India's paper mills uses integrated solar collectors with a maximum temperature of 98 ° C to support their processes (Table 2.11) (Farjana et al., 2018).

Table 2.11

Suitable solar collectors in the Pulp & Paper industry

Process	Temperature (°C)	Existing fuel source	Suitable solar component
Cooking, drying	60–80	Fuel oil, pet coke, rice husk and coal	FPC
Boiler feed water	60–90		FPC
Bleaching	130–150		ETC

Pharmaceutical industry

It is estimated that the temperature conditions required for pharmaceutical production processes are in the range of 160-180 ° C. Based on the available information, it has been identified that the Egyptian and Greek pharmaceutical industries use solar energy systems to support specific processes, such as processes such as steam generation and cooling (Farjana et al., 2018).

In Jordan, the first solar steam system was installed in 2015. The collector system consisted of Fresnel-type collectors with a total area of 396 m^2 and a maximum capacity of 223 kWth. The solar collectors were placed on the roof of the pharmaceutical company providing steam at 160 ° C, which was used for sterilization, drying and fermentation processes in the pharmaceutical plant. It was estimated that the use of solar energy in production processes could save about 30% of the annual consumption of diesel fuel, which was previously used to provide pharmaceutical processes (Farjana et al., 2018).

Textile industry

Regarding the use of solar energy in textile production processes, the dominant countries are Greece, China and India (Table 2.12). Flat plate collectors are used to providing hot water to reach the maximum possible temperature of 100 °C. The heat generated from solar energy was used in primary heating, dyeing processes and for the production of the textile itself (Farjana et al., 2018).

China

In the Shandong province, Jinhao Textile Industrial Park, glass tube-type solar collectors were installed on the factory roofs to provide hot water for dyeing processes in an area of approximately 8583 m^2. It is estimated that another Chinese plant reduced CO_2 emissions by 3100 tonnes and SO_2 emissions by 350 tonnes by installing glass tube-type collectors on the roof of approximately 7460 m^2 connected to a heat storage tank for hot water supply. It was estimated that the invested investment could be recouped within six years, as well as using solar collectors instead of coal, it is possible to save 2080 tons of coal (Jia et al., 2018).

Table 2.12

Existing SHIP in textile industries

Country	Name	Industrial Operation	Solar Collector	Temperature (°C)
USA	Acme McCrary	Hot water for textile drying process	Flat plate collector	
Greece	Allegro S.A. Childrens' clothing manufacturer	Hot water for washing machines	Flat plate collector	33–60
	Kastrinagiannis S.A.	Hot water directly for dyeing machines	Flat plate collector	40–90
China	Daly Textile	Water heating for dyeing process	Flat plate collector	~55
	Jiangsu Printing & Dyeing	Solar preheating for printing & dyeing process	Evacuated tube collector	~50
Vietnam	Grammer Solar Vietnam	Textile production process	Air collector	
Spain	Harlequin	Painting	Flat plate collector	
Germany	Meiser Textile	Other process heating	Parallel trough collector	~140
India	Purple Creations	Iron the children's garments-steam processing & washing	Other or various collectors	
	Sharman Shawls	Hot water requirements for dyeing, bleaching & washing garments	Flat plate collector	~100

India

In India, the textile industry accounts for 14% of total industrial output. The heat required for the production of textiles is provided by using flat plate collectors and tube-type collectors with a performance temperature below 150 C (Table 2.13) (Suresh & Rao, 2017).

Indian studies estimated that the introduction of solar collectors in the textile industry could save fuel oil by about 439 kilotonnes, as well as reduce CO2 emissions by about 1420 kt per year (0,06% of India's total emissions) (Suresh & Rao, 2017).

Table 2.13

Suitable solar collectors in the Textile industry

Process	Operating Temperature (°C)	Fuel sources used	Suitable solar collector
Sizing	60–90	Electricity, petroleum, coal and other fuels	ETC
Scouring	90–110		ETC
Bleaching	90–95		ETC
Mercerizing	60–70		FPC
Dyeing	70–90		FPC
Finishing	40–100		ETC

Mineral processing

Mineral processing processes can use medium-high temperatures to generate steam, which is a crucial component of the processing process, and thus solar energy systems can be used in this process (Farjana et al., 2018).

Chemical industry

The most common processes using solar energy are water heating, steam heating, cleaning and painting using flat plate collectors as an energy source with a maximum temperature of 130 ° C (Farjana et al., 2018).

China

Chinese studies have shown that parabolic collectors can be used in methanol decomposition processes, providing a reaction temperature of 200-300 °C. In other studies, it was estimated that solar thermal energy could be used as an energy source to produce hydrogen or methanol industrially as a result of chemical reactions. It was also determined that the steam obtained through solar collectors could be used for drying natural rubber using FPC and ETC type collectors, the basic principles of operation of which have already been described above. First, the outdoor air needs to be heated to 70 °C using flat plate collectors, and then using tubular solar collectors, temperatures up to 110 °C can be obtained (Fig. 2.18) (Jia et al., 2018).

Metal processing

In most European countries, solar energy is used in metalworking processes to produce hot water for use in processes as well as in drying and cleaning processes. It is estimated that the maximum achievable temperature when operating different types of solar collectors is 180 °C (Farjana et al., 2018).

China

Solar thermal energy can be used in metal surface treatment processes, such as galvanizing and metal cleaning processes, as well as for cleaning metal parts. For example, an electrolytic coating plant in the Yuan Province, Zhejiang Province, is known to use solar energy equipment as a primary energy source for galvanizing processes, completely replacing coal-fired heating systems. It is estimated that the installation of solar thermal equipment reduced CO_2, SO_2 and NO_x emissions by 390 tonnes, 1,400 tonnes, 45 tonnes and 22 tonnes respectively (Jia et al., 2018).

Chile

The obtained solar thermal energy can also be used in cooling processes. Chile has one of the world's largest solar thermal installations for industrial operations. For the refining of mining copper, which is one of the most energy-intensive industries. In Chile 39,3000 m_2 of flat plate collectors (FPCs) were installed, which were connected to a solar energy storage tank with a capacity of 4,000 m3, with a total plant capacity of 27,5 MW. Solar thermal power plants were installed to cover 85% of the energy required by the processes to provide copper purification in a state-owned mining company (Farjana et al., 2018).

Tobacco production

China

Solar energy equipment in tobacco production can mainly be used for steam generation, hot water supply, as well as hot air storage for further use in tobacco production processes. It is estimated that 0,83 tons of steam can be saved daily (Jia et al., 2018). Solar thermal energy in tobacco production can also be used in tobacco drying processes. In one of China's cigarette factories, 2,000 m^2 of tubular glass collectors were installed to provide the necessary heat for the tobacco drying system. It was possible to store the obtained heat energy using a storage tank, as well as an additional heat pump was used as an energy source, which was used in cases of solar energy interruptions, including adverse weather conditions. The system is estimated to save around 1,42 MkWh of energy and 5,74 × 102 tonnes of coal while reducing CO_2, SO_2 and NO_x emissions by around 1.42 × 103 tonnes, 11.5 tonnes and 8,6 tonnes per year (Jia et al., 2018).

The Luohe Cigarette Factory in Henan Province combined solar energy and an air source heat pump to provide the necessary temperature for tobacco drying processes. It was estimated that the system used reduced CO_2 emissions by 450 tonnes, with a total payback period of six years. It was determined that the project saved 12 tonnes of coal each year.

Oils, natural gas exploitation industry

China

In China, solar thermal systems are used to collect and transport crude oil. In order to prolong the heat storage time and optimize the efficiency of the system, storage tanks are used to store the obtained heat energy. The South China University of Technology has developed a solar energy system to save energy and provide the appropriate temperature conditions needed to collect and transport crude oil. The solar energy system indirectly heats crude oil through a heat exchanger. The low-temperature water leaving the heat exchanger flows back to the water storage tank and is then pumped into the solar panels for reheating. If the solar radiation is not sufficient, the additional combustion plant and furnace can heat the crude oil secondary. It is estimated that using this system, it is possible to save 30% (900-1200 m_3) of natural gas consumption used for oil processing every day. The system was introduced at one of China's oil refineries (Jia, et al., 2018).

Other industries

In addition to the industries already mentioned, solar heat can also be used in industries like cement production, mining, wastewater treatment, seawater desalination, as well as refrigeration and ice production (Jia et al., 2018).

China

Solar collectors and an air source heat pump were installed in one of China's cement plants in Jiangsu Province to replace the original combustion plant of 129.6 m_2. As a result of the changes, 210 tonnes of coal were estimated to saved annually, CO_2 emissions were reduced by 558 tonnes, SO_2 emissions by 1.47 tonnes, NO_x emissions by 0.76 tonnes and PM particulate matter emissions by 5.03 tonnes.

Sewage sludge drying

The study estimated that the use of solar heat using 8400 pipe type collectors could be used to use the obtained heat energy for sludge drying.

It is estimated that the obtained heat energy can also be used in the treatment of polluted wastewater - using a chemical oxidation wastewater treatment system with solar thermal energy. This system can promote the degradation of persistent organic matter, promoting efficient wastewater treatment and low energy consumption (Jia, et al., 2018).

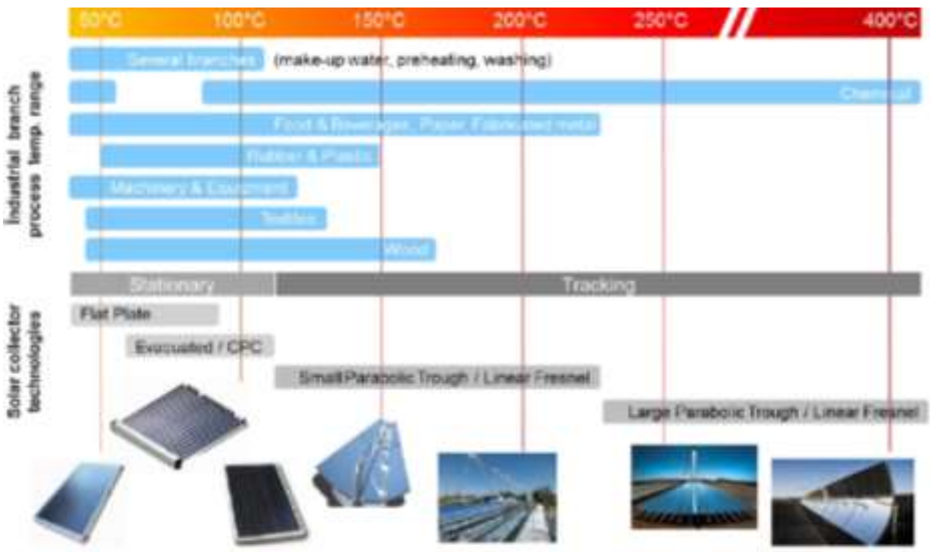


Fig. 2.18. Temperature range required for industrial processes in different industries

For China, it is estimated that the use of solar energy systems in industrial processes could reduce coal consumption by at least 39.40 million tonnes and CO_2 emissions by 98.22 million tonnes in the industrial sector as a whole in 2020. It is estimated that using solar panels can save $ 18.15 million per year and achieve a total CO_2 reduction of approximately 76 kt (Jia et al., 2018).

2.2.2. Possibilities of using wind energy in industry

It is estimated that China has increasingly used wind turbines in its manufacturing industries in recent years (Edomah, 2019) Despite their actual and potential use of wind energy, it is affected by its periodic nature and wind power outages. Wind energy can be used in combined systems with other renewable energy sources or energy storage systems, however, compared to other renewable energy sources, there is less research on the use of wind energy in various industries.

The study evaluated the production of agricultural fertilizers using renewable energy sources as an energy source. The results showed that the use of wind energy as an energy source in ammonia production could significantly reduce fossil energy consumption and greenhouse gas emissions compared to the traditional production process. Hydrogen was first obtained by water electrolysis, then hydrogen and nitrogen were mixed to form syngas. Ammonia and its hydrogen precursor, in addition to its fertilizer function, can be used as a means of storing solar or wind energy in the event of interruptions. This would allow the development of integrated systems in the future using stored hydrogen and/or ammonia to generate electricity when energy production capacity is low.

In another study at the Western Central Research and Information Center at the University of Minnesota, a pilot plant produced ammonia using wind energy as an energy source to produce the pure hydrogen for the ammonia production process.

It was estimated that at times of low electricity demand, such as at night, wind energy can be used to produce hydrogen for further ammonia production and is estimated to generate higher revenues than electricity sales (Tellaksen, 2015).

2.2.3. Possibilities of using geothermal energy in industry

Although the potential of geothermal energy is increasingly being used in the household sector, in the service sector, in the industrial sector, the actual use of geothermal energy is considered to be relatively small. Nevertheless, the possibilities of using geothermal energy in the industrial sector have several advantages, for example, by using geothermal energy sources, it is possible to reduce energy costs, including a large part of the total production costs, as well as to ensure the supply of energy in one place and to carry out production processes under high load conditions. Usually, a shallow geothermal system is used to provide heat energy - a closed-loop or open-loop geothermal exchange system, in which the depth used for heat energy underground is 100-200 meters.

A geothermal energy source (with a temperature <100 º C) connected to a heat pump in the system can be used for - heating and cooling of buildings, surface energy storage, hot water preparation, icing and snow melting, as well as heat storage and reuse in industrial processes. Heat pumps use heat from surrounding sources, and the warmer the source, the higher its efficiency.

Geothermal heat production. Traditionally, geothermal water is discharged through an evaporator that heats a secondary liquid - usually an organic liquid with a low boiling point. The steam generated in the evaporator, after being compressed, is used to power the turbine. The organic liquid is then condensed and pumped back to the evaporator. Medium enthalpy geothermal energy is estimated to have great potential as a source of central heating and cooling, and the use of geothermal energy is expected to increase in the future.

According to the studies considered, geothermal energy in the industry sector is currently used mostly in the agriculture sector and wineries. At European level, there are several examples of the use of closed-loop geothermal energy to ensure appropriate temperature conditions in greenhouses and wine cellars. Low enthalpy geothermal energy can also be used in wine production processes, such as grape cooling and fermentation cooling processes. It is estimated that geothermal energy can be used in freshwater extraction and desalination processes. It is recognized that in order to ensure greater efficiency of stored renewable energy, shallow (at a depth of 100-200 meters) geothermal energy systems are integrated into combined solar thermal energy systems, which is an excellent solution in the case of solar energy interruptions (Foccaccia et al., 2016).

2.2.4. Possibilities of using hydropower in the industry sector

Hydropower accounts for almost one-fifth of the world's electricity and more than 80% of the world's renewable electricity. If hydropower as one of the renewable energy sources is adequately implemented in the common system, then the advantages of hydropower are related to the possibilities of use in flood control, households, in the industrial sector and the management of the irrigation system.

China

In China, hydropower is estimated to be the most important source of renewable and clean energy, accounting for 18.6% of total energy in 2017 (Hussain et al., 2019). Hydropower, like other renewable energy sources discussed above, can be combined with other renewable energy sources, such as wind energy. The advantages of hydropower are related to its flexibility and ability to compensate for wind energy in the event of its fluctuations and interruptions (Wang et al., 2019).

China has abundant hydropower resources with great development potential, and the Yangtze River Basin is considered a major source of hydropower. By the end of 2016, the world's installed hydropower capacity exceeded 1 billion kilowatts. In developed countries, the use of hydropower is assessed as high, reaching an average of 60% - 95%, while in developing countries, the use of hydropower is assessed as relatively low. It is estimated that by the end of 2016, China's hydropower installed capacity had reached 330 million kilowatts, representing 20% of the total installed capacity. According to studies, China's hydropower installed capacity is expected to reach 380 million kW by 2020 (Penghao et al., 2019).

Hydroelectric power plants consist of a turbine and a generator, and the main operating principles are based on reaction, pulse or hydrokinetic turbine operations (Sari et al., 2018).

Electricity generated by hydropower plants is used to provide lighting, in the transport sector, in manufacturing and to increase agricultural productivity (Sovacool et al., 2018).

Ecuador

For Ecuador current economic development strategy, one of the key areas for action is the development of strategic energy-intensive industries like refining, petrochemical, aluminium, copper and steel industries, which require the use of hydropower resources and large-scale hydropower infrastructure. Consequently, the use of hydropower in Ecuador is currently considered to be a key solution for energy security while reducing electricity prices and greenhouse gas emissions and providing a basis for the implementation of the above industrial and economic development strategy (Carjaval et al., 2019).

2.2.5. Possibilities of using biomass energy in the industry sector

Industrial energy consumption is currently being reviewed at the European level, and the potential for biomass is being assessed. Available alternatives to solid biomass feedstock and energy conversion are being evaluated, as well as future uses of biomass in several industries.

The combined production of electricity and heat required for industrial processes are mainly based on steam cycles. Studies have shown that the use of biomass can effectively achieve the temperature range required for industrial processes.

Based on 2017 data, it was estimated that biomass was the only source of renewable energy in the 28 countries of the European Union with a significant share of energy use: 93% of the renewable energy used in the industrial sector was solid biomass, 3% municipal waste and 2% biogas.

2.2.5.1. Solid biomass

In 2017, the final consumption of energy from solid biomass in the industrial sector of the European Union was estimated at around 898 PJ. It is also estimated that of the 28 European Union industries, the most biomass for thermal energy processes was consumed in those sectors where biomass residues are generated, such as pulp, paper production and printing, as well as wood processing plants. In total, the biomass used for energy in these sectors accounted for about 85% of the total energy consumption of industrial biomass. Based on 2017 data, it was estimated that 3986 PJ of solid energy (excluding charcoal) can be produced as a primary energy, which corresponded to 12.5% of the total share of primary energy production and 69% of the share of primary energy production using biomass. In 2017, Ireland was the only country to use more than half of its solid biomass in the industry (53%), while Finland, Sweden, Slovakia and Portugal accounted for more than 40%.

Solid biomass for energy can be obtained from organic residues from forests and uncultivated land, energy crops, organic waste and residues from industry, waste from agriculture and forestry and organic residues from raw materials or products, as well as municipal waste.

Solid biomass can be used in the industry without thermal transformation, such as wood chips, wood bark or nut shells), but industrial processes more often use thermally processed biomass - charcoal or calcined biomass. One of the reasons for the thermal conversion of biomass is higher efficiency of the biomass used. In several sectors, like the iron and steel industry, it is estimated that the use of unprocessed biomass is not efficient so that the biomass is heat-treated before use, which in turn increases the energy density.

2.2.5.2. Thermal conversion of biomass

Thermochemical conversion of biomass has been assessed as the most common method and the most suitable for the conversion of solid biomass into energy. Five methods of thermochemical conversion are mainly used in heat and cogeneration processes: combustion, gasification, pyrolysis, hydrothermal treatment and hydrolysis.

The most widely used technologies for biomass conversion are granulation, pyrolysis, which, depending on the required end product, are divided into fast, slow and light type pyrolysis, as well as biomass conversion using combustion processes. Bio-oils can be obtained using a slow pyrolysis process. It is estimated that bio-oil can also be obtained by hydrothermal processing of biomass using wet consistency materials, such as grain milling by-products. Slow pyrolysis is commonly used to produce charcoal that has no significant industrial use in Europe, while light pyrolysis is used to obtain torrefied biomass.

From the thermochemical conversion methods, the combustion method is the most widely used, and it is estimated that more than 90% of the obtained bioenergy is obtained through combustion processes. For charcoal and torrefied biomass, heat treatment makes biomass more similar to coal.

Solid biomass can be used as an energy source to provide heat and the temperature regime required for processes in various sectors of the industrial industry, and some of them are described in more detail below.

Manufacture of paper and pulp

In 2017, the final energy consumption of the pulp, paper and printing industry in the industrial sector of the 28 countries of the European Union was estimated at 1438 PJ, which corresponds to 13% of the total final energy consumption in the industrial sector. The actual use of biomass for energy in the industrial sector depends on the country and can range from 0%, for example in Italy up to 89% in Sweden. Pulp, paper and board production are known to consume more than 98% of the energy demand in this sector.

At European level, a significant amount of solid biomass is already used for pulp and paper production, for example, biomass is used for the recovery of chemicals and for the production of steam to support processes.

Production of wood

According to 2017 data, it is estimated that in the 28 Member States of the European Union, the final energy consumption of wood and wood products in the industrial sector was 371 PJ or 3% of the total final energy consumption in the industrial sector. In almost all EU countries, the share of solid biomass in the total final energy consumption of the industrial sector in 2017 was more than 30%, and in Belgium, Denmark, Ireland and Luxembourg this share exceeded 70%.

It is estimated that production of wood or products of wood requires large amounts of energy in various processes, such as drying, pressing and heat treatment with a required temperature of up to 500 °C. In the wood processing industry, processes result in producing granules (Malico et al., 2019).

Cement production

It is estimated that 12-15% of the world's total energy consumed in the industrial sector is consumed by the cement processing industry (CMI) and accounts for about 7% of global CO_2 emissions.

Cement production mainly consists of three main stages: raw material preparation, clinker production and cement preparation. It is estimated that about 40% of CO_2 emissions come from the combustion of fuels used in the production process, where non-renewable resources are used as an energy source. It is estimated that 50% is produced by heating limestone to produce lime, while electricity and transport each account for 5%.

It is estimated that traditional fossil energy resources used in cement production processes can be replaced by biomass. Furnace incineration is one of the main cement production processes where fossil fuels are used, which can be replaced by biomass or biomass residues and in that way reduced fossil fuel consumption. The high temperature in cement kilns makes biomass residues suitable for incineration for further energy production. In order to maintain stable combustion process conditions and constant clinker quality, the recommended replacement factor is at least 20%.

Wood and other agricultural and forestry residues are the most common type of biomass used for combustion processes or gasification (Abriyantoro et al., 2019).

Food and beverages industry

It is estimated that in the food and beverage industry, the temperatures required for production processes are below 200 °C and 83% of the heat necessary for the operations is below this temperature. At present, solid biomass accounts for only 3% of energy in the food industry.

The food industry generates a considerable amount of biodegradable waste that can be converted for further energy, but in most cases, these raw materials have a high moisture content and are not suitable for thermochemical conversion processes. In such cases, an anaerobic digestion method is used that is directly suitable for the treatment of biodegradable kitchen or garden waste.

The food industry also uses raw materials or solid biomass residues that are suitable for combustion processes due to their low moisture content, like rice husks, olive stones, nut shells or pine cones. The main barriers to the introduction of solid biomass energy systems in the food and beverage industry are related to high investment costs.

Chemical and petrochemical industry

It was estimated that the chemical and petrochemical industry in the ES in 2017 was the sector with the highest final energy consumption - 2206 PJ, which accounts for 20% of the total energy need for the industrial sector.

The steel and iron industries are one of the major emitters of CO_2 greenhouse gases and, as a result, alternatives to fossil fuels and the reduction of fossil emissions are increasingly sought.

In addition to the use of biomass for biofuels and electricity, the potential of biomass is increasingly linked to the use of biomass as a raw material in the chemical industry, as it can replace traditional fossil fuels such as acetic acid, ethylene, methanol, ethanol or acetone.

It is recognized that sugar and starch-based biomass is currently the most common way to obtain chemical raw materials from biomass. Studies estimate that wood biomass should be used in the future to replace the significant volumes of petrochemicals that are produced today. Biomass by-products can also be used for further energy production to provide adequate heat and process temperature conditions.

Iron and steel production

It is estimated that in 2017, the final energy consumption of the iron and steel industry in the Member States of the EU was 1166 PJ, which corresponds to 11% of the total energy consumed by the industrial sector. In the iron and steel sector, the production of iron, steel and iron alloys is the largest consumer of energy, accounting for 73% of the sector's energy demand. The proportion of biomass used depends on the country's interests, investment and biomass potential. At EU level, biomass is used only to a small extent in the iron and steel industry, while in Brazil 34% of the fuel used in the iron and steel industry is biomass.

Studies have estimated that the partial replacement of coal and coke by biomass in iron production processes is one of the options that are economically and technically viable in the short and medium-term. Carbonaceous fuels and biomass for iron production are the only sources of renewable energy that can provide this. It has been estimated that the thermostatically treated biomass should be used in the iron and steel sector (Malico et al., 2019). Studies have identified the use of biochar as a carbon source to increase the carbon content of steel (Mayyas et al., 2019)

2.2.5.3. Possibilities of using torrefied biomass

It is recognized that pre-treatment of biomass can improve its competitiveness, for example, the granulation of biomass for commercial use provides a higher energy density compared to raw biomass. In the industrial sector, it is possible to use torrefied biomass as an energy source, and the use of it has a growing potential in the future. It is estimated that there are promising opportunities for the use of torrefied biomass in industries such as the steel industry, as well as pulp and paper production.

Torrefied biomass has been studied as a promising technology, as a result of which the properties of biomass for further use for energy production are significantly improved. Torrefied biomass can be described as a light heat pre-treatment process, in which biomass is heated at 200-300 °C in oxygen-deficient conditions with the time required for the operation from 0,5 to 2 hours (Fig. 2.19). Biomass torrefaction process parameters are evaluated as similar to be used in the roasting of coffee beans.

Impact of the process of biomass. The effect of the process on biomass can be described as light type pyrolysis. As the final heating temperature increases, volatile substances are released during the process, while hemicellulose, lignin and cellulose are degraded. The process results in a solid phase, liquid and non-condensable gas (Fig. 2.19) Burned wood using the above treatment has an energy content and energy density similar to coal and higher than wood pellets.

It is estimated that using this method, the torrefied biomass has a lower ash content and it is more environmentally friendly compared to fossil fuels (Proskurina et al., 2017).

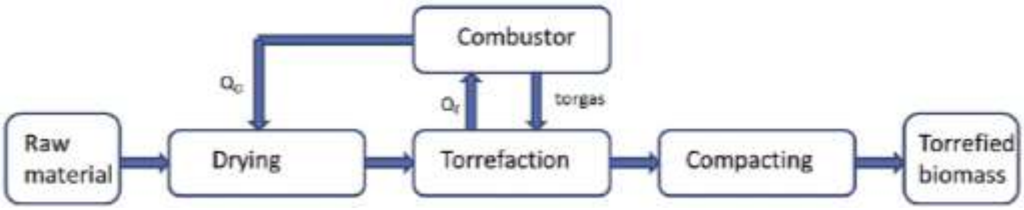


Fig. 2.19. Thermochemical transformation of biomass using the combustion process

Possibilities of using biomass in various industries

It is estimated that the share of torrefied biomass use in the industrial sector in the European Union in the coming years could be 5 to 10% of the total amount of biomass intended for further use. In the Nordic countries, mainly Sweden and Finland, the pulp and paper industry has set a target for reducing CO_2 emissions, and biomass pre-treatment technology for torrefied biomass has been identified as a suitable solution to achieve this target.

The total biomass available for incineration in Europe is estimated at 4,2 EJ. Biomass torrefaction plants are used in several European Union countries, such as the Netherlands, Sweden, France and Spain. It is also estimated that the United States and Canada, which have large-scale combustion biomass production facilities, could become the leading countries for torrefied biomass production in the coming years. Mississippi is home to North America's largest torrefied biomass plant.

Iron and steel industry

Steel production and processing processes require high-quality fuels, but mostly biomass-based fuels do not meet the necessary criteria for ash content and energy density. One possible solution could be to replace coking coal with torrefied wood. Studies show that in iron and steel production it is possible to completely replace the injection of pulverized coal instead of injecting torrefied biomass in the proportion of 150-200 kg/t of heated metal. It is recognized that, for example, in the Swedish steel industry, which is currently the country's largest consumer of coal, pulverized coal can easily be replaced by torrefied biomass.

The study assessed the potential for the use of torrefied biomass in the steel industry in Finland, where approximately 92 PJ of steel is produced per year. The results showed that powdered coal could be entirely replaced by charcoal (Proskurina et al., 2017).

Paper production

The use of biomass for energy production plays a vital role in the production of pulp and paper. One of the Austrian engineering companies owns two torrefied biomass production plants in Austria and Denmark. One of Japan's largest pulp and paper companies has evaluated the use of torrefied pellets for further energy.

Glass, ceramics, cement industry sector

Cement production is estimated to be the third-largest energy consumer in the industrial sector and the second-largest emitter of CO_2 greenhouse gases. It is recognized that the most commonly torrefied biomass can be used in co-incineration with coal - in pulverized coal combustion plants and cement kilns.

Torrefied biomass can also be used in the production of ceramics and ceramic products, for example, one of Canada's leading ceramic companies has reported excellent results in the use of torrefied biomass in the ceramics industry. Another Canadian company has been producing 25,000 tonnes of burned biomass per year since 2015 in aim to replace coal in cement plant in British Columbia.

Chemical and petrochemical industries

The use of biomass in the chemical and petrochemical industries is currently intensively researched and developed. The use of the gasification process in the chemical industry requires a significant amount of biomass, as well as a large area of biomass storage, therefore the use of torrefied biomass is assessed as an effective solution.

Other industries

Studies have estimated that the inclusion of torrefied biomass in the wood pellet production and distribution chain could contribute to cleaner and cheaper biofuels. According to research viewed, if the market for torrefied biomass grows significantly and develops in the coming years, then torrefied wood pellets will be able to compete with traditional wood pellets. Studies have made predictions for the calculation of possible scenarios and estimated that in the most probable scenario, the demand for torrefied biomass could reach 8-10 million tons (335-420 PJ) by 2030 (Proskurina et al., 2017).

2.2.5.4. Possibilities of using biomethane in the industrial sector

In Sweden, the iron and steel industry (IRI) is the main source of greenhouse gas emissions and, based on 2016 data, it is estimated that steel industry account for 35% of total industrial greenhouse gas emissions and about 12% of total fossil greenhouse gas emissions. Emissions from the steel and iron industries mainly come from the use of coal and coke in the iron ore reduction process, as well as from the use of liquid and gaseous fuels to provide heat. The study evaluated the possibility of replacing fossil gaseous and liquid fuels used in the iron and steel industry processes with liquefied biomethane (LBG), which is obtained in the gasification process using forest residues as raw materials.

It has been recognized that in order for the Swedish iron and steel industry (ISI) to achieve zero greenhouse gas emissions, specific production processes would require the use of biofuels instead of fossil gaseous and liquid fuels for heat production (Ahlström et al., 2020).

<u>Indonesia</u>

One of the industrial development strategies promoted by the Indonesian government is the creation of industrial clusters or the creation networks of the companies or corporations concerned within a defined geographical network. It is recognised that some of the current developments in Indonesian industrial clusters offer great potential for the use of renewable energy. One example is Sei Mangkei, in North Sumatra, where it has been estimated that hydropower, solar energy (PV panels) and biomass, for example, could create competitive prices compared to non-renewable energy sources. The structure of the proposed industrial cluster consists of five elements: technology, consumer industries, suppliers, drivers and the workforce. Some successful examples of industrial clusters are the chemicals cluster in Sweden and the textile cluster in China (Hidayatno et al., 2019).

2.2.6. The attitude of industrial companies towards renewable energy resources

This section analyzes the attitude of industrial companies towards renewable energy resources to find out how many industrial companies are open to the use of renewable energy resources and what are the possibilities to use them by installing RES technologies and investing in them.

2.2.7. Methodology

2.2.7.1. Survey for manufacturing enterprises

Compared to other EU countries, the share of renewable energy in final consumption in Latvia is relatively high (European Environmental Agency, 2019). This is mainly due to the installed hydropower plant capacity and the fact that in Latvia, historically biomass (wood) is used as a fuel, and it is widely available (in Latvia forests cover 52 % of the total land area (LSM.lv, 2019)).

Concerning the level of energy consumption by sector, according to the data available in the database of Central Statistical Bureau of Latvia, the industry and construction sector ranks third after the transport and household sectors in terms of total final energy consumption. As can be seen from Fig. 2.20, the percentage difference between sectors is not vast, so it can be argued that the industrial and construction sector plays a significant role in the energy balance.

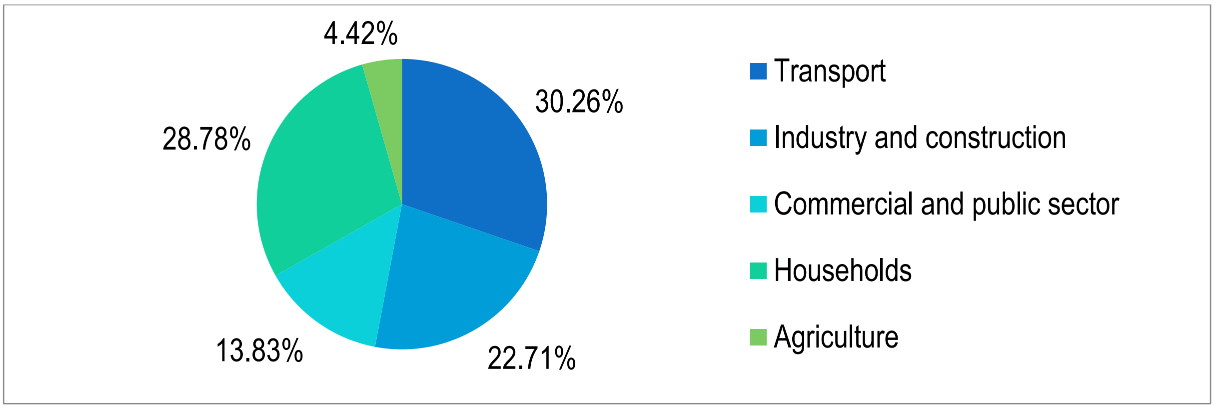


Fig. 2.20. Final energy consumption by sector in 2018 (Central Statistical Bureau of Latvia, n.d.-a)

Considering the previously mentioned, the industry and construction sector also plays an important role in the changes in renewable energy share. The aim of the Master's Thesis is to promote the use of renewable energy resources in manufacturing enterprises; therefore one of the tasks for this purpose was to conduct a survey of manufacturing enterprises in order to get answers to questions related to the topic of renewable energy in general as well as obtain the necessary information (needs, potential barriers and the companies' position on the renewable energy issue as such) for the fulfilment of other tasks set in the Master's Thesis such as the development of policy recommendations in order to increase the share of renewable energy in manufacturing enterprises.

The target group of the survey is manufacturing enterprises. The survey was prepared using the online software "Typeform" and sent out to 2000 manufacturing enterprises. A total of 146 responses were received. The survey was based on the following questions:

1) *Are renewable energy technologies used in your company?*

The purpose of this question is to obtain general information on the current situation in companies. Companies that use RES technologies already have some experience and own perspective on them, while for companies with no such experience, the right incentives and access to wholesome information need to be available that could stimulate their interest in the transition to RES technologies.

2) *Please specify which of RES is/are used?*

If the first question is answered in the affirmative, the survey participant is asked to specify which of the RES technologies is/are used in the company. The summary of answers to this question will create a list of top choices for RES technologies that may be useful to better understand why this is the case today and what are the least used RES technologies. If it is desirable to increase the installed capacity of the least used technologies, while looking at the answers to other survey questions, appropriate proposals may be developed.

3) *In your opinion, what limits the use of RES?*

The answers to this question will indicate the main obstacles or barriers that will be taken into account when developing appropriate recommendations.

4) *In your opinion, what would facilitate the use of RES?*

The answers to this question will indicate what instruments/assistance survey participants expect and which, in their opinion, would create more interest in the transition to RES technologies. In the light of the responses received, appropriate recommendations can be made, including on financial and policy instruments. By evaluating the answers received, appropriate recommendations may be made, including on financial and policy instruments.

5) *Which three RES technologies, in your opinion, could have the most potential in your company?*

By summarizing the answers to the specific question, a list of RES technologies will be obtained in the order of priority according to their implementation potential in the opinion of enterprises.

When summarizing the result, to take into account whether the technology is indicated as the first, second or third priority, coefficients have been selected that are multiplied by the number of respondents who have indicated the specific RES technology at the respective priority. This coefficient for the first priority is 3, for the second priority – 2 and for the third priority – 1. The incidence of each RES technology is calculated using Eq. (2.11):

$$R_{RES} = \frac{p_1 * 3 + p_2 * 2 + p_3 * 1}{\sum_{i=1}^{n} p_1 * 3 + p_2 * 2 + p_3 * 1} * 100, \quad (2.11)$$

where

R_{RES} – incidence of specific RES technology among respondents, %;

p_1, p_2, p_3 – number of respondents who indicated RES technology under the first priority (p_1), the second priority (p_2) and the third priority (p_3);

n – number of total RES technologies considered.

Given that any decision is based on a specific knowledge base, RES technologies at the top of the resulting list indicate that they are more acceptable to enterprises, as the potential for their implementation is at least considered. The RES technologies at the bottom of the resulting list do not mean that they do not have the potential to be implemented – rather, they are not associated with conventional RES solutions due to limited distribution and lack of information, so they are less acceptable to companies.

6) *What is the approximate monthly electricity consumption of your company?*

7) *Is energy consumption one of the top three cost positions in your company?*

Questions 6 and 7 are interrelated, and the answers to them indicate whether the company is aware of the energy consumption in its company, which is essential in determining the potential savings before making a decision. To reduce the enterprise costs, one option is to reduce the company's energy consumption, which can be done by reducing energy consumption as a result of energy efficiency, and the other option is to reduce purchased energy by introducing or increasing the company's energy consumption for self-consumption, for example, by introducing RES technologies.

8) *Would you be interested in the results of this survey and learning more about RES technologies?*

The purpose of this question is not only to provide feedback to the enterprises involved in the survey but at the same time to see whether the enterprise has an interest in RES at all, as change can only take place if there is a will.

For the full survey, see Appendix 1.

2.2.7.2. Multi-criteria decision analysis for renewable energy technologies

Taking into account the conclusions of the literature review, the author uses MCDA as a basis for further analysis of RES technologies with an AHP method.

As mentioned before, MCDA basically includes the target definition, definition of alternatives, selection of criteria, determination of their weight, and evaluation of alternatives. The following description of the methodology follows the sequence of these steps.

The primary purpose of the analysis is to make a well-informed decision, namely – decide for the transition to a specific RES technology, taking into account sustainability as a whole, opposite to the decisions which are based primarily on economic, environmental, or social considerations. In short – the goal is to choose the best RES technology in accordance with the principles of sustainable development.

Alternatives represent various options/choices among which the decision-maker can make a selection. In this case, alternatives are various RES technologies which are previously discussed in the literature review: solar PV, solar thermal collectors, wind turbines, geothermal energy (heat pumps), and biomass combustion technologies.

The evaluation of RES technologies will be made separately for RES technologies for electricity generation and for heat generation because the technologies of these types of energy cannot be compared equally with each other.

Taking into account the findings of the literature review, four main criteria are used for AHP (and other MCDA methods): technical criteria, economic criteria, environmental criteria, and social criteria. For each of the main criteria, appropriate sub-criteria are selected, which more precisely describe the nature of each of the criteria as such. The following subsections describe the selected criteria and sub-criteria, as well as the values for their comparison, which will be used for the evaluation of RES technologies.

2.2.7.3. Technical criteria

Reliability describes the ability of technology to work continuously and independently – without unforeseen damage, interruptions, and additional monitoring. Reliability is one of the most commonly used criteria in the multi-criteria analysis and has always been a topical issue in the energy sector (Wang et al., 2009). Reliability is affected by conditions such as the quality of technical equipment, required maintenance, the type of energy source used, etc. Reliability can be described both qualitatively and quantitatively. Quantitative indicators of reliability include, for example, a capacity factor expressed as the ratio of actual power output to theoretical power output over a given period and an availability factor expressed as the time at which the technology is capable of producing energy over the total time in the period considered (Troldborg, 2014).

A quantitative indicator, precisely a capacity factor, has been chosen to characterize reliability in the Master's Thesis. Geothermal energy has the highest capacity factor, as it is less affected by external factors compared to other RES (Gude, 2018). Capacity factors of RES are depicted in Table 2.14.

Table 2.14.

RES technology technical criteria

RES technology	Capacity factor (reliability, %) (Gude, 2018)	Technology maturity (qualitative sub-criterion)	Local technical know-how (qualitative sub-criterion)
Geothermal	95	4	3
Biomass	80	4.5	5
Solar thermal	35	4	3
Wind	30	5	3
Solar PV	20	4	4

The maturity of the technology is related to the prevalence of the technology – the more mature the technology, the more widespread it will be; the prevalence of technology can be seen at different territorial scales, such as at the national level. At the same time, the maturity of the technology characterizes how advanced the technology is, i.e., whether there is potential for efficiency gains or whether the theoretical maximum level of technological productivity has already been reached (Haddad et al., 2017). The scale from 1 to 5 is used to characterize the maturity of the technology. The value (see Table 2.14) is assigned according to the following degrees of technological maturity (similarly as presented in (Tsoutsos et al., 2009; Wang et al., 2009; Troldborg et al., 2014; Haddad et al., 2017)): 1 – technology is tested and researched in a laboratory; 2 – technology at a pilot-project level for demonstrative and experimental purposes; 3 – technology that still requires significant improvements; 4 – commercially available technology with a stable place in the market, that still has the potential for improvements; 5 – commercially available technology with a stable place in the market that has been practically used for a long period, initial malfunctions have been eliminated, and it is as close as possible to the theoretically possible efficiency.

The maturity of the technology is related to local know-how; however, due to certain factors (e.g., availability of resources) there may be situations where the technology with high maturity does not have ample local know-how, for example, in Latvia, it could be applied to high-temperature geothermal technologies. Local know-how is related to all available information and knowledge about a particular technology in relation to its production, installation, operation, and maintenance. Local know-how is also assessed on a scale of values from 1 to 5, where 1 means that the technology is not present in the specific area and accordingly no experience in using and operating the technology in specific conditions is accumulated, and 5 – that the technology is widespread and there is relevant experience in installation, adjustment, and maintenance.

2.2.7.4. Economic criteria

In order to assess the economic aspect, two main sub-criteria were selected for evaluation – investment cost and operational and maintenance cost. Investment costs consist of several parts (equipment costs, installation costs, other system element costs, etc.). For example, the most prominent part (~45 %) of investment costs in the solar thermal system is from collectors themselves, the second largest part (~25 %) of the investment is for installation, ~20 % of the investment is required for the purchase of storage-related equipment and another 10% - for other elements of the overall system (GREBE, 2017).

Operation and maintenance costs are regular costs associated with the maintenance and optimal operation of technological systems. These may include, for example, regular (scheduled) maintenance, system repairs, etc. These costs are often expressed as a percentage of the total investment costs. In the previously described case of solar collectors, operation and maintenance costs are ~0.9–1.8 % of investment cost (GREBE, 2017).

Table 2.15

RES technology economic criteria (International Renewable Energy, 2018)

RES technology	Investment cost, euro/kW	Operational and maintenance cost, euro/kW/year
Solar PV	1118	28
Biomass (CHP)	3600	72
Wind (onshore)	1383	18
Solar thermal	625	21.7
Heat pump (ground source)	1171	4.5
Biomass (CHP)	3600	72
Biomass (boiler)	374	22

2.2.7.5. Environmental criteria

As it was shown in Table 2.16, emissions and land use are some of the most commonly used criteria that characterize the environmental impact. Emissions from the life cycle are chosen as a sub-criterion to compare the environmental impact of RES technologies. Life cycle emissions take into account the impact at all stages of the technology, which is essential in sustainable decision making. This sub-criterion is quantitative and is expressed in g CO_2 eq/kWh. The emission values of the RES technologies considered in the thesis are shown in Table 2.16.

Table 2.16

RES technology environmental criteria (Amponsah et al., 2014; Schlömer et al., 2014; Thornley et al., 2015; Troldborg et al., 2014)

RES technologies for electricity generation	Emissions, CO_2 eq/kWh	Land use, m^2/kW
Solar PV	41	150
Biomass (CHP)	21.6	4000
Wind (onshore)	11	200
RES technologies for heat generation		
Solar thermal	21.6	40
Heat pump (ground source)	107	50
Biomass (CHP)	25.2	4000
Biomass	108	4000

As it is pointed out in (Troldborg et al., 2014), land use can vary widely from one source to another, mainly due to the extent to which land use is considered – whether it is just the area needed for the deployment of technology or the impact on land use throughout technologies life cycle. A review of the available literature reveals a lack of information on land use throughout the life cycle, especially for thermal energy technologies. The land-use values used for RES technology evaluation are shown in Table 2.16. Values are expressed as m^2 per kW of installed power. The value is affected by the type of fuel/energy used to operate the technology, for example, biomass as a fuel has the highest land use demand among all – renewable and non-renewable fuels (OECD, 2018) – and thus has an impact on biomass technology land use.

2.2.7.6. Social criteria

For the social aspect evaluation, two sub-criteria have been chosen – acceptability and job creation. Job creation is described quantitatively. This sub-criterion shows the jobs created during the life cycle of each RES technology by the installed capacity. Job creation is likely to have an indirect effect on the performance of a particular enterprise, but this sub-criterion is clearly important for the development of the economy as a whole.

Table 2.17

RES technology social criteria

RES technology	Acceptability (qualitative sub-criterion)	Job creation, jobs/MW (Ochs, 2015)
Solar PV	5	1.45
Wind	3	0.54
Solar thermal	4	0.91
Geothermal	2	2.00
Biomass	4	1.53

Acceptability is a qualitative sub-criteria, and it characterizes if the technology is satisfactory to the decision-maker/society and is capable of being accepted. Acceptability is affected by both knowledge of technology and existing positive or negative experiences. Public opinion can also have a major impact on the technology sector. Eliminating various myths and prejudices can improve the acceptability of technology.

2.2.7.7. Hierarchy framework

After the definition of target, alternatives, and selection of criteria and sub-criteria, the hierarchy framework of the AHP can be created (see Fig. 2.21).

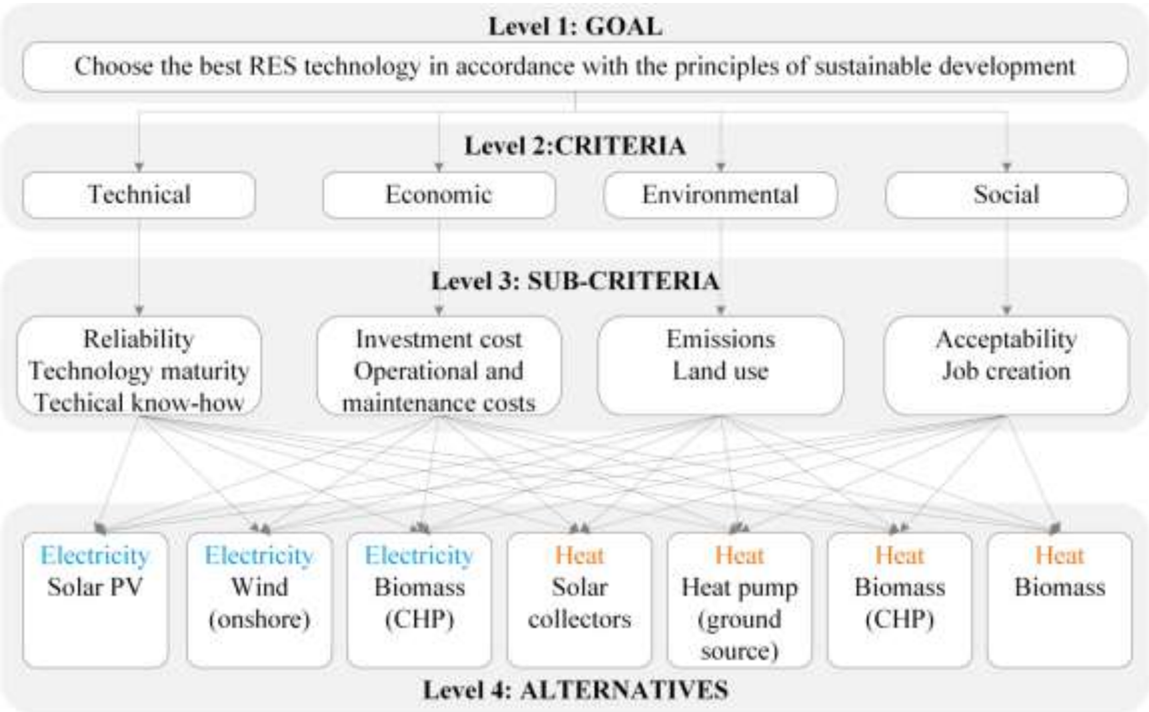


Fig. 2.21. AHP hierarchy structure

Pairwise comparison and consistency calculation

For the pairwise comparison, the nine-integer value scale is used as presented in (Maletič et al., 2016) (see Table 2.18.). The nine-integer value scale was initially suggested by Saaty (1977), and although other scales have been developed and evaluated and the particular nine-integer scale has received its share of criticism, finding an alternative/more appropriate value scale is beyond the scope of this work.

Table 2.18

Scale for pairwise comparison (Maletič et al., 2016)

Scale	Definition
1	Equal importance
3	Moderate importance of one over the other
5	Essential or strong importance
7	Very strong or demonstrated importance
9	Extreme or absolute importance
2, 4, 6, 8	Intermediate values between the two adjacent judgments

The first step is the pairwise comparison. Each of the elements (criteria, alternatives) is compared to all the other elements. Eq. (2.12) indicates the size of the matrix to be created, *n* is the total number of elements to be compared, and that means the matrix will have dimensions of *n* x *n* (Cabala, 2010):

$$[a_{ij}], where\ i, j = 1, 2 \dots n. \quad (2.12)$$

Eq. (2.13) shows that the same elements, when compared with each other, are not differentiated by preference. That is why all values in the diagonal of the matrix when the element is compared to itself are always equal to 1. When comparing elements it is always assumed that the element on line *i* is compared with the element in column *j* and a_{ij} shows how much the importance of the *i*-th element is greater, equal, or less than that of the *j*-th element using scale presented in Table 2.14 (Cabala, 2010).

$$a_{ij} = 1\ if\ i = j. \quad (2.13)$$

Eq. (2.14) shows that the preferences are reciprocal, for example, if $a_{ij} = x$, then $a_{ji} = 1/x$. This means that only values above matrix diagonal can be determined as the values below can be calculated as inverse values (Cabala, 2010).

$$a_{ij} = \frac{1}{a_{ji}}\ if\ i \neq j\ . \quad (2.14)$$

Considering the previously mentioned, the comparison matrix *A* is filled by following the order in the Eq. (2.15) (Klutho, 2013).

$$A = \begin{bmatrix} 1 & a_{12} & \dots & a_{1n} \\ 1/a_{12} & 1 & \dots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ 1/a_{1n} & 1/a_{2n} & \dots & 1 \end{bmatrix}. \quad (2.15)$$

In order to determine the ranks of elements, the next step is the solving of the eigenvector problem. There are three methods for solving the eigenvector problem – Saaty's method, the power method, and the geometric mean method. In this case, Saaty's method is chosen, given its simplicity compared to the other two methods. The first step is a normalization of comparison matrix *A* to the normalized matrix *B* = [b_{ij}], where each b_{ij} is calculated by Eq. (2.16) – the sum of each column is calculated, and the values in the corresponding column are divided by it (Cabala, 2010).

$$b_{ij} = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}}. \quad (2.16)$$

The next step is the calculation of eigenvectors of each matrix row by Eq. (2.7) – values in each row are summed and divided by the number of criteria. The eigenvectors give the ranking (weight) of the elements (Cabala, 2010):

$$w_i = \frac{\sum_{j=1}^{n} b_{ij}}{n}. \quad (2.17)$$

However, so that these weight values can be used with some certainty for further evaluation, it is necessary to calculate the consistency index (*CI*) and consistency ratio (*CR*). The consistency index is calculated by Eq. (2.18) and consistency ratio by Eq. (2.20):

$$CI = \frac{\lambda_{max} - n}{(n-1)}. \quad (2.18)$$

In Eq. (2.18) λ_{max} represents maximum eigenvector, which is calculated by Eq. (2.19). Values from comparison matrix *A* are multiplied by weights obtained by Eq. (2.17). The obtained values form another matrix in which values are summed by rows. Each sum of a row is divided by the corresponding weight. The average of all these values is equal to λ_{max}.

$$\lambda_{max} = \frac{1}{n}\sum_{i=1}^{n}\frac{(Aw)_i}{w_i}, \tag{2.19}$$

$$CR = \frac{CI}{RI}. \tag{2.20}$$

In Eq. (2.20) *RI* represents a random index, which varies depending on *n*. If the *CR* value is smaller or equal to 0.1, it can be considered as acceptable consistency (Saaty, 1977). The *RI* values for *n* values from 2 to 10 are shown in Table 2.19.

Table 2.19

Random index values (Kolios et al., 2016)

N	2	3	4	5	6	7	8	9	10
RI	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

In the thesis, the calculation procedure described first is applied to the main criteria – technical, economic, environmental, and social criteria – in order to weigh their importance with respect to the defined target. Similarly, pairwise comparison is conducted for the sub-criteria with respect to criteria and pairwise comparison for all alternatives with respect to each sub-criterion.

Quantitative criteria transformation to a pairwise comparison scale

As previously mentioned, AHP is capable of working with both – qualitative and quantitative data. In order to transform quantitative data into the AHP scale, the following steps must be taken – calculation of the step value *h* using Eq. (2.21), where O_{max} and O_{min} represent maximum and minimum values among alternatives for the criterion considered:

$$h = \frac{O_{max} - O_{min}}{9}. \tag{2.21}$$

The next step is the calculation of rank numbers *RN* of each alternative *x* using Eq. (2.22). There are two types of cases for the calculation: if O_{min} is the best value (for example, the lowest amount of emissions) and if O_{max} is the best value (for example, the creation of new jobs). O_x represents the value of the alternative for which the *RN* is calculated. The minimum *RN* value shall be 1, in cases where the *RN* value in the calculation is 0, it shall be replaced by a value of 1.

$$RN_x = \begin{cases} integer\ value\ of\ \left(9 - \frac{O_x - O_{min}}{h}\right), if\ O_{min} is\ the\ best \\ integer\ value\ of\ \left(\frac{O_x - O_{min}}{h}\right), if\ O_{max} is\ the\ best \end{cases}. \tag{2.22}$$

The last step in the transformation of quantitative data is scoring value *SV* definition by Eq. (2.23), where *RN* values of each pair of alternatives x_1; x_2 considered are used.

$$SV_{x_1;x_2} = \begin{cases} 1/(RN_{x_2} - RN_{x_1} + 1), if\ RN_{x_1} - RN_{x_2} < 0 \\ RN_{x_1} - RN_{x_2} + 1, if\ RN_{x_1} - RN_{x_2} \geq 0 \end{cases}. \tag{2.23}$$

As a result, a comparison matrix is obtained with comparisons between alternatives with regard to specific criteria or sub-criteria (depending on the hierarchy framework of the case).

In order to obtain the final result, which will represent the ranking of alternatives main criteria weights (level 2 (see Fig. 2.21)) are multiplied with sub-criteria local weights (level 3 (see Fig. 2.3)). The result of this multiplication gives global weights, which will show how significant influence on the final result will have each of the sub-criteria.

When the evaluation of all alternatives under each sub-criterion is completed, obtained local weights of alternatives are multiplied with the global weights of sub-criteria. By summing the obtained values from this multiplication, the desired end result is obtained, which reflects the ranking of the alternatives.

2.2.8. Policy recommendations

The development of policy recommendations is mainly carried out by dividing the proposals into three groups: 1) proposals for changes to existing legislation, 2) informative measures aimed at raising awareness and understanding of various aspects of RES technologies, 3) proposals for various financial support instruments. The main shortcomings for the solution of which policy recommendations will be developed will be highlighted during the review of the regulatory framework, but especially after the survey conducted in enterprises. Given that the EU framework has given the countries a role to play in setting a good example in both renewable energy and energy efficiency, proposals will be made in this direction as well.

After the development of policy recommendations, they will be prioritized according to various aspects, which take into account the economic side, the potential for implementation, the impact on the removal of barriers. The prioritization of recommendations will be carried out in a simplified way by evaluating assertions compiled in Table 2.20.

Table 2.20

Policy recommendation prioritization assertions

Aspect	Points	Assertion
Funding	0	Not applicable/cannot be assessed
	1	Additional public funding is needed
	2	Can be implemented within the existing state budget funds
The measure will have an impact on the main barriers indicated by enterprises	0	Not applicable/cannot be assessed
	1	Constraints of existing infrastructure could be overcome
	2	Decrease payback period
	3	Encourages investment in RES
The measure is in line with the incentives deemed necessary by the enterprises	0	Not applicable/cannot be assessed
	1	Improvement of legislation/Tariff increase
	2	Energy independence/Tax credit
	3	A better understanding of technology
	4	Grant/subsidy
Time and effect of the implementation of the measure	0	Not applicable/cannot be assessed
	1	A long-term measure without immediate effect
	2	A medium-term measure with an effect within a reasonable time
	3	Short-term measure with immediate effect

After the evaluation of the recommendations, by summing up the obtained points, the recommendations are divided into the following priority groups: 1) High priority measures with 9–12 points; 2) Medium priority measures with 5–8 points; 3) Low priority measures with 0–4 points.

2.2.9. Results and discussion

The next two sub-chapters describe the results of the enterprise survey and the results of the multi-criteria analysis. The third sub-chapter presents the results obtained in developing policy recommendations.

2.2.9.1. Enterprise survey results

The survey results from 146 enterprises were compiled and analysed only in aggregate form. 42 % of respondents already use renewable energy technologies in their enterprises, while the majority or 58 % do not. Fig. 2.22 shows the percentage distribution of renewable energy technologies according to the respondent's answers.

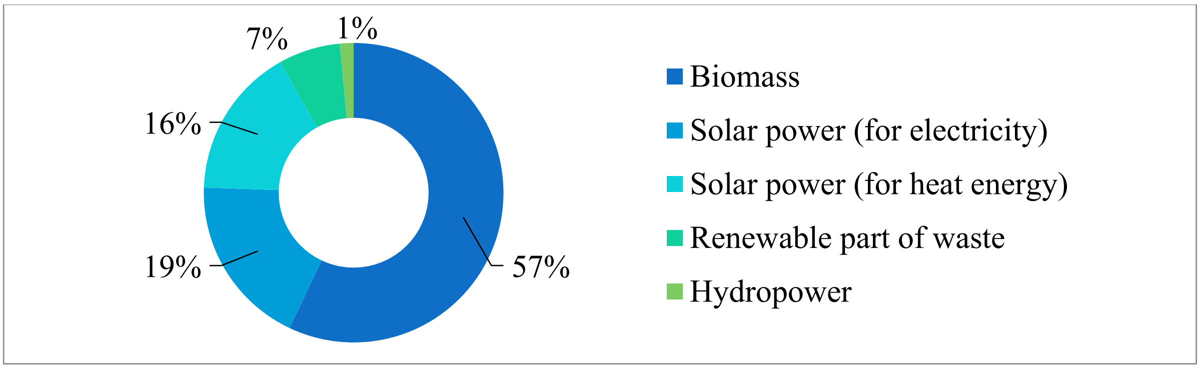


Fig. 2.22. RES used in enterprises represented by respondents

The results show that most companies use technologies that use biomass, which is justified by the earlier mentioned about the wide availability of biomass in Latvia and thus its historically widespread use. Solar energy is also a relatively common energy resource for enterprises.

33 % of respondents as main key constraints for the broader use of renewable energy technologies mention other investment priorities, 26 % of respondents – long payback periods that have primary reference to costs and 20 % of respondents – constraints of existing infrastructure, which is connected with technical aspects as well as economic aspects.

Fig. 2.23 shows the percentage distribution of possible incentives and instruments according to the respondents' answers that, in their opinion, could promote the use of RES technologies in enterprises.

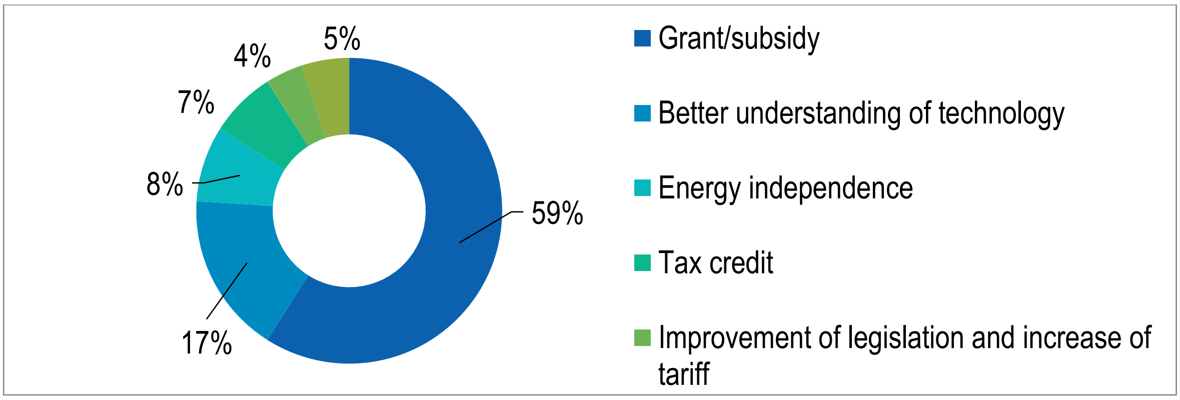
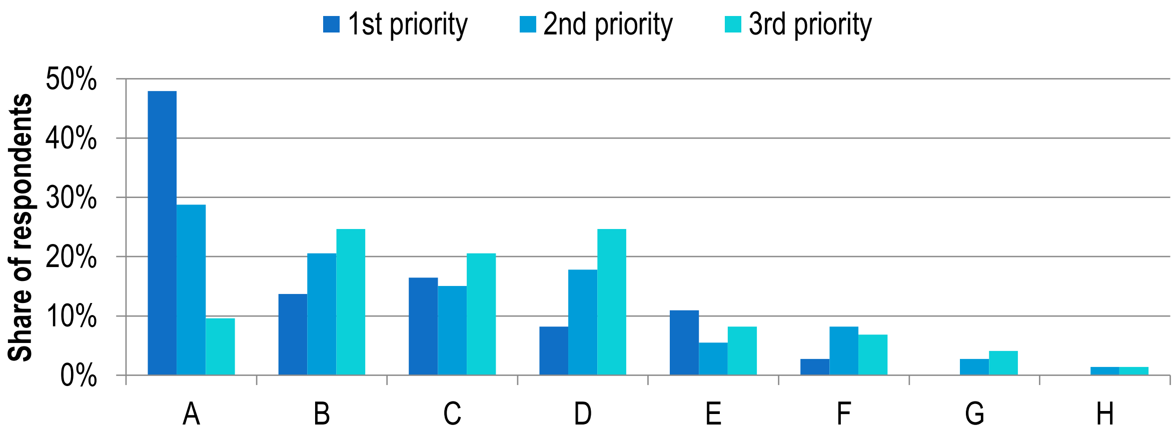


Fig. 2.23. Incentives to encourage the use of RES in surveyed enterprise view

The result that places the grant/subsidy in the first place among the incentives is not surprising, given that finance-related questions in the company are one of the most important issues. The availability of a grant/subsidy can, for example, reduce the payback period of RES technology, making the introduction of it more attractive to enterprises. As the results show, apart from the availability of grants/subsidies, awareness-raising as a better understanding of technology is the second most frequently mentioned option to help increase the use of RES technologies. This means that efforts should be made to make information on RES technologies widely available for as many enterprises as possible, for example, by organizing training sessions, seminars, sharing best practices, providing personalized counselling, etc.

Question 5 of the survey asked enterprises to indicate, in order of priority, for which three RES technologies they see the highest potential in their enterprise. Fig. 2.24 shows the distribution of RES technologies by enterprise priority.



A – Solar energy (for electricity); B – Solar energy (for heat energy); C – Biomass (wood, straw, biogas, biofuel); D – Wind energy; E – Renewable part of waste; F – Geothermal energy; G – Hydropower; I – Tidal energy

Fig. 2.24. RES technologies by priority as a percentage of total responses for each priority

As can be seen in Fig. 2.24, solar energy for electricity generation has a significant predominance when indicating the first priority – almost half (48 %) of respondents have indicated this RES technology as their first priority. Biomass with 16 % and solar energy for heat generation with 14 % is the next most selected RES technologies with the highest priority according to respondents' answers. When indicating second and third priority, the distribution between RES technologies is more even.

Also, under the second priority, solar energy for electricity generation is the most indicated technology (29 %), leaving solar energy for heat generation (21 %) and wind energy (18 %) in second and third place, respectively. It should be noted that, given a more even distribution, when indicating second priority, four RES technologies ranks at the top (with at least a 10 % response rate), ranking biomass technologies in fourth place with 15 %.

When looking at the third priority, a completely different distribution appears ranking two technologies – wind power and solar power for heat energy – in the first place with a 25 % response rate leaving biomass (21 %) in third place and solar energy for electricity generation (10%) in third place.

Taking into account the priorities, the aggregated results calculated by Eq. (2.11) show that according to the respondents' answers the top three RES technologies for which they see the highest potential in enterprises are:

1) solar energy for electricity;

2) solar energy for heat energy;
3) biomass.

In the author's view, the result which ranks these three technologies as the technologies with the highest potential in view of enterprises can be directly linked to a "better understanding of technologies". These three technologies are already the most widely used (known) among the enterprises surveyed, and some experience has been gained in their utilization. For this reason, it is possible that preference is not given to the most appropriate RES technology but in favour of the technology for which the enterprise has a sufficient amount of information. Fig. 2.25 shows the rankings of all RES technologies, as proposed in the fifth question of the survey.

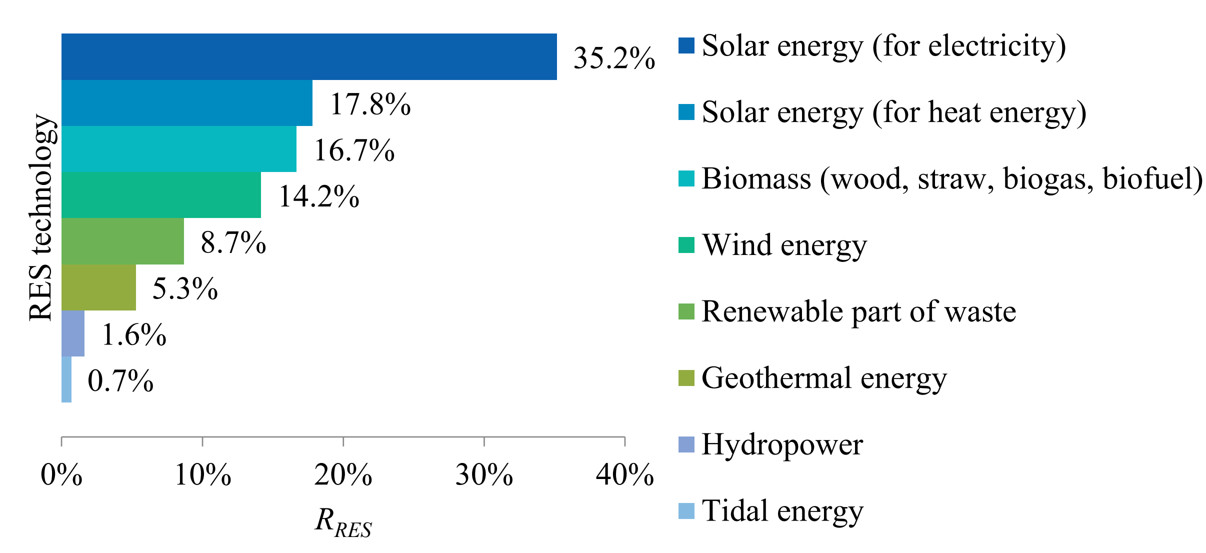


Fig. 2.25. Ranking of RES technologies according to enterprise survey results

The summary of question 6 of the survey shows that 22 % of respondents could not specify their electricity consumption in terms of quantity or cost, while most of the respondents could indicate both consumption and costs or at least one of them. The average electricity consumption in enterprises surveyed is 312 MWh per month, and the average electricity bill is 16 075 euros per month. Nevertheless, only 29 % of respondents indicate that energy consumption is among the top three cost positions in their enterprise, while for 63 % of respondents, energy costs are not among the top three cost positions, and 8 % of respondents cannot indicate if it is or not. Although the energy costs for a large proportion of respondents are not between the top three cost positions, this does not mean that the energy costs of these enterprises are not high, as any enterprise that follows its financial flows will always be interested in reducing costs, regardless of the number of costs for a specific position.

At the end of the survey, enterprises were offered to receive the results of the survey and indicate whether they would be interested in obtaining additional information regarding RES technologies. The majority of respondents (72 %) answered in the affirmative, while a relatively large proportion (28 %) answered in the negative.

The relationship between the last survey question and the answers to other survey questions were studied further. Fig. 2.26 and 2.27 show two critical aspects – Fig. 2.26 shows that for 25 % of the respondents, who responded in the negative, energy costs are high; however, they are not interested in receiving additional information on RES that could be beneficial for them. Similarly, a large proportion of enterprises that have answered in negative are not aware of their energy consumption, which may also justify their lack of interest. It is important to focus on interested companies, but it is even more important to work with companies that do not have such an interest – to understand the reasons and find solutions to remove existing barriers, change attitudes and behaviour. Appropriate instruments and policies need to be put in place to foster the competitiveness of enterprises and the development of a sustainable economy in general.

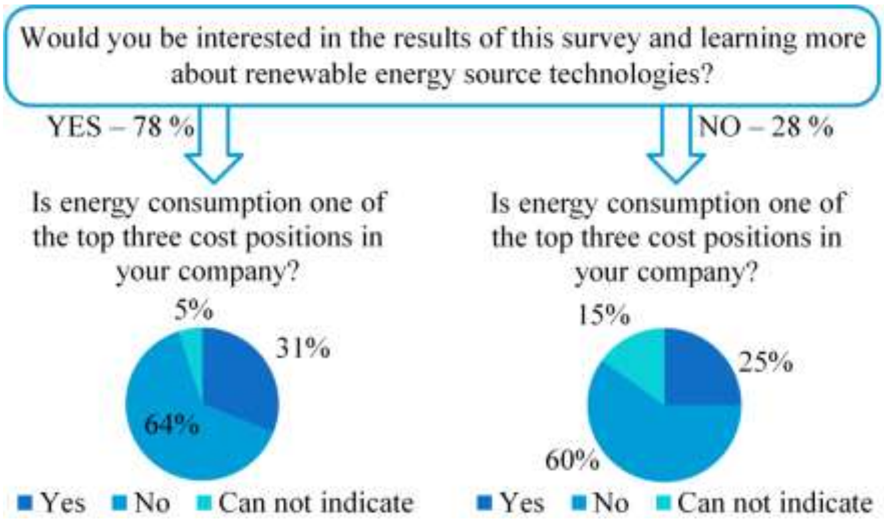


Fig. 2.26. The relationship between the answers to the survey question No. 7 and 8

Fig. 2.26 shows that most of the companies that answered in the negative do not use RES technologies in their enterprise. However, the majority of respondents have expressed interest, and it is positive that among them are not only enterprises that do not use RES technologies, but also those, who already have introduced such technologies for the operation of their enterprise.

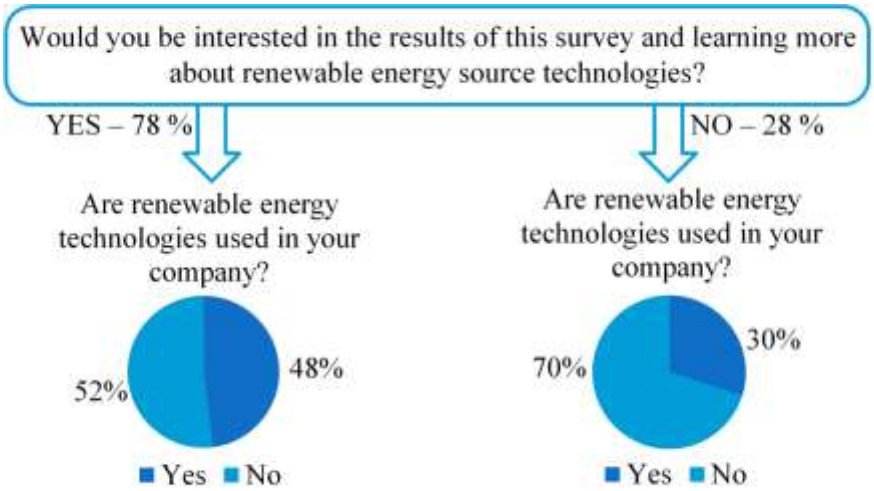


Fig. 2.27. The relationship between the answers to the survey question No. 1 and 8

Another interesting aspect in the analysis of the survey results shows that for respondents, who answered that they do not want to receive the survey results, the average energy consumption is 454 MWh per month, and the average cost of electricity is 26 727 euros per month.

For respondents, who answered that they want to receive the results of the survey, the average energy consumption is 280 MWh per month, and the average cost of electricity is 14 232 euros per month.

Respondents, who answered that they do not want to receive the results of the survey, mention other investment priorities as the main reason that limits the use of renewable energy sources (30 % of respondents), followed by long payback period (27 %), existing infrastructure constraints (14 %), no faith in technology (14 %), legislation shortcomings (10 %) and other reasons or no answer at all (5 %).

2.2.9.2. Analytic hierarchy process results

The results of AHP are presented in three main parts, where the first part summarizes the weights obtained for the four criteria and nine sub-criteria, but in the second and third parts – the results of the evaluation of RES technologies for electricity and heat generation, respectively.

Main criteria and sub-criteria pairwise comparison results

According to the AHP hierarchy (see Fig. 2.21), first, evaluation of the criteria on level 2 was carried out with respect to the goal using Eq. (2.15) and the value scale in Table 2.18. Technical, economic, environmental, and social criteria were compared pairwise based on the Master's Thesis author's assessment. The results are shown in Table 2.21.

Table 2.21

Pairwise comparison matrix of level 2 criteria

Criteria	Technical	Economic	Environmental	Social
Technical	1	0.3333	2	7
Economic	3	1	3	5
Environmental	0.5	0.3333	1	5
Social	0.1429	0.2	0.2	1
Column total	4.6429	1.8667	6.2	18

The normalization of the matrix is done by Eq. (2.16). The row "column total" in Table 2.21 represents denominator value in Eq. (2.16). Each of the pairwise comparison matrix value is divided with the corresponding column sum (for example, for the column "technical" – 1/4.6429=0.2154; 3/4.6429=0.6462; 0.5/6.6429=0.1077; 0.1429/4.6429=0.0308). The normalized pairwise comparison matrix is shown in Table 2.22.

Table 2.22

Normalized pairwise comparison matrix of level 2 criteria

Criteria	Technical	Economic	Environmental	Social	Average
Technical	0.2154	0.1786	0.3226	0.3889	0.2764
Economic	0.6462	0.5357	0.4839	0.2778	0.4859
Environmental	0.1077	0.1786	0.1613	0.2778	0.1813
Social	0.0308	0.1071	0.0323	0.0556	0.0564

The average values of each of the rows in Table 2.22 correspond to the relevant criteria weight (see Eq. (2.17)). Economic criteria are of the utmost importance with the weight of 0.4859; technical criteria rank second with the weight of 0.2764, third – environmental criteria with 0.1813, and the fourth – social with the weight of 0.0564. The result expressed as a percentage is shown in Fig. 2.28.

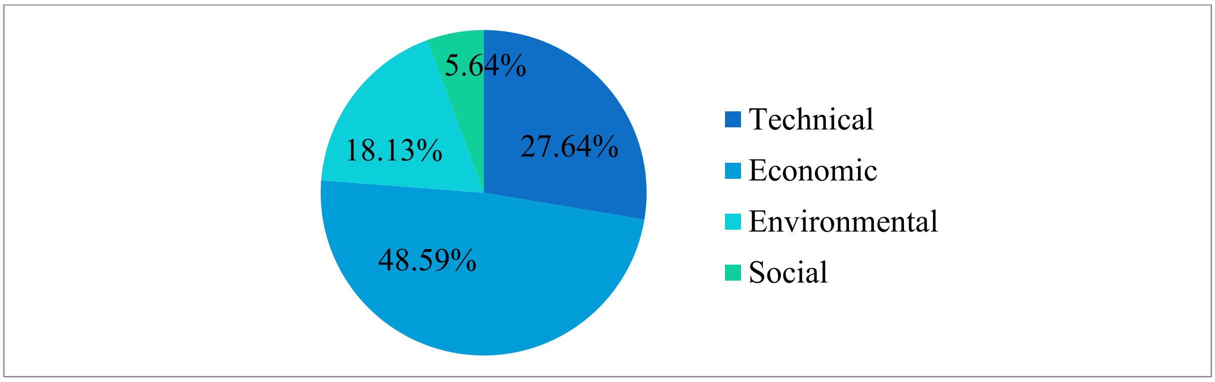


Fig. 2.28. Importance of RES technology evaluation criteria

For the *CI* calculation, it is first necessary to determine λ_{max} by Eq. (2.19). Each of the pairwise comparison matrix values presented in Table 2.23 is multiplied with the obtained weight values (average values from Table 2.22). The calculation process is shown in Table 2.23.

Table 2.23

The part of λ_{max} calculation process

Criteria	Technical	Economic	Environmental	Social	Sum
Technical	1*0.2764	0.3333*0.4859	2*0.1813	7*0.0564	1.19600
Economic	3*0.2764	1*0.4859	3*0.1813	5*0.0564	2.14110
Environmental	0.5*0.2764	0.3333*0.4859	1*0.1813	5*0.0564	0.76363
Social	0.1429*0.2764	0.2*0.4859	0.2*0.1813	1*0.0564	0.22935

The sum of each row in Table 2.23 is further divided by the criteria weights (average values from Table 2.21). The average of these obtained divisions ((4.32775 + 4.40666 + 4.21119 + 4.06428) / 4 = 4.25247) equals λ_{max} which is used for the calculation of *CI* using Eq. (2.18):

$$CI = \frac{4.25247-4}{(4-1)} = 0.08416. \qquad (2.24)$$

The *CR* is calculated using Eq. (2.20). The *RI* for the case with four compared criteria is 0.9:

$$CR = \frac{0.08416}{0.9} = 0.09351. \qquad (2.25)$$

Given that the *CR* = 0.09351, which conforms to the condition that *CR* must be ≤0.1, it can be concluded that the comparisons are consistent.

In the next step, pairwise comparison matrices for each group of sub-criteria were conducted in the same way – using Eq. (2.15)–Eq. (2.20). Table 2.24 summarizes the results (local weights) obtained. The consistency ratio for all sub-criteria pairwise comparisons did not exceed the permissible limit value of 0.1.

Table 2.24

Local weights of sub-criteria

Criteria	Sub-criteria	Local weight
Technical criteria	Reliability	0.72
	Technology maturity	0.08
	Local technical know-how	0.19
Economic criteria	Investment cost	0.67
	Operation and Maintenance Cost	0.33
Environmental criteria	Emissions	0.75
	Land use	0.25
Social criteria	Acceptability	0.83
	Job creation	0.17

In order to obtain the global weights, criteria weights are multiplied with local weights of sub-criteria. The obtained result is visualized in Fig. 2.29, where global weights expressed as percentage shows the importance of each sub-criterion when it will come to the final decision.

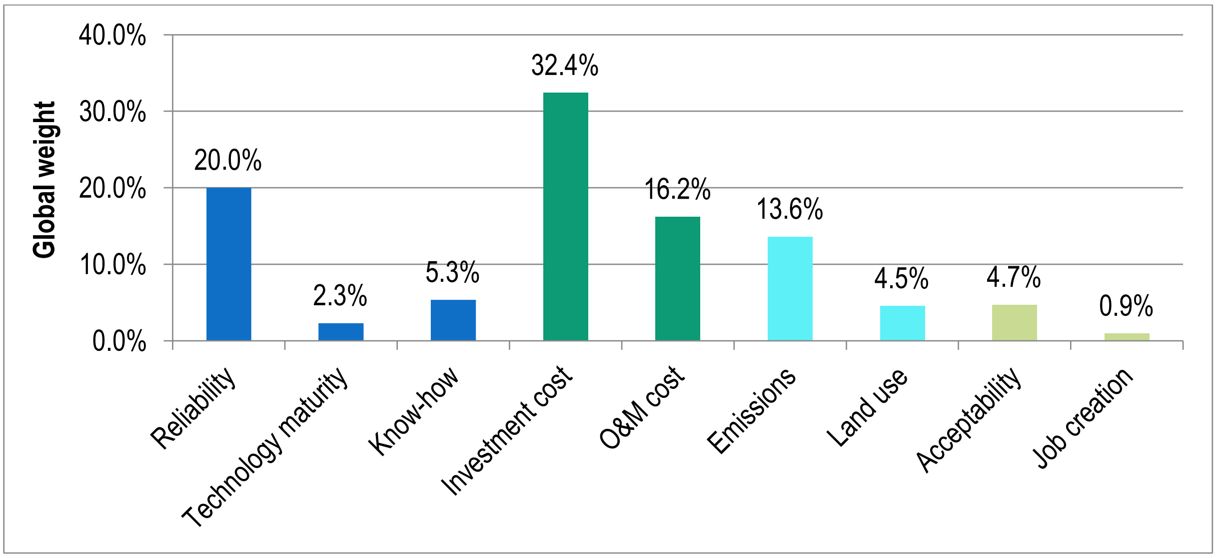


Fig. 2.29. Global weights of sub-criteria expressed as a percentage

Given that economic criteria have the highest weight, the sub-criteria of this criterion has also gained the highest weight values – the highest importance of all sub-criteria obtained investment cost (32.4 %), operation and maintenance cost is also among sub-criteria with high importance (16.2 %). From technical criteria, the highest importance is for reliability (20.0 %), among environmental criteria – emissions (13.6 %), and among social criteria – acceptability (4.7 %).

2.2.9.3. Renewable energy technologies for electricity generation – ranking results

Similarly, as with criteria and sub-criteria, evaluation of each of the alternatives with respect to each of the sub-criterion was carried out (level 4 (see Fig. 2.21)). In addition to the earlier calculations, Eq. (2.21)–(2.23) are used in this step to transform quantitative values to the AHP scale. The first step is the calculation of the step value using Eq. (2.21). As a calculation example, the conversion of investment costs of thermal energy technologies is considered.

$$h = \frac{3600-374}{9} = 358{,}44.$$

The next step is the calculation of rank numbers using Eq. (2.22):

$$RN_{Solar\ thermal} = integer\ of\left(9 - \frac{625-374}{358.44}\right) = 8,$$
$$RN_{Heat\ pump\ (ground\ source)} = integer\ of\left(9 - \frac{1171-374}{358.44}\right) = 7,$$
$$RN_{Biomass\ (CHP)} = integer\ of\left(9 - \frac{3600-374}{358.44}\right) = 1,$$
$$RN_{Biomass\ (boler)} = integer\ of\left(9 - \frac{374-374}{358.44}\right) = 9.$$

The next step is the calculation of scoring values using Eq. (2.23). As mentioned earlier, diagonal values are always equal to 1, and values under this diagonal can be calculated as inverse values. The calculation process and the results are combined in Table 2.25.

Table 2.25

Scoring value calculation process for an investment cost evaluation for thermal energy technologies

Alternative	Solar thermal	Heat pump (ground source)	Biomass (CHP)	Biomass (boiler)
Solar thermal	1	8–7+1=2	8–1+1=8	1/(9–8+1)=0.5
Heat pump (ground source)	1/2=0.5	1	7–1+1=7	1/(9–7+1)=0.33
Biomass (CHP)	1/8=0.125	1/7=0.14	1	1/(9–1+1)=0.11
Biomass (boiler)	1/0.5=2	1/0.33=3	1/0.11=9	1

The following steps are performed according to the Eq. (2.16)–(2.20). This approach is used for all quantitative data. Only the final results are described below, taking into account that the calculation process does not differ from the calculation examples already presented above.

Fig. 2.30 shows the result of each RES technology in each of the criteria groups. From an environmental point of view, wind technologies have the highest performance. In terms of performance under each of the environmental sub-criteria, wind technologies have a significant lead by emissions, while in terms of land use, they are on an equal footing with solar panels. In the group of technical criteria, the best results are given by biomass technologies, which have the highest rating when it comes to reliability. By looking at the economic criteria, it can be seen that solar PV and wind technologies are at the forefront, unlike biomass technologies, the results of which are influenced by high investment as well as operation and maintenance costs. Although the group of social criteria has the least impact on the final result, in this group, the highest rating is given to solar PV.

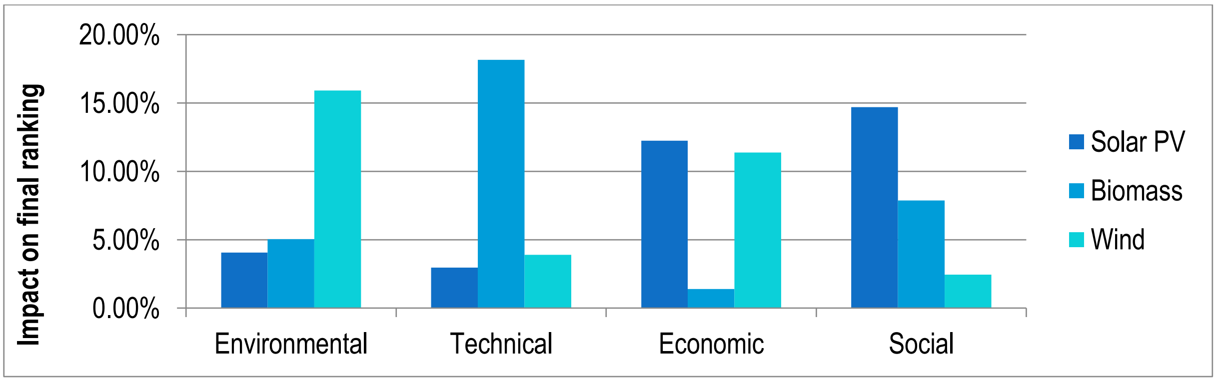


Fig. 2.30. Renewable energy technologies for electricity generation – result per criteria

By summing the result of each criterion to the respective technology, the final result, which shows the final ranking, is obtained (see Fig. 2.31).

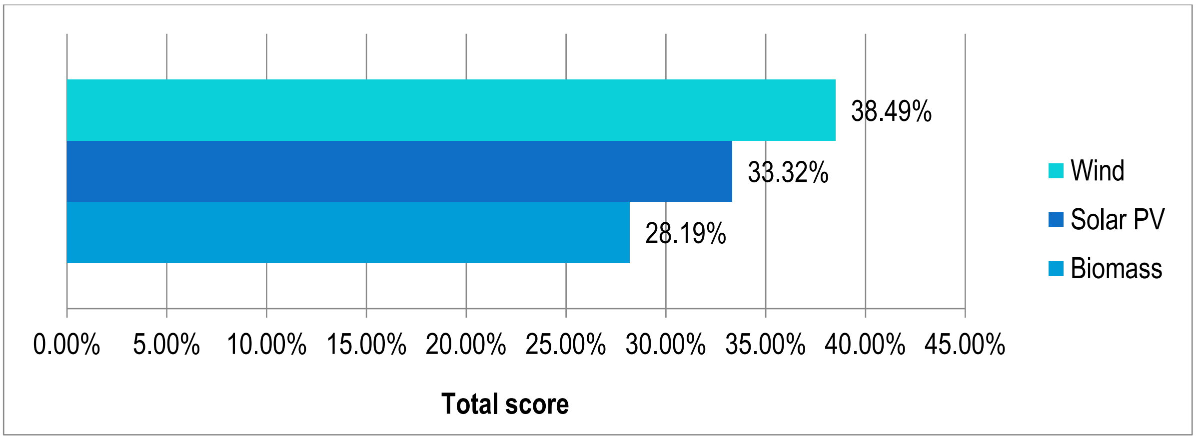


Fig. 2.31. The final ranking of renewable energy technologies for electricity generation

The results of the AHP show that the best technology, taking into account the principles of sustainable development, which respects environmental, economic, and social aspects, is wind energy technologies, with an overall result of 38.49%. In second place is solar PV with 33.32%, and in third place – biomass technologies with 28.19%. It should be noted that the results that rank the technologies do not have a very strong predominance. Instead, the distribution is even, because none of the technologies stands out in all of the criteria; for example, wind energy technologies have the highest score in economic criteria. At the same time, it also has the lowest score in social criteria.

Considering that small-scale wind technologies in Latvia (including manufacturing enterprises) are not widespread, as well as they are not so popular in comparison with biomass and solar energy technologies, the obtained result leads to the conclusion that these technologies should be paid more attention.

2.2.9.4. Renewable energy technologies for heat generation – ranking results

Fig. 2.32 shows the AHP interim result of each RES technology for heat generation in each of the criteria groups.

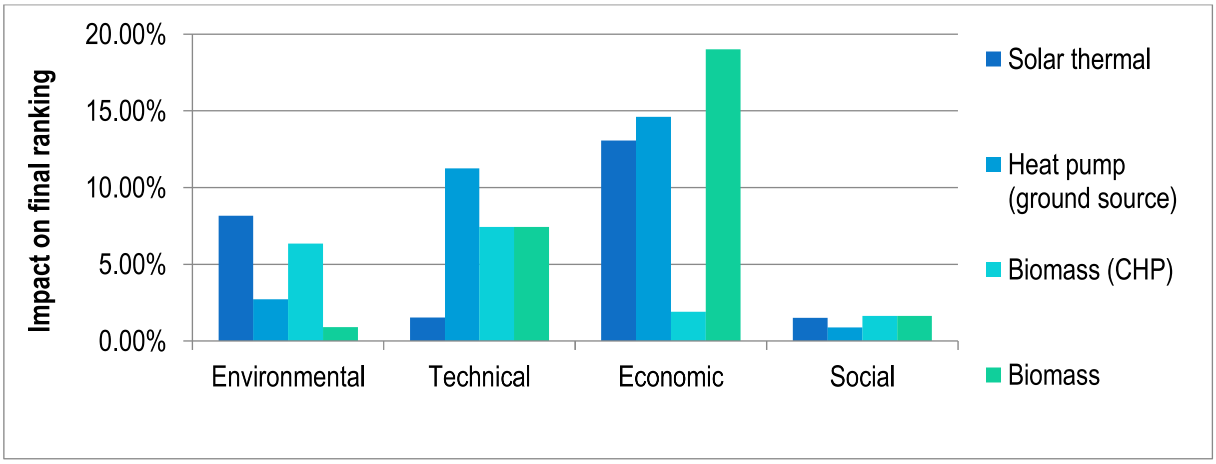


Fig. 2.32. Renewable energy technologies for heat generation – result per criteria

From an environmental point of view, solar thermal technologies have the highest performance. In terms of performance under each of the environmental sub-criteria, solar thermal and biomass CHP have the same impact by emission level, while in terms of land use, better performance is for solar thermal technologies overall ranking it as the best technology regarding the environmental impact. In the group of technical criteria, the best results are for geothermal energy technologies (in this case – ground source heat pump), which have the highest reliability score. By looking at the economic criteria, it can be seen that biomass combustion technologies for heat production are at the forefront, while biomass CHP has the lowest score in this criteria group due to high investment costs. In the group of social criteria, almost all alternatives have similar scores except for heat pumps, which received the lowest score in this group of criteria due to lower acceptance.

By summing the result of each criterion to the respective technology, the final result, which shows the final ranking, is obtained (see Fig. 2.33).

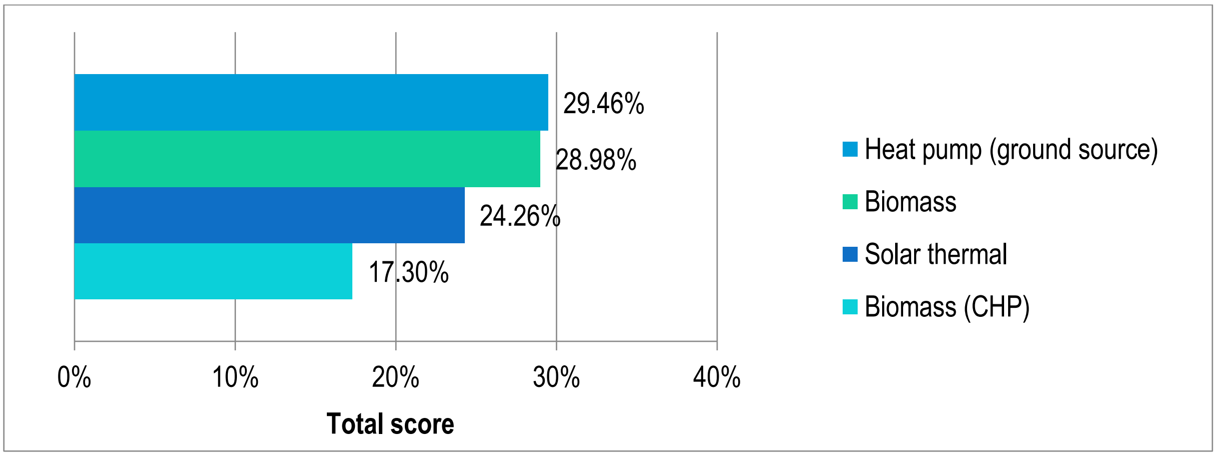


Fig. 2.33. The final ranking of renewable energy technologies for heat generation

With a very small predominance, geothermal energy technologies, or in this case – ground source heat pumps are in the first place with a result of 29.46%. Biomass technologies are in second place, with only a half-percent lower total result. With a slightly larger derogation, the third-place takes solar thermal energy technologies in the last place, leaving biomass CHP. Comparing the top two technologies shows that geothermal technologies have the best performance in terms of reliability as well as the lowest operation and maintenance costs, while biomass technologies have the best performance in terms of low investment costs.

2.2.9.5. Sensitivity analysis

The results presented above rank the RES technologies considered, taking into account, firstly, that the impact of technical, economic, environmental and social criteria is not equal – some of the criteria have more influence than others in final decision-making – this depends on the evaluator's assessments in favour of one or the other criterion, which, in his personal opinion, is more relevant to the final decision. However, the question arises: should a sustainable decision take into account all aspects on an equal footing? Assuming that the weight of economic, technical, environmental, and social criteria is equal (0.25), the ranking results of electricity technology and thermal energy technologies are different. These differences are compiled in Table 2.26.

The change of criteria weights changes the final results of RES technology ranking significantly levelling individual results and changing the position of technology leaders after the initial results. After sensitivity analysis, the first place among the RES technologies for electricity generation is taken over by solar PV leaving wind technology in second place. As regards biomass, although the overall individual result has been improved, it still ranks third. Among the RES technologies for heat generation, only the last place with biomass CHP remains unchanged, while in the first place, raising its initial position by two places ranks solar thermal energy. Heat pumps and biomass in total ranking moves one place lower, taking the second and third place, respectively.

Table 2.26

Sensitivity analysis of RES technologies with equal criteria weights

RES technology	Result at various criteria weights		Result at equal criteria weights		Difference by score	Difference by rank
	Score	Rank	Score	Rank		
RES technologies for electricity generation						
Solar PV	30.84 %	2	33.95 %	1	+3.11 %	+1
Biomass (CHP)	28.19 %	3	32.44 %	3	+4.24 %	0
Wind	40.97 %	1	33.61 %	2	–7.36 %	–1
RES technologies for heat generation						
Solar thermal	24.26 %	3	26.05 %	1	+1.79 %	+2
Heat pump (ground source)	29.46 %	1	25.35 %	2	–4.11 %	–1
Biomass (CHP)	17.30 %	4	23.64 %	4	+6.34 %	0
Biomass	28.98 %	2	24.95 %	3	–4.03 %	–1

Although in the previous analysis, the criteria weights were changed equally for all four aspects, there still remained differences between the sub-criterion weights. When assuming that each sub-criterion is equally important, the result gives different individual scores but the same ranking as in the case where both criteria and sub-criteria have different weight values.

Another way how to look at the results obtained is to change the weights of the four main criteria. For example, if only economic and technical criteria are relevant for the decision-maker (possible case for an enterprise), with weights 60 % and 40 % respectively, and environmental and social criteria are not taken into account, solar PV receive the highest score in the group of electricity-generating technologies, while among heat technologies, heat pumps rank first with a very small predominance over biomass technologies which ranks second. Only small changes need to be made to the weight of the criteria to obtain a different result. For example, if in the case considered above, in addition to the economic and technical criteria, the final decision also takes into account the environmental aspect, even if only to a minimal extent (5%) thus reducing the weight of the economic criterion to 55% and technical criteria leaving with the same weight (40 %), in the group of electricity technologies, wind technologies convincingly take the leading position, but solar PV takes the third place. On the other hand, where environmental aspects are of primary importance to the decision-maker (for example, in the development of a relevant policy instrument), this aspect can be highlighted as the main one, which will lead to a different result in terms of technology ranking. Such variations show how much a small change in the weights of the criteria can affect the final result.

2.2.10. Policy recommendations

The following sub-chapters include the prepared policy recommendations and proposals in five different categories. The results of the prioritization of policy recommendations are summarized at the end of the chapter.

2.2.10.1. Legislative changes

Although according to the results of the enterprise survey, the improvements of the existing regulatory framework do not appear at the top as the most significant, it cannot be denied that any other of the incentives will not work efficiently if there remain legal restrictions. Public policy is important for increasing the role of RES in the national energy balance. Policies can be both "carrot" and "stick" oriented, but the most optimal results can be achieved if there is a balance between both of these approaches. The following are suggestions for improving the existing framework.

Expansion of the range of net payment system users to entrepreneurs. From April 2020, changes in legislation promoting RES for self-consumption in households have been adopted. This approach should be adopted in the same way for entrepreneurs. Such a change would allow entrepreneurs to install and recoup their investments in RES technologies faster, as the electricity generated on weekends, when, for example, the manufacturing plant is not in operation, could be used during working hours on a net payment system basis without paying additional mandatory procurement component. The expansion of the range of net payment system users could reduce the payback time of RES technologies, which would make their installation more attractive to entrepreneurs.

Changes in the process of energy audits in enterprises. It is well known that throughout the EU, large enterprises are required to conduct a mandatory energy audit every four years. The energy audit focuses on identifying energy flows in the company, as well as looking for potential improvements. Usually, these improvements are related to the increase in energy efficiency, although it is not excluded that the amount of energy used from RES in the enterprise is also increased at the same time. An energy audit is an excellent instrument for information about potential improvements in an enterprise to reach its management. Energy auditors are qualified professionals who, in their work process, have gained experience from different types of enterprises. They can help not only pass essential information on to the enterprise but also ensure that it will serve as a reliable basis for future investment decisions. In view of the above, the proposal is to stipulate that when performing an energy audit for an enterprise, the energy auditor not only assesses potential energy efficiency measures but also assesses the enterprise's ability to switch to RES technologies. The results of energy audits are currently one of the essential measures that work without state support to achieve energy efficiency goals. Potentially energy audits could also contribute to the achievement of RES goals.

Changes in the regulations governing the support programs. Existing support schemes limit the number of potential beneficiaries to entrepreneurs whose one of the sectors of activity is manufacturing ("C" according to the NACE classification). It cannot be denied that support for manufacturing enterprises is necessary. However, it is possible to consider an option that favours the manufacturing sector but does not prevent enterprises from other sectors of activities from applying if they have the potential (e.g., high energy consumption, obsolete, fossil fuel technologies), as the main target of such measures is to increase the share of total RES in the country. The more and more widely RES technologies are introduced, the more it will influence other entrepreneurs to make a favourable decision. In addition, existing programs often provide support for projects where RES technologies are implemented on the roofs of buildings. In this way, the useful area/land is not occupied; however, not in all cases, there are technical possibilities to install RES technologies on existing structures. There are different situations, so such restrictions are not conducive. Opportunities for efficient use of parking areas, as well as the installation of RES technologies in degraded areas, if it is technically and economically justified, should be considered.

Review of environmental requirements. It is necessary to evaluate the possibility of facilitating environmental requirements for individual RES projects. If there are problems, it is necessary to look for ways how to combine RES technologies with public interest and wildlife, not to look for excuses to prohibit the installation of new RES technologies. For example, with regard to the installation of wind turbines – yes, bird migration routes must be taken into account, but the reason for banning the installation of wind turbines, given the negative impact on birds, must be carefully considered and not used as a slogan for any installation. Studies show that the impact of domestic cats on bird death is significantly higher compared to wind turbines (Nazir et al., 2020; Trouwborst et al., 2020); however, it is not talked about publicly in Latvia.

2.2.10.2. Fiscal instruments

According to the results of the AHP, the economic aspect is one of the most important in decision-making. In the Master's Thesis, its impact is almost 49 %, so it is important to introduce measures that have a positive impact on the payback period of the project, as well as measures that ensure the availability of various funding solutions.

Real estate and corporate tax credit. Such an instrument will not be the determining factor in making a choice in favor of the introduction of RES technology, but it will have a facilitating effect. In cases where a company invests in RES projects, it is granted a tax credit.

Raising excise duties. The excise duty aims to limit the consumption of goods that are harmful to the environment and human health. Currently, excise duty is applied to oil products and natural gas. Raising excise duty could encourage a reduction in the use of fossil energy resources and incentivize the transition to RES. Until now, Latvia has regularly and gradually increased the excise tax on oil products. The last increase in excise duty took place on 1 January 2020 (VID, 2020).

Pension fund for financing "green" energy. The proposal is to create a state pension fund that would invest in RES projects, giving the opportunity to issue loans at a relatively low rate to entrepreneurs to implement these projects, and at the same time, the pension fund would have a stable long-term return. This fund could invest in RES projects of state and municipal capital companies of various sizes, as well as in private capital companies. Such a fund would be able to provide long-term loans at a low-interest rate. In this way, the state would obtain both a stable investment and an instrument for promoting RES.

2.2.10.3. Informative instruments

Taking into account that enterprises have indicated the promotion of a better understanding of technologies as one of the most important incentives for the wider use of RES technologies (17 % of respondents), several proposals in the format of informative measures have been developed. As regards AHP results, these measures can not only increase local know-how but also increase acceptability. The impact of these two sub-criteria on the final result when choosing RES technology was 10%.

Training course for enterprise energy managers and employees. One of the possible measures could be educational activities for enterprises. For example, a free training course for energy managers or employees implementing their functions in the enterprise, within which in-depth information on RES technologies is obtained starting from the idea to the project implementation. There are already good examples, which can serve as a basis for developing similar measures regarding RES. For example, an EU-funded project "Support and Training for an Excellent Energy Efficiency Performance" also involving the Latvian Chamber of Commerce and Industry. As a result of the project, the enterprises involved can be expected to save energy, as well as to understand the energy management issues better. The project has received good feedback from enterprises and, importantly, has helped them not only to understand their energy consumption better but also to successfully implement various measures to reduce it (STEEP, n.d.). Lack of information is one of the barriers that prevent or hinder enterprises from making decisions, so measures to overcome these barriers are critical.

Training course for specialists in the involved sectors. It is essential to provide knowledge for enterprises as potential decision-makers, but it is equally important to ensure qualified outsource experts who can then implement and enforce the decisions made by enterprises in practice. This includes correct technical calculations, selection of an appropriate financing solution, selection of appropriate equipment, correct installation, and maintenance of equipment if required as an outsourced service. Such training could also be organized as state-organized training courses for specialists in the involved sectors (such as bank employees, energy auditors, architects, builders, construction board representatives, and others) in order to develop a better understanding of RES technologies.

A website dedicated to RES issues. Obtaining reliable and verified information is a time-consuming process. An informative website created and maintained by a state body would provide easier access to necessary information. All up-to-date information on RES technologies, funding opportunities, support mechanisms, legislative nuances, project implementation, good practice examples, and other useful information could be published on the website. This type of information in one place would not only contribute to a better understanding but also ensure the credibility of information, reliability, and additional confidence for entrepreneurs. This would increase the understanding of RES issues and help to make a favourable decision for the implementation of such projects. Given that renewable energy is linked to energy efficiency and is equally important for an enterprise operation, such a website could also be supplemented with information on energy efficiency improvements. In addition, such a website should be supplemented with a calculation tool with the help of which entrepreneurs would be able to evaluate their options, select and compare RES technologies more conveniently, for example, development of a tool in which solar PV performance indicators are linked to the enterprise hourly electricity consumption data, to make it easier to determine the required installation capacity. The results of the AHP showed that small changes in priorities in decision-making could have a drastic effect on the end result. Such a tool could point out in a comparative way the strengths and weaknesses of each RES technology. In addition, it is important to evaluate the enterprise's energy consumption data (load graph), geographical location, building specification, preferences, and other necessary data that will serve for the future decision. At this stage, given that it would not be useful to generalize such an assessment as a tool due to various important nuances, it would be worthwhile to involve energy specialists as consultants.

2.2.10.4. Public bodies as exemplary

The action of state institutions as an example of good practice. The public bodies should act as a model in implementing various RES projects. For example, a state-owned electricity generation and the trading company could implement a long-term project – the installation of solar PV for electricity generation and transmission to the common grid. Projects of this type would increase the recognition of RES in the country and would be a good sign for entrepreneurs to think about the implementation of similar projects at their sites. They would have a shorter payback period, given that the electricity received from the grid is partially replaced by the electricity produced by RES technology. One of the largest RES projects that have promoted RES recognition at the national level is the project implemented by "Salaspils siltums" Ltd., which included a field of solar collectors, an accumulation tank, and a 3 MW wood chip boiler house. One thousand seven hundred twenty solar collectors were installed to increase the use of renewable energy in district heating (Salaspils Siltums, 2020). Contrary to a good example, on March 25, 2020, Tukums County Council decided not to accept the planned operation of "Pienava Wind" Ltd. – investing 100 million euros in the construction of the wind farm "Pienava". Unfortunately, such decisions have the exact opposite effect. According to wind industry experts, such a decision is unfavourable for the society and Latvia as a whole, taking into account the mandatory energy and climate targets set by Latvia and the EU. In this case, it is also essential to work with informing the society, because there is also prejudice or misconception about RES technologies (DELFI, 2020).

2.2.10.5. Other instruments

Transition to biomass use for high value-added products. Although historically, the use of biomass has a significant place in Latvia's energy balance, in the long run, it is necessary to slowly move away from the direct use of biomass for energy production. Instead, it is necessary to focus on the use of solar, wind, and geothermal energy, which is freely available. Biomass combustion has a high level of emissions compared to other RES technologies and has significant land use, which could be used for other purposes, such as food production. Biomass should be used in more value-added ways, such as the use of wood for wood fiber production, which clearly provides more added-value. In this way, it is possible to increase the country's competitiveness and, consequently, the opportunity to better support the use of the other RES solutions mentioned before.

Funding of science at national and transnational levels with a view to developing new technological solutions, as well as improving technology efficiency, utilization, and other energy

sector-related issues. The role of science is essential for the development of a sustainable, modern, competitive energy sector in Latvia and the Baltics. It is important that in the research process, there is cooperation with the social partners of the energy sector, research teams are formed to solve energy problems at the national and international (for example, the Baltic States) level, and knowledge and technology transfer is ensured in practice. One of the possible research directions could be related to the integration of energy storage solutions into the energy system, as capital investments decrease significantly every year, which can significantly shorten the payback period of RES. This, in turn, opens up greater opportunities for efficient use of RES not only by enterprises but also by state and local government institutions. It is essential to create a mechanism in which science, business, and public administrations work in a coordinated way to achieve a common goal – transition to the carbon-neutral energy sector in the best possible way. Although each company is individual, it may be useful to research the possibility of setting up standard RES technology implementation projects that would reduce costs and administrative burden.

Reduction of administrative burden. Facilitation of the existing procedures for project implementation, so that entrepreneurs would be able to get to practical project implementation in a more convenient and faster way. It could also include consultations of a state-paid specialist, simplification of the project development and coordination process in the necessary institutions, which would significantly facilitate the development of RES projects. In this way, it is also possible to find out the needs/concerns of enterprises and work to achieve the best possible result.

Collective marketing platform. By installing higher capacity technologies, specific costs are reduced, so it is possible to develop a platform that would bring together enterprises in the same region that want to install RES technologies (a similar approach is already implemented in building renovation in order to reduce costs). In this way, capital investment for individual projects could be reduced, as technology suppliers/installers would be able to participate in more significant procurements. This, in turn, would result in a shorter payback period for entrepreneurs. Such a principle is similar to the concept of energy communities and can be implemented not only at the level of enterprises but also at the level of individual regions, quarters.

2.2.10.6. Prioritization of policy recommendations

In the previous step, a total of fifteen policy proposals were developed in five different categories. In order to prioritize these proposals, or in other words, to better understand which measures could be implemented first, but which proposals have a lower priority and can be implemented on an optional basis, proposals were evaluated. The result of prioritization is depicted in Fig. 2.34.

HIGH PRIORITY MEASURES	MEDIUM PRIORITY MEASURES	LOW PRIORITY MEASURES
• Reduction of administrative burden • Expansion of the range of net payment system users to entrepreneurs • The action of state institutions as an example of good practice • A website dedicated to RES issues • Training course for specialists in the involved sectors • Training course for enterprise energy managers and employees • Real estate and corporate tax credit	• Collective marketing platform • Funding of science at national and transnational level • Review of environmental requirements • Changes in the regulations governing the support programs • Pension fund for financing "green" energy	• Raising excise duties • Changes in the process of energy audits in enterprises • Transition to biomass use for high value-added products

Fig. 2.34. Policy recommendations breakdown by priority

Seven recommendations received high priority, five received medium priority, and three received low priority. Some of the high-priority recommendations can be combined, at least in part (in terms of results). For example, information from training courses in video format could be published on the established RES website, as well as examples of good practice from the public sector, including news related to changes in legislation.

The full evaluation of recommendations is included in Appendix 2.

2.2.11. Conclusions and recommendations

1. Technological developments, the growing demand for environmentally friendly generated energy, and the need for a reduction of the use of fossil fuels over the last decade have left a positive impact on renewable energy technologies as the capital costs have decreased significantly.
2. Latvia has a relatively high share of renewable energy in final consumption; however, this is mainly due to the historically installed hydropower plant capacities. As regards the newly installed electrical capacities of other renewable energy technologies – there is a moderate increase in the last decade.
3. Multi-criteria decision analysis is often used in the field of energy and energy policy, including the analysis of various renewable energy technologies given the fact that it is possible to freely choose the most important criteria covering all the necessary aspects for the decision-maker, and by evaluating the performance of each alternative according to the criteria – choose the best one.
4. Mandatory procurement as a renewable energy support mechanism has failed to fulfill its purpose in a fair way and has become a displeasing topic that has created negative associations in society affecting renewable energy acceptance in society. At the same time, the acceptability of renewable energy is also affected by certain societal prejudices or exaggerated impact assessments.
5. Given the high final energy consumption in the industry and construction sector, it can be concluded that it has not only a significant role in the energy balance but also a high potential for transition to alternative energy sources.
6. A survey is a good tool to acquire the necessary information from the identified target group by formulating questions with a specific goal. The survey provides opportunities not only to evaluate the individual answers to each question but also to assess the interrelationships between the answers to different questions.

7. The choice of evaluation criteria, but even more so of sub-criteria, is critical in the process of multi-criteria decision analysis, as it can significantly affect the final result.
8. Data in the available literature for renewable energy technology characterization not only differed from one source to another, but are also not widely available, so data availability, as well as data quality, is an essential aspect that should be improved for a better and improved process of evaluation.
9. Apart from the availability of grants/subsidies, awareness-raising as a better understanding of technology is the second most frequently mentioned option by the survey respondents to help increase the use of RES technologies; therefore, it is essential to work on the development of informative measures.
10. To understand the reasons behind the reluctance to make changes in the "business as usual" model and to find solutions for the removal of barriers, as well as change attitudes and behaviour, it is important to work with enterprises. Appropriate instruments and policies need to be put in place to foster the competitiveness of enterprises and the development of a sustainable economy in general.
11. The results of the analytic hierarchy process show that the best technology for electricity generation with the highest rank is wind energy. Considering that small-scale wind technologies in Latvia are not widespread, as well as they are not so popular in comparison with biomass and solar energy technologies, the obtained result leads to the conclusion that these technologies should be paid more attention.
12. The results of the analytic hierarchy process show that the best technology for heat generation is the heat pump. Heat pump technologies have the best performance in terms of reliability as well as the lowest operation and maintenance costs compared to other technologies evaluated in the Master's Thesis.
13. Sensitivity analysis shows that unequal change of the weights of the criteria, when setting higher importance for one of the criteria, and in some cases – no or little importance for another criterion, can have a considerable change on the final result even when a small change in weights is made.
14. The highest priority during the evaluation of the policy recommendations received a reduction of administrative burden, expansion of the range of net payment system users to entrepreneurs, the action of state institutions as an example of good practice, a website dedicated to RES issues, a training course for specialists in the involved sectors, a training course for enterprise energy managers and employees and real estate and corporate tax credit. So it can be concluded that informative measures and dissemination of knowledge are one of the most important directions in which it is necessary to work with both enterprises and specialists in the field of renewable energy.

The following recommendations are suggested:

1. There is a possibility to improve the developed methodology of renewable energy technology evaluation, both by diversifying the considered technologies (for example, by detailing specific biomass technologies, different types of solar panels, horizontal and vertical wind turbines, etc.) and by choosing additional sub-criteria. The most important limitation is the availability of data.
2. It is necessary to present the prepared policy recommendations to the policymakers in order to discuss the possibilities of their implementation, as well as to carry out further research on the expected policy measure outcomes and their impact on, for example, the achievement of the mandatory target for renewable energy.

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2.3. POSSIBILITIES FOR THE USE OF RENEWABLE ENERGY IN THE SERVICE SECTOR

The role of the services sector has continued to grow in recent decades, making it one of the main drivers of GDP in both developed and developing countries (Pozo et al., 2018). The services sector includes various sectors except for the primary and secondary industries. The services sector may include, for example, wholesale and retail trade, hotel industry including accommodation and catering, information technology services, financial services, real estate, rental and business services, research and technology services, education, health sectors, social services, culture, sports and entertainment, as well as community organizations, international organizations, agricultural, forestry, animal husbandry and fisheries services (Zhang & Lin, 2018).

According to various international studies, the service sector is gradually becoming the largest sector in terms of employment (Xiao et al., 2018). It is estimated that in 2016, the services sector accounted for 65.08% of world GDP (Wang et al., 2020).

<u>China</u>

It is estimated that the service sector in China is currently recognized as the dominant sector in terms of share. In line with China's central government policy guidelines, the service sector has become a driver of China's economy. Given the development of China's services sector, emissions are also rising and, as a result, carbon reduction measures in the services sector have come to the attention of both scientists and governments (Wang et al., 2020). It is estimated that in 2017, the services sector in China accounted for 52% of GDP (Hu, Zhou & He, 2019).

Office services, which account for a significant share of energy consumption and trade in goods, are considered to be the dominant sub-sectors of the services sector (Xing et al., 2018). According to the OECD/IEA, the services sector mainly accounts for 9% of total final energy consumption and 12% of total carbon emissions (Zgang & Lin, 2018).

With regard to the share of the service sector in Europe, it has been estimated that in recent years the service sector in the EU accounts for about two-thirds of total output and four-fifths of overall growth (Voulis et al., 2017).

2.3.1. Use of renewable energy in various service sectors

Studies estimate that demand for the services sector in developed countries currently accounts for one quarter to one-third of total energy demand, depending on the country. The share of demand in the services and household sectors is presently estimated and projected to increase by up to 40% in 2050 (Voulis et al., 2017).

2.3.2. Characteristics of specific service sectors

2.3.2.1. Tourism

The tourism sector has been identified as one of the largest emitters, and thus the tourism sector has a crucial role to play in reducing greenhouse gas emissions as one of the possible solutions using renewable energy resources (Coles, Dinan & Warren, 2016).

2.3.2.2. Hotel industry

The service sector is considered to have a lower environmental impact than the industrial sector, but studies have shown that it is the service sector that generates a significant share of carbon emissions from indirect actions. It is recognized that energy consumption accounts for the largest share of costs in the hotel industry (Pace, 2016).

Given the significant energy consumption and emissions of the hotel sector, it would be necessary to think of solutions to help reduce overall energy consumption and introduce renewable energy technologies in the hotel sector. The hotel industry is recognised as having considerable potential to reduce greenhouse gas emissions by investing in renewable energy technologies to generate electricity.

Hotel buildings are estimated to be one of the most energy-intensive due to the need for continuous air conditioning, space heating and hot water supply, as well as other energy-intensive services. Therefore, the use of renewable energy is considered to be an effective way to ensure sustainable energy and reduce the energy consumption of the hotel sector. (Dhirasasna, Becken, & Sahin, 2020). Studies have shown that the implementation of appropriate energy efficiency measures in the hotel sector can reduce energy consumption by 20% or more. Studies have shown that the combined use of a combined cooling, heating and electricity (CCHP) system can significantly reduce primary consumption and improve energy efficiency.

Research has shown that from renewable energy technologies it is possible to use: various types of heat pumps, solar panels, solar energy absorption coolers, biomass boilers, micro-hydropower, as well as small-scale wind turbines. Renewable energy sources in the hotel sector can be used to provide various functions and cooling, hot water and heating, as well as lighting are considered to be the largest energy consumers (Mardani et al., 2016).

In Nepal's tourism sector, priority has been given to the provision of renewable energy - solar, wind or hydropower in the outermost and mountainous regions where accommodation is located, thus ensuring a sustainable and secure energy supply (Nepal et al., 2019).

2.3.2.3. Catering industry

The food sector is considered to be the largest consumer of energy and a source of greenhouse gas emissions. Over the last decade, the share of catering services has increased significantly, and so have emissions from the sector, because people increasingly consume food outside their homes.

The catering industry is generally divided into the catering sector or catering based on specific contracts, such as canteens in workplaces, schools, hospitals and for-profit cafes, restaurants or fast-food chains. It is estimated that the catering sector employs 600,000 people across Europe and provides around 6 billion meals each year.

The most crucial sectors with the most significant amount of food resources are the health sector (42.7% of all meals served), followed by the education sector (31.4% of all meals served) and business and industry (17.8% of total meals served) meals). Catering service is determined as a sector where significant environmental improvements can be achieved in the public sector (Mistretta et al., 2019).

2.3.3. Possibilities for the use of solar energy in the service sector

In recent years, solar energy has been used more and more in the service sector. Based on information available in publications, solar energy is used in the tourism sector, office service buildings, as well as information on the use of solar energy systems in public institutions, including for the provision of heat and electricity to schools (Navratil et al., 2019).

2.3.3.1. Possibilities of using solar panels and solar collectors

Tourism industry

<u>Renewable energy options in "green" hotels</u>

The tourism sector is recognised as one of the primary energy consumer and hotels are responsible for a significant share of energy consumption and carbon emissions in the tourism sector. The guarantee of high comfort and quality of hotel services results in high energy and water consumption. Energy consumption in tourism is higher than elsewhere and varies depending on the region and visitor structure. Hotel buildings consume more energy than other types of public buildings. It is estimated that hotels and other accommodation have a high potential to become ideal alternative energy sources. Combined renewable energy sources are often used in accommodation, combining the potential of different energy sources (Navratil et al., 2019).

Hotel operators are advised to reduce electricity consumption by implementing energy management programs based on technology-saving energy-saving devices. Energy-saving kitchen equipment and renewable energy technologies can be used in hotels to reduce energy consumption, and low-flow showerheads can be used to save water. It has been estimated that solar collectors can be used in hotels for hot water production, swimming pool heating and cooling (Chan, Okumus & Chan, 2020).

Chan et al. (2008) in southern China studied solar control window film as an energy-saving device in hotels (Coles, Dinan & Warren, 2016).

Hotels are one of the most energy-intensive types of buildings. The Pacific Gas and Catering Services Center (FSTC) found that "hotels are the world's largest energy consumers." They consume almost five times more energy per m_2 than any other commercial building, producing nearly 490 tons of carbon dioxide per year per restaurant (Aomar & Hussain, 2017).

Green hotels using solar energy

Hotel customers are increasingly demanding “green” hotels, which incorporate environmental ideas and opportunities into their design and pay even more for green products and services (Chan, Okumus & Chan, 2020).

The hotel industry uses solar energy technologies from renewable energy sources, and in particular solar PV panels for electricity supply and solar water heating systems. Currently installed technologies often combine photovoltaic energy with water heating using solar energy technologies (Navratil et al., 2019).

The study estimated that people prefer and accept solar panels installed on the roof rather than those installed on the ground. Compared to other renewable energy sources, solar - land panels were assessed by the public as the least desirable (Fig. 2.35).

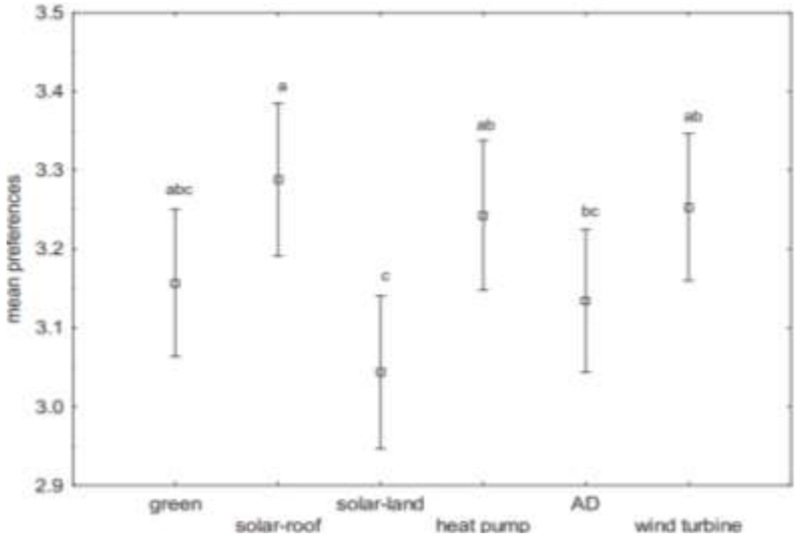

Fig. 2.35 Renewable energy technologies depending on consumer choice (Navratil et al., 2019)

Greece

According to the requirements of Greek national law, at least 60% of the required hot water in all new or refurbished buildings is supplied by solar energy systems. The share of renewable energy in service sector buildings in Greece was estimated at 27% in 2015 and is projected to reach 39% in 2020.

EPC mechanism in Greece

Energy Performance Contracting (EPC) is a mechanism that offers an integrated end-user solution, including the planning, financing, installation and monitoring of renewable energy systems. The EPC mechanism enables the end-user to take energy efficiency and renewable energy measures without investing in equipment.

Greek EPC projects are linked to national or European Union projects targeting schools, local administrations, the healthcare sector, hotels and various companies in the industry. EPC projects evaluated solar PV panels for electricity generation, as well as solar collectors for hot water production and heat pumps as the most common types of renewable energy sources.

The study assessed the energy-saving potential of three sub-sectors in the service sector using solar energy technologies as an energy source. The study examined renewable energy, energy efficiency measures, including installation of solar PV panels, heat pumps, as well as assessed EPC potential. Three pilot studies were conducted in Crete and Athens, representing these Mediterranean regions (Frangou et al., 2018).

Family hotel complex

The first case viewed was a hotel with seasonal summer activities, consisting of seven buildings and an accommodation capacity of more than 300 beds and services such as swimming pools, pool bars, restaurant, market place, playground, conference hall, respectively. The study used a 50 kWp photovoltaic installation placed on the roof, also using EPC mechanisms, which allowed the hotel complex to save up to 21% of electricity consumption, the payback period of the investment was five years. The annual energy savings using solar PV panels were calculated up to 75,000 kWh/year. (Frangou et al., 2018).

Fig. 2.36. Distribution of service consumption in a family-type hotel complex

Recreation complex

The second case was a complex of 15 buildings that acted as a resort and resort hotel with a capacity of 1,036 beds. The recreation complex included several services, such as a spa centre, five heated swimming pools, restaurants, bars, kids' club. Fig. 2.37 show the energy consumption required in the complex. As in the first case viewed, one of the first measures was to replace biomass and oil burners or, in the case of biomass, to be partially replaced by heat pumps to ensure cooling function and hot water preparation requirements.

The results showed that due to the change in technology, the electricity consumption required for cooling processes was saved by 30%, while the hot water consumption was reduced by 89%. In combination with a heat recovery system, it has been estimated that this solution reduced biomass consumption for hot water by 70%.

The second renewable energy measure considered in the study was the installation of a 50 kWp PV solar energy system on the roof of the complex, as in the first case with a hotel complex. It should be noted that the recreation complex already had existing solar panels of 144 m^2, which was able to cover approximately 22,5% of the required hot water demand. The study estimated that by installing additional solar panels in the area of 170 m^2, it was possible to cover 50% of the hot water demand required by the complex (Frangou et al., 2018).

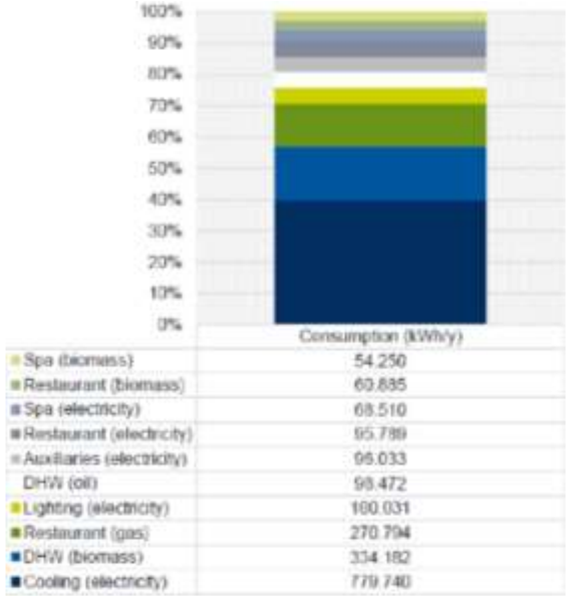

Fig. 2.37. Distribution of service consumption in the recreation complex

Office service buildings

The third case in the study was a relatively new type of office service building built in Athens after 2008 using the basic principles of bioclimatic architecture. Concerning the mentioned building, the goal was set to achieve the status of an almost zero energy building by 2020 using RES technologies. An office building consisted of several units that require the use of electricity, such as elevators, server rooms, refrigeration equipment, lighting, ventilation, IT technology, etc. (Fig. 2.38) In order to achieve the goal set, the installation of solar PV panels on the roof was evaluated, the installed capacity was 64 kWp (Frangou et al., 2018).

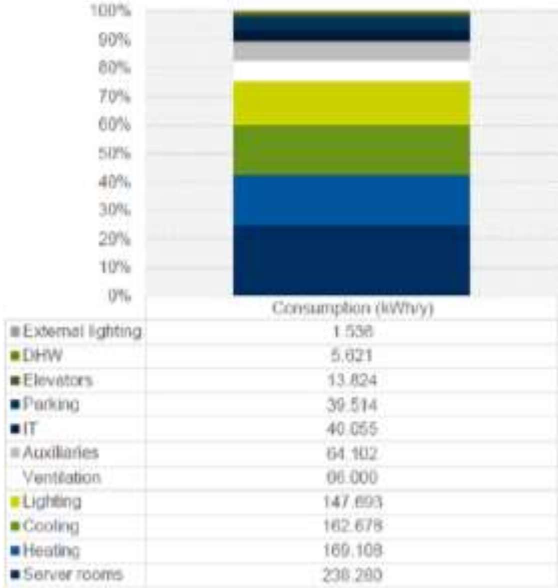

Fig. 2.38. Distribution of service consumption in an office type building

According to the study, the energy savings after the installation of solar PV panels were 86,700 kWh, which corresponds to 11% of the total annual energy consumption with a payback period of 6 years. Table 2.27 showed the amount of energy saved in the three cases considered.

Table 2.27

EPC scenarios for RES measures installations in the pilot buildings

Building	Pilot case 1 - Family resort hotel	Pilot case 2 – Resort & spa hotel			Pilot case 3 - Office building
Measure description	50 kWp rooftop PV system	50 kWp rooftop PV system	60 heat pumps with heat recovery	170 m² of additional solar thermal panels	64 kWp rooftop PV system
Annual energy savings (kWh)	75.000	75.000	1.191.820	18.000	86.700
Investment (€)	57.500	57.500	300.000	46.500	74.000
Economic savings (€/yr)	10.500	10.390	73.170	18.500	10.580
% economic savings (on yearly energy costs)	17	3	23	5	10
Investment cost (€/kWh saved during the system lifetime)	0.04	0.04	0.03	0.02	0.04
Investment cost (€/kg CO_2eq saved during the system lifetime)	0.03	0.04	0.03	0.03	0.04
Loan percentage		60%			
Interest rate		4.9%			
EPC loan repayment term (yrs)	12	12	10	10	12
EPC project duration	12	12	10	10	12
Client shared savings		5%			
Project rating	A	A	A	A	A
IRR[a] (%)	19.8	19.5	28.1	52.8	15.0
NPV[b] (€)	15.729	15.313	131.280	53.564	11.122
Discounted payback (yrs)	5.0	5.0	4.0	3.0	6.0
Min DSCR[c]	1.9	1.9	2.4	3.6	1.5
Average DSCR	2.8	2.8	3.2	5.2	2.2

Overall, the study estimated that savings of between 3% and 23% of total annual energy costs could be achieved, depending on the measure taken and the type of building. Also, depending on these factors, it was estimated that the amount of investment could be recovered in 3 to 6 years (Frangou et al., 2018).

<u>Educational sector</u>

One study in South Africa evaluated the use of a simplified method for optimizing hybrid renewable energy systems in schools. In research, the energy use of school buildings was evaluated (Gerber, Rix & Booysen, 2019).

In South Africa, the largest state budget is allocated for public education, which was 240 billion in 2018. Almost 75% of the allocated budget is allocated to compensation of employees, while less than 10% is allocated to subsidies and infrastructure for the construction of new schools. It is estimated that this part could be channelled to the deployment of renewable energy technologies, such as solar and smart technologies, as well as smart grids.

A South African study evaluated the use of solar panels in combination with a smart schedule, load reduction to reduce grid energy consumption, carbon emissions, peak load and the school's electricity bill. A South African study evaluated the effectiveness of several energy-saving methods (Gerber, Rix & Booysen, 2019).

2.3.3.2. Smart schedule and use of solar PV panels

According to the study, a smart schedule should balance the need to limit water heater losses with the need to ensure hot water supply while diverting excess solar energy to electric water heaters (Ewhs).

Smart schedule combined with solar PV panels and bi-thermostat

Using this method, in addition to the smart schedule, a bi-thermal heating mechanism (BiTherm) was implemented in combination with solar PV panels. Electric water heaters were heated to different temperatures, allowing solar energy to be diverted to electric water heaters if excess energy was accumulated from the obtained solar energy. The bi-thermostat heated to 50 ° C provided heat for transmission in the grid and 90 ° C providing heat using excess solar energy (Gerber, Rix & Booysen, 2019).

Demand limitation combined with solar PV energy and bi-thermostat

Demand limitation combined with solar PV energy and a bi-thermostat was evaluated as an effective energy-saving method that controls electric water heaters so that they do not affect the total maximum monthly energy consumption of the building. The energy-saving methods considered in the study shown presented in Table 2.28.

Table 2.28

Energy-saving methods

Energy saving intervention	Prioritised heating	Excess solar dumping	Schedule Control	Bi-thermostat	μGrid demand limiting
Thermostat-control	✗	✗	✗	✗	✗
Smart-schedule control and solar PV	✓	✓	✓	✗	✗
Bi-thermal control and solar PV	✓	✓	✓	✓	✗
Demand-limiting control and solar PV	✓	✓	✗	✓	✓

Results of the simulations used in the study case

The study performed modelling using solar PV panels using the System advisor model developed by the National Renewable Energy Laboratory. For solar PV simulations, 110 modules with an installed capacity of 35,2 kWp were selected, ensuring the highest cost-benefit ratio. According to the results of the study viewed, the cost of the installed solar energy system was estimated at USD 30,750, but the school's annual cost of energy consumption was reduced by 24% (USD 15,859) without even using a smart schedule for water heater operation planning (Gerber, Rix & Booysen, 2019).

The study estimated that using electric schedules for electric water heaters, additional improvements for reducing utility bills from electric water heater planning were as follows:

1. Annual energy costs were reduced to $ 15,558 using solar energy system and water electric heaters prioritization scheduler.
2. In the control systems of electric water heaters using network heating and solar thermal energy, the annual utility service cost was 15093 USD.

3. Using the demand-limiting control scheme and limiting the maximum energy consumption of electric water heaters, the utility cost savings were $ 14,671 per year, which was 30% less than the initial school costs, while also reducing projected carbon emissions to 78 tons of CO_2 per year.
4. The study estimated that by making optimal use of solar energy, the maximum energy consumption per month, with minimal solar energy losses, was reduced by 24%.
5. The smart planner was tuned to heat the water necessary by the school, while shifting the excess solar energy to the water heaters to take advantage of the stored energy potential, further increasing the school's energy bill savings to 26% per month (Gerber, Rix & Booysen, 2019).

2.3.3.3. Concentrated solar heating systems

In the case of using solar energy systems, it is possible to achieve medium and high temperatures suitable for electricity generation, industrial use, hot water production or cooling, as well as use for desalination. Concentrated solar thermal system technologies are based on direct solar radiation.

It is estimated that four types of solar energy technologies are currently used on a commercial scale: parabolic tube, linear Fresnel-type collectors, solar disks and central receivers. Recently, parabolic trough-type collectors are recognized as the dominant solar energy technology. Parabolic trough-shaped collectors can be defined as concentrated linear systems that concentrate direct sunlight or sunlight on the receiver tubes. A liquid with a high heat storage capacity is circulated through the pipes, which collects solar heat energy (Drosou, Kosmopoulos & Papadopoulos, 2016).

2.3.3.4. Office services

Greece

Greece is recognized as having a high potential for the use of renewable energy sources because of its favourable climatic conditions. Greece is rated as one of the leading countries in the use of solar energy systems for hot water using solar collectors - mainly flat plate collectors with storage tanks. It is estimated that Greece has solar cooling systems with a total installed cooling capacity of around 1,500 kW. It is also estimated that the building sector in Greece is the most intensive, consuming more than 66% of the final energy produced.

The study evaluated the introduction of an integrated solar cooling system using parabolic low-solar collectors for cooling office buildings in Greece, Athens and Thessaloniki. Solar cooling systems can be used alone or in combination with traditional cooling systems (Drosou, Kosmopoulos & Papadopoulos, 2016).

Parabolic solar collectors, as well as a two-stage steam cooler with a nominal cooling capacity of 1.163 kW, were used in the study as solar energy technologies for office building. The study used modelling techniques to assess the thermal "behaviour" of a building with the aim of developing annual building energy consumption forecasts for the cooling process from April to October, which is usually the traditional cooling period for office buildings.

The office building in Athens used flat plate collectors and a solar-powered single-stage cooler to provide cooling functions. According to the modelling results of the study, it was obtained that the heat energy capacity of the parabolic collector per m^2 was 755.7 kWh/m_2 (Drosou, Kosmopoulos & Papadopoulos, 2016).

2.3.3.5. Opportunities for energy recovery from wastewater

Other energy options using solar energy technologies include the recovery of heat from wastewater, which is mainly already treated. Heat pumps are used to recover energy from wastewater and electricity is generated from solar PV panels (Power, McNabola & Coghlan, 2014).

2.3.4. Opportunities for the use of wind energy in the service sector

Compared to other renewable energy sources for wind energy in the service sector, the publications contain a small amount of information, which could be primarily related to the fact that the service sector is the public sector, while wind energy is associated with the installation of wind turbines. There are controversial views among the relevant target groups related installation of wind turbines. The study has estimated the use of wind energy as an energy source in the service sector based on energy production can provide efficient energy production and in some cases wind energy technologies are assessed as more advantageous compared to the use of solar energy. The disadvantages of wind energy use are related to energy interruptions in conditions of insufficient wind, however the use of wind energy in combination with other sources of renewable energy that can compensate for shortages or build storage systems can be used as an effective solution.

The most information on the possibilities of using wind can be found in the tourism sector, where wind energy technological equipment often also serves as a tourist attraction object, especially on the coast (Navratil et al., 2019).

2.3.4.1. Possibilities of using wind energy in the tourism sector

Wind energy as an energy source is often used in hotels and guest houses, which focus on sustainability in their thinking. Similarly, "green" tariffs use "green" tariff energy - hotels use electricity from the grid, which is obtained from renewable resources, which often wind energy (Navratil et al., 2019). It has been estimated that wind farms in themselves can attract tourists and promote the development of the tourism industry (Smith et al., 2018). Wind turbine generators are considered to be the "greenest" way to generate electricity on tourist-filled coasts, even if wind speeds are moderate (Navratil et al., 2019).

2.3.5. Possibilities of using geothermal energy in the service sector

The possibilities of using geothermal energy can be divided into two main types - for electricity generation, where the required temperature is above 150 ° C and for heating, where the corresponding temperature is below 150 °C. Additional geothermal energy in the recreation sector is used for therapeutic purposes. According to the type of methods used, two heat production methods are mainly used - open and closed-loop systems (Galgaro et al., 2015).

2.3.5.1. Tourism sector

<u>Italy</u>

Eugene thermal pool is assessed as one of the most significant thermal and mud treatment sites in the world. More than 250 hotels offer hospitality to more than 3 million tourists each year. Almost every hotel and spa has a geothermal well, which is located at a depth of about 50 to 200 m underground, providing hot water production at a temperature of 60-87 ° C.

Abano Terme is rated as an impressive complex in Italy, consisting of more than a hundred hotels and resorts for health and recreation. *Abano Terme* building complex uses a closed-loop geothermal system to provide heating. It is estimated that considering that the minimum temperature at which the obtained thermal water can be used for therapeutic purposes is around 60 degrees, the *Bornholm* heat exchanger unit analysed in the study is a suitable and sustainable solution for use in hotel spas.

The results of this study showed the potential and high sustainability of *Bornholm* heat exchangers for heat supply in various parts of the world with shallow geothermal anomalies, such as the *Euganean* thermal basin (Galgaro et al., 2015).

2.3.5.2. Thermal pools

Geothermal waters can be used for tourism and recreation. Recreation and tourism are the other most common uses of geothermal water after heat and energy production. Due to the balneotherapeutic potential of geothermal pools, 25% of them are used in bathing and healthcare facilities worldwide. The World Energy Council has stated that the use of geothermal resources in spas and balneology (therapeutic geothermal water treatments) in 75 countries is a business worth about $ 50 billion. This study focuses on the geothermal resources used in Polish spa recreation centres and tourism infrastructure.

It is recognized that tourism based on geothermal energy is considered a crucial part of local development. Municipalities with geothermal spas highlight the importance of job creation and the contribution to the local budget determined by the services offered and the new specialization of tourism. The introduction of geothermal centres promotes the socio-economic development of the municipality (Kurek et al., 2020).

<u>Poland</u>

In Poland, geothermal recreation centres are the second most common use of resources after energy supply. In Poland, in 2018, there were 15 geothermal water parks, which were either created next to municipal geothermal facilities or companies with their infrastructure. Geothermal resorts form a local tourism potential as an additional function (Kurek et al., 2020).

2.3.5.3. Possibilities of using thermal sources

Geothermal energy, compared to other renewable energy sources and technologies, is an energy resource with the main advantage of uninterrupted availability 24 hours a day.

<u>Serbia</u>

Serbia is one of the 36 leading countries in the world in terms of geothermal energy capacity. In order to achieve the European Union's target of 27% renewable energy in electricity generation by 2020, the use of geothermal, renewable energy sources should be particularly encouraged in the *Kopaonik* tourist region and similar regions which can be defined as thermal sources abundant. It is estimated that geothermal energy in Serbia is used in the amount of 104,5 MW, respectively 1714 TJ/ year. Of these, 24,1 MW were attributed to the *Pannonian Basin*.

It is estimated that in 2013, a total of more than 700 heat pumps with a total capacity of 11 MWt were installed in Serbia, corresponding to 88,45 TJ/year. They are mainly used for heating commercial and residential buildings in cities such as Belgrade, Novi Sad and Nice. The main uses of geothermal energy in Serbia are balneology and recreation. There are 59 spas in Serbia that use thermal waters for balneology, sports and recreation.

There are about 240 natural thermal springs in Serbia with temperatures above 15 °C. 90% of all thermal springs are located up to 600 m above sea level. Geothermal energy is mainly used to heat rehabilitation centres (*Vranjsk, Nishk, Ribarsk and Sirejinsk spas*) and hotels (*Vranjsk, Nishk, Ribarsk and Prolom spas*). The springs with the highest temperatures are located in the Vranjsk Spa (96 ° C), the *Jošanička Spa* (78 ° C), the Helyrinsk Spa (76 ° C), the *Kursumlij Spa* (68 ° C) and the Novopazarska Spa.

The *Kopaonica t*ourist region has many thermal-mineral springs with temperatures ranging from 21 to 78,7 ° C. The main aim of the study viewed was to determine the capacity, heat and energy potential of 19 thermal springs in four spas in the region of *Kopaonica*, in Poland. The thermal potential of the thermal springs in the *Kopaonika* tourism region has been assessed as significant. The total calculated heat energy was 758,51 TJ/year, while the heat energy capacity was 24,1 MW. It was estimated that thermal sources in the region accounted for 9.06% of the assumed geothermal energy potential in Serbia and 7.53% of thermal energy, which can reduce CO_2 emissions and has a positive impact on the quality of the environment. The study estimated that the use of geothermal energy has the potential to reduce heat energy costs, as well as ensure a stable electricity supply (Ristić et al., 2019).

According to the results of the study, the total calculated thermal energy capacity of all thermal waters was 24,1 MW, ranging from 0,49 MW to 8,43 MW. The total calculated heat energy was 758,51 TJ / year, ranging from 14,13 TJ / year to 265,91 TJ / year. The overall flow of thermal springs in the *Kopaonika* tourist region was about 195,8 kg/s. Compared to the total geothermal energy used in Serbia, the thermal sources in the region accounted for 44.25%. Compared to the heat used, they accounted for 23,06% (Ristić et al., 2019).

Thermal waters with temperatures ranging from 64 °C to 67 °C were able to heat two hotels and rehabilitation centres in the Lukovsk Spa. It was estimated that one of the possibilities is to heat hotels and rehabilitation centres near thermal springs in the cold season. This would provide many benefits that would reduce heating costs as well as improve the ecological image and market performance of tourist spas (Ristić et al., 2019).

2.3.5.4. Swimming pools

Geothermal energy accounts for less than 1% of global energy production. Geothermal water is used for a variety of purposes depending on the water temperature, including electricity generation, which is the primary use for high-temperature geothermal resources (>120 °C). It is estimated that renewable energy technologies can be a cost-effective solution for swimming pool heating, which can otherwise lead to high costs due to high energy demand.

Low enthalpy geothermal stations do not require special environmental conditions and store heat energy in the depths of the earth. In winter, heat is transferred to the surface, while in summer, excess heat from buildings is injected into the ground. By using geothermal heat pumps, heat energy can be used directly, with the coolant exchanging energy with ground heat energy.

Combined systems - geothermal energy can be combined with solar PV panels that produce the energy needed for the heat pump. Even solar PV energy can be used to cool buildings with the heat pump running in reverse.

Swimming pool heating costs can be reduced by using an active system based on renewable energy sources. The period of payback can be less than five years (Barbato et al., 2018).

Italy

The swimming pool, located in the Campi Flegrei area (Naples area, Italy), is powered by geothermal energy. Campi Flegrei is considered to be a very advantageous and suitable place for the installation of geothermal technological equipment at low or medium temperatures. The specific swimming pool is located in the south of Italy, and the geothermal system has low and medium enthalpy. The possibilities of using the geothermal extraction potential were assessed using a combined geothermal pump or energy generator. The main advantage of using the system was related to the low environmental impact. (Barbato et al., 2018).

2.3.5.5. Use of geothermal energy in cooling processes

Greece

A study in Greece assessed the cooling and heating possibilities of an office building in Athens built-in 2008 based on the basic principles of bioclimatic architecture. Several energy efficiency and renewable energy measures were taken in the building, such as providing cooling using a geothermal energy source (Barbato et al., 2018).

2.3.6. Possibilities of using hydropower in the service sector

Concerning hydropower use, it is recognized that, overall, hydropower accounts for approximately 25% of the total share of renewables globally, with China, Africa, Latin America and South-East Asia having the most considerable estimated hydropower potential. The overall market potential for economically viable hydropower projects is estimated at 9500 TWh (Hauer et al., 2018).

It is estimated that currently about 17% of all electricity produced is based on water resources and about 70% of water is used as a renewable energy resource. Hydroelectric power generation ensures sustainable energy consumption without contributing to greenhouse gas emissions, and its use has been assessed with low operating and maintenance costs (Alam et al., 2017). Nevertheless, with regard to the service sector, the publications contain a small amount of information on the use of hydropower resources in this sector, which could be primarily related to the human factor and their perceptions of adverse effects on the environment.

2.3.6.1. Possibilities of using hydropower

Hydraulic turbines are often installed in existing hydropower plants, and their use can be multifunctional. Hydropower can also be used with other renewable energy sources. For example, solar collectors with a capacity of 10 kW, 10 kW hydropower turbines, as well as 25 kW heat pumps were used as energy sources in the Korean industrial processing plant. It was estimated that the hydropower plant accounted for about 0,75% of the total energy required in the industrial processing plant and saved about 32 tons of CO_2 /year.

The Nona plant in Switzerland, which provides industrial services, initially installed hydropower turbines that provided 220 kW. The hydroelectric power plant was initially designed with a flow of 0,24 m3/s, taking into account the increase in the number of visitors and changes in visitor amount during the winter months. The new turbine was designed at a speed of 0,1 m^3/s, resulting in a 45% increase in electricity production (Power, McNabola & Coghlan, 2014).

2.3.6.2. Energy recovery from wastewater

Study evaluated the potential for kinetic energy recovery from wastewater using micro-hydropower turbines in wastewater treatment plants (Power, McNabola & Coghlan, 2014).

2.3.6.3. Small-scale hydroelectric power stations

Small-scale hydropower is increasingly seen as a green solution, with low environmental impact and a short payback period compared to other technologies (Manders et al., 2016).

<u>Island</u>

It has been acknowledged that Iceland has seen a rapid increase in tourism in recent years, as well as faster rate of electricity consumption. The study assessed options for the development of hydropower plants in two locations in Iceland, Villinganes and Skatastajir. The aim of the study was to evaluate the potential impact of three power plants on recreational opportunities and tourism development.

On the eastern side of the country is one of the largest hydroelectric power plants in Iceland - Kárahnjúkavirkjun.

According to the results of the study, including the survey, the majority of respondents highlighted the possible negative impact of hydropower plants on the natural environment, which could be expected to have an adverse effect on tourist activity in the region (Burns & Haraldsdóttir, 2019).

2.3.7. Possibilities of using biomass in the service sector

Biomass can be used to provide heat. In the service sector, this renewable energy source is mostly used in the catering sector, where the surplus generated by catering companies can be used for energy production.

Portugal

The quality and structure of biomass used in thermal power plants in Portugal are variable, mainly forest residues from forest management services are used (Matias, Catalão, 2017).

2.3.7.1. Catering sector

China

Considering the growing food consumption, food waste management possibilities and prospects for future, the Chinese government is increasingly pursuing policies and legislation to promote the widespread use of food waste from restaurants by reducing the amount of food waste and providing its use for energy.

Restaurant waste accounts for about 50% of all food waste in China. Based on 2014 data, it was estimated that around 40 million tons of restaurant waste were generated this year. Taking into account that along with the increase of welfare, the consumption of food also increases, as well as taking into account the population of China, alternative solutions are becoming more and more important, including using renewable energy sources. China's National Development and Reform Commission conducted pilot projects in 100 cities to implement restaurant food waste treatment.

According to the information in the reviewed publications, by the end of 2015, it was planned to introduce 242 restaurant food waste treatment facilities with the aim to reach a 50% waste treatment level, which means that 50% of the generated waste can be treated (Clercq, Wen & Fan, 2017).

Studies provided information on food waste treatment facilities in Beijing, Suzhou City, Jiangsu Province, and Haikou City, Hainan Province (Clercq, Wen & Fan, 2017).

Beijing Kitchen Waste Treatment Project.

Within the framework of the project, a biogas production plant with a kitchen waste treatment capacity of 200 tons per day was installed. It was estimated that the average biogas production (73,7% of the designed production) reached 73,000 m^3 per year (Clercq, Wen & Fan, 2017).

2.3.7.2. Biomethane extraction

Hainan biogas plant

In the Hainan project, various organic wastes were used as raw materials in the biogas plant. Household sludge, sugar cane residues, bananas, rice straw and food waste from the catering sector were used together with livestock manure. The designed capacity of the plant was 500 tons per day.

Biogas from organic waste was treated and used as a vehicle fuel. The Hainan, waste treatment plant, was the first pilot project to assess the efficiency of adding food waste to other feedstocks, as well as the potential use of the resulting biomethane in vehicle fuels. Pig manure, sewage, sugar cane residues, alcohol production waste and other waste (including food waste) accounted for 21%, 12%, 35%, 12% and 20% of the total amount of these raw materials, respectively. The waste treated in the plant was converted into 10.500.000 Nm^3 / year (30.000 Nm^3 / day) in biogas, which was further processed (up to 5.250.000 Nm/year (15.000 Nm^3/day)) to obtain biomethane with 97% CH_4 content.

Each tonne of waste consisted of 123.5 Nm^3 of biogas or 61.7 Nm^3 of biomethane. It was estimated that at the Hainan waste treatment plant, organic waste could be used for biogas, biomethane production and digestate sales. Biomethane can be used as a vehicle or as a gas for cooking.

The study discussed above estimated that 86% of respondents were interested in improving food waste management and that biogas conversion to biomethane quality properties may be the most cost-effective option for biogas plants in China (Clercq, Wen & Fan, 2017).

2.3.7.3. Sewage management services

Biofuels from biomass can also be used as an energy source for wastewater treatment, for example, biodiesel generators can provide the necessary energy for pumping and treating wastewater (Power, McNabola & Coghlan, 2014).

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2.4. RENEWABLE ENERGY USE POSSIBILITIES IN THE HOUSEHOLD SECTOR

It is estimated that business and household initiatives on climate change will play an important role and that concrete measures in these sectors could reduce carbon emissions by one billion metric tonnes per year over the next decade. In order to effectively reduce carbon emissions, it is necessary not only to choose the right technologies by choosing technologies with high energy efficiency but also change people behaviour to promote the introduction and appropriate use of technologies. (Chen et al., 2020).

Households have become one of the most important sectors for achieving sustainable development. The household sector makes a significant share of total energy consumption worldwide and, as a result, alternatives to reducing energy consumption and meeting climate change targets are becoming increasingly important. The household sector accounts for about 25% of total energy consumption in the United States, 26% of total consumption in Japan, half of the total consumption in Saudi Arabia and the household sector, 39% in Sweden and 40% in Guinea (Camara et al., 2018).

2.4.1. Smart systems

One of the alternatives for reducing energy consumption and ensuring sustainable energy is to use smart technologies in combination with renewable energy sources, often, for example, together with solar energy systems. Smart systems also serve as a solution to reduce the frequency of solar or wind energy, for example and can include both smart meters and smart grids.

A smart energy system is a cost-effective, sustainable and secure energy system in which renewable energy production, infrastructure and consumption are integrated and coordinated through energy services, energy end-users and technologies. Such systems would ensure the sustainable and efficient use of resources in households, as well as the integration of locally produced energy resources in real-time and provide feedback on household energy consumption (Hall & Foxon, 2014).

2.4.1.1. Smart meters

The European Commission's Directives 2006/32 / EC on energy end-use efficiency and energy services and 2009/72 / EC on common rules for the internal market in electricity have ensured that smart systems continue to evolve. The data provided by smart meters, together with the development of building energy management systems and building management systems, open up opportunities for new energy supply and service business models, as well as closer relationships between utilities, service providers and consumers (Hall & Foxon, 2014).

<u>Sweden</u>

It is estimated that Sweden was one of the first countries in Europe, introducing large-scale smart meters. Consequently, it has been possible to analyze in detail the implementation of such systems. Anders Nilsson et.al. In its study, HEMS assessed the impact of smart meters on household energy consumption across Sweden. HEMS is a home energy management system that enables enhanced monitoring and control of household energy consumption through smart home features and real-time feedback on energy consumption through home displays. Previous studies in Sweden have shown that energy feedback can save approximately 5-15% of energy, depending on its content, frequency and design. The above study looked at HEMS with a household display, with the following features:

- The display is able to show the current consumption of electricity, hot water and heating, plus historical comparisons for the relevant period (hour/day/week/month) and comparisons with other households of a similar size.
- Smart lighting. Remote control of room lighting (on/off / dimming).

- Smart plugs: Each household has two smart plugs that can be connected to appliances to monitor and control (on/off) the energy consumption of the appliances.
- Smart Washer / Dryer: Allows you to schedule washer/dryer sessions.
- Start / Absence switch: to turn on / off all lighting and smart plugs at the same time (Hall & Foxon, 2014).

A simplified version of the home display is available from a mobile phone. The HEMS system also offers additional information and functions outside the scope of this study, including - planning functions for charging electric vehicles; monitoring of solar energy production from roof solar PV panels (Hall & Foxon, 2014).

The target group of the study was the "best-case scenario" of households with an income an above-average level of education. The survey revealed that there are two main motivators for energy consumption - economic savings and the desire to be more environmentally friendly. The real-time consumption comparisons displayed on the displays were judged to be too complicated for users: when participants were asked to explain and interpret these meters, none of the interviewees answered completely correctly. Only one of the interviewees, who worked as an engineer, considered the display design to be completely understandable, while the others considered the displays to be too complex to design and unsuitable for everyday household use. It was concluded that the interviewed users responded to the video system by changing their behaviour in two ways: a direct response to current consumption values (i.e. real-time feedback) and informed decisions based on the feedback provided over a period of time (i.e. historical comparisons). In addition, the direct response was much more common (Nilsson et al., 2018).

Another component of smart energy systems for households is smart grids. It is estimated that smart grids are able to promote sustainable RES integration and implementation of the microgrid concept (Hakimi et al., 2019).

2.4.2. Producing consumer

A new concept has entered the energy sector: the productive consumer, which refers to small-scale end-users using electricity from the grid, produce energy for their own use and feed it back into the electricity system. Such a principle is often considered more appropriate than complete disconnection from the centralized electricity grid, as it provides a greater sense of stability, allowing consumption to be covered even when local production is insufficient or disrupted, and making a profit from selling surplus electricity generated in the grid. Households, as consumers of renewable electricity, can play a variety of roles, such as promoting decarbonisation, decentralizing the energy system, and involving new groups of players in the energy market, which can contribute to a significant change in the future. Germany launched a pilot subsidy scheme for small-scale PV in 1990, aimed at the first households to be categorized as productive consumers.

Other countries, for example the United Kingdom and Norway, later launched support programs. Norway started supporting productive consumers in 2011. The growth curves of the number of productive consumers in Germany, the United Kingdom and Norway were similar - slow start and relatively rapid growth thereafter (Inderberg et al., 2018).

2.4.3. Use of solar energy in households

The use of solar energy offers several essential benefits, such as reduced CO_2 emissions, diversification of energy supply and regional/national energy independence. The two most common uses of solar energy in households are solar PV panels for electricity generation and solar collectors for heat generation (Inderberg et al., 2018).

2.4.3.1. Electricity generation in households using solar energy technologies

Lately, solar PV panels have been increasingly installed on the roofs of private houses. Private households are increasingly generating electricity at home, taking advantage of technological advances and falling prices. A study on the use of solar energy in household electricity generation as productive consumers by three of the most developed economies in the EU, Germany, the United Kingdom and Norway, concludes that:

- A stable support scheme addressing the price of electricity fed into the grid is emerging as a critical factor in motivating the generating consumer. (based on the German and British examples). Preliminary evidence from Norway also shows that low economic support has resulted in a small number of productive consumers. Production in Norway has also increased in recent years. Reducing the prices of PV solar panels can help reduce the need for economic support, although Norway's low electricity prices have been shown to work in the opposite direction.
- Third parts - technology installers, providing knowledge, advice, technical solutions and facilitating legal procedures - act as catalysts for the process.
- All three countries considered followed the following steps:
    - launched technical testing and pilot schemes to help reduce (local) bureaucratic barriers.
    - Created a market for third-party installers, reducing transaction costs for potential consumers.
    - The last and less pronounced step was the transition to a mass-market where freely available services such as the installation of solar PV panels offered by several companies compete with each other and further reduce transaction costs for potential consumers (Jackson et al., 2018).

The study found differences between Norway and the other two countries, as Norway already generates electricity from RES and has low electricity prices, so household PV will not help increase the share of RES and pay off more slowly (Inderberg et al., 2018; Ghaith et al., 2017; Tervo et al., 2018).

2.4.3.2. Heat production using solar energy

The integration of solar thermal devices into building constructions is currently evolving rapidly as engineers, architects and individual consumers become more interested in renewable energy sources. This is mainly due to global warming and the need to replace traditional energy sources with renewable energy sources.

<u>Central Europe</u>

Solar collectors can be integrated into building structures in various ways, for example, as a facade element or on the roof or balcony. A Balanced integration process for solar collectors was developed by Anna Bać et. al. The considered heat energy system was made of two main components: a solar collector and a rock bed storage, the function of which was the temporary storage of the produced heat energy (Fig. 2.39). The working environment throughout the system was the air that after heating in the solar collector, was directed to the stone bed storage or directly to the premises of the building to be heated. At night, as well as on days with low solar heat radiation, heating took place using the energy stored in the rock bed storage (Ba´c et al., 2019).

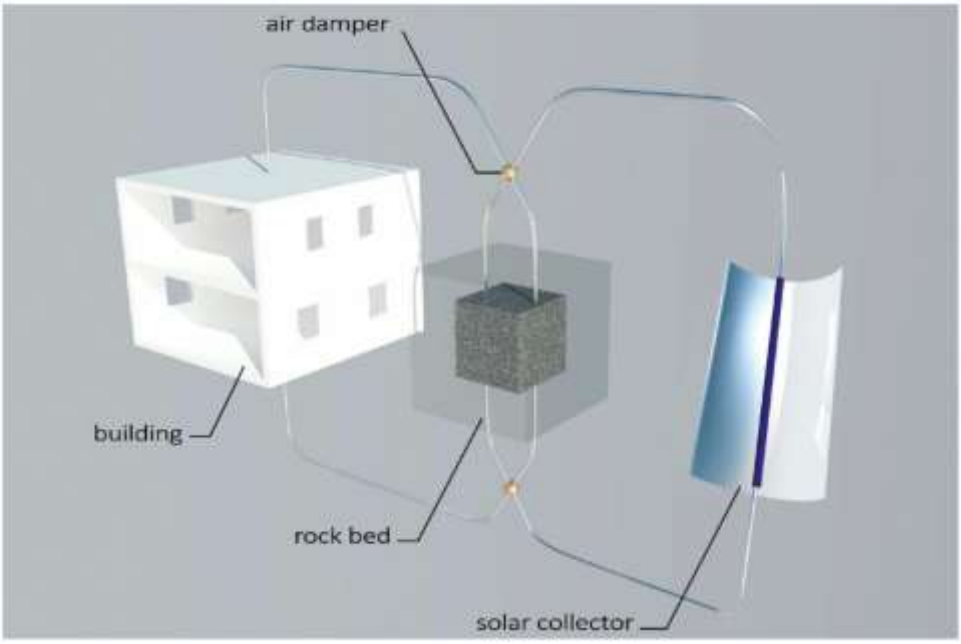


Fig. 2.39. Solar collector, energy storage and building system

The principle of operation of the solar heating system is shown schematically in Fig. 2.40.

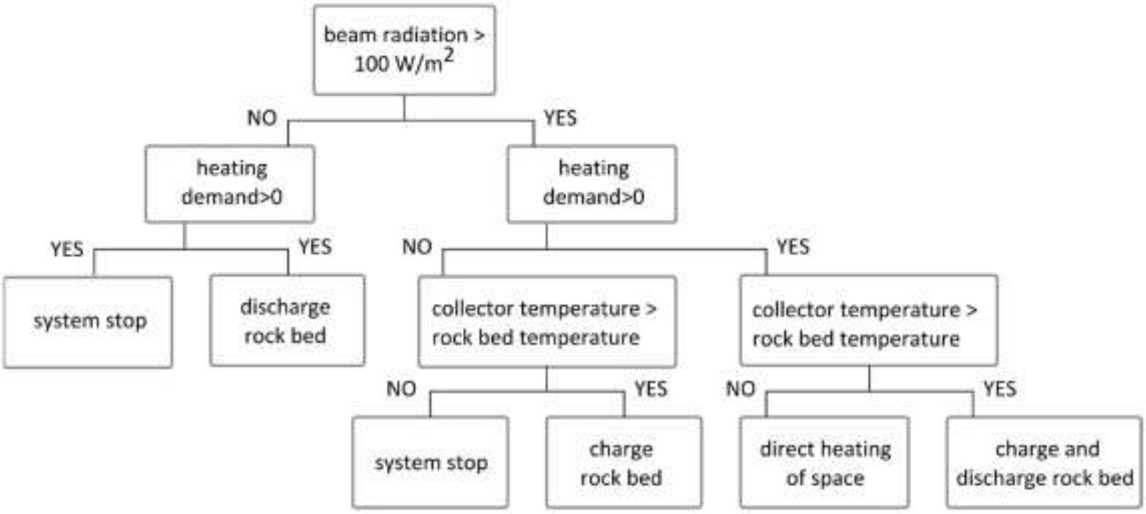


Fig. 2.40. Principle of operation of a solar thermal energy system

Different types of solar collectors can be used for the operation of the analysed energy system. Studies have shown that high temperatures can be obtained using concentration collectors that use only direct sunlight. This allows the system to operate throughout the year in Central European climatic conditions. The integration analysis carried out in the study showed that the location of the heating system not only affects the architecture and functionality of the building but also affects the operation of the whole building and the overall energy balance.

A study on the use of solar energy in building structures was estimated that the highest degree of integration could be achieved for buildings that are directly in the design phase and not for existing structures. The system can be fully utilized, and heat loss can be reduced or compensate by using the smallest size of the solar collector and heat accumulator.

The annual concept system simulation tests in Wrocław's climatic conditions showed that with properly selected parameters, it is possible to build a heating plant based on long-term heat storage from a solar collector. Such an installation would provide thermal comfort to the single-family house all year round (Ba´c et al., 2019).

Brazil

The study estimated that the use of solar thermal energy for domestic hot water in Brazil has a high potential for use, although the use of solar energy in Brazil is still limited. Brazil's 2050 energy plan predicts that the percentage of households using solar thermal systems will increase to 23,8% by 2050, while electricity consumption is expected to fall to 24,2% (Cruz et al., 2020).

2.4.3.3. Zero energy buildings

Conceptually, a zero energy building is defined as an energy-efficient building that is able to produce electricity or other energy carriers from renewable energy sources to compensate energy demand. Compared to another similar term: a network zero-energy building, which refers to buildings connected to the public energy infrastructure, ZEB is more general and may include autonomous buildings. The first prototype of a zero-energy building was developed as a building that used solar thermal energy to achieve zero-energy heating (Ba´c et al., 2019).

Spain

Analysing the concepts of 33 solar zero-energy buildings, which were presented in the Solar Decathlon competition, the European part of which took place in 2010 and 2012 in Madrid, Zhongqi Yu. Et. Al. identified seven critical decisions to be made when designing a zero energy building based on the use of solar technology: shape, functional location, microclimate management, solar PV system, heating, ventilation and cooling system, industrial production system and payback period.

Both passive and active technologies can be widely integrated into such buildings. The most popular of which are high-performance insulation, PV system, solar thermal system and heat pump as an additional energy source, as well as other technologies such as natural light, shading, passive ventilation, high-efficiency devices, passive ventilation and air conditioning are also widely used. It is estimated that double-glazed windows with aluminium frames, concrete and insulation are the main carbon-intensive building materials, the use of which should be reviewed in the future.

It was estimated that five strategies - form factor; shading; insulation material; advanced technologies; module, significantly correlated with higher results in the field of architecture. These kinds of strategy played a crucial role in ensuring the comfort of the microclimate: higher heat mass, better buffer material, lower form factor, lower insulation value, lower annual heating, ventilation and cooling energy consumption. Other important strategies - window-wall ratio on the south side, capacity, slope angle to the south, type of PV solar panels, type of module - were significantly correlated with project payback time (Yu et al., 2019).

2.4.4. Integration of wind energy in households

Lately, more and more people want to be independent of centralized electricity supply and want an individual power plant to be installed in their yard or on the roof of their house, thus increasing the interest in small wind turbines that can be installed in households. The small increase in the use of wind turbines is also confirmed by the international competition for small wind turbines organized by the NHL University of Applied Sciences in Leuven, the Netherlands. The aim of this competition is to design and build an SWT (small wind turbine) with optimal energy production in a predetermined wind mode. It is estimated that a real-life problem to be solved by designing small wind turbines, is that the design must be efficient to be able to successfully perform at low wind speeds, the economic aspect is also crucial because equipment must be able to be installed by households' holders without specific technical knowledge.

One of the small wind turbine concepts presented at the International Small Wind Turbine Competition is the traditional horizontal axis wind turbine. As a result of the differences in rotor diameters, the geometry was increased by a factor defined, as the ratio between the modified and the original rotor radius. The main criterion taken into account in the design process was to maximize annual energy production. Because of the wind conditions, the whole structure had to be adapted to the specific parameters. The geometry was focused on reducing wind speed, increasing power factor, and extending the operating range of nozzle speed factors (Grapow et al., 2018; Leary et al., 2019).

United States of America

In the United States, Oklahoma-equipped households with smart meters have the option of charging for electricity based on a traditional schedule, a smart schedule, or households have the option of installing a grid-connected wind turbine for a different tariff. The American Wind Energy Association (AWEA) has adopted a set of wind turbine performance standards for household wind energy.

One of the studies aimed to assess the economic aspects of installing a grid-connected microgeneration wind turbine system (6 kW and 10 kW) taking into account alternative pricing structures for households in five different locations, where the availability of wind energy also differs. For each of the sites, long-term data on wind speed over a 20-year period were collected, as well as data on electricity consumption in each of the households.

The study also took into account that, given the periodic nature of wind, wind energy will not always be available during peak periods. Hybrid wind and solar power systems were used, providing all year electricity for homes in five different locations in Oklahoma. The study estimated that the limitations in the use of both energy sources were related to the fact that energy consumption differs from a particular month and hour of the day (Ghaith et al., 2017).

2.4.4.1. Use of wind energy outside urban households

It is estimated that a significant number of household-type wind turbines have been installed in recent years to provide electricity to non-urban households and at the same time improve their quality of life.

2.4.4.2. Hybrid solar and wind systems

By using a hybrid system, where several energy sources are combined, it is possible to eliminate the instability caused by only one renewable source. For example, a solar PV system is likely to produce energy more consistently than a solar PV system alone, as the peak and off-peak operating times of wind and solar systems are different at different times of the day and year. In that way, wind and solar energy, which act as substitutes for fossil energy as a hybrid system, can create greater stability in renewable electricity generation. Second, the hybrid system can be integrated with energy storage technologies, providing secure reserves when and if consumption exceeds production. Energy storage can help reduce the size of other components (such as photovoltaic panels or wind turbines) and reduce costs (Fikru et al., 2019).

The right combination of wind and solar photovoltaic (PV) systems can create optimal configurations that could increase annual energy production (AEP) while also being cost-effective. Within the framework of the research, a methodology was developed for minimizing the amount of energy produced and reduce investment costs. According to this methodology, the power required by the consumer, the potential of solar energy and wind energy at the specific location was used as input data. The developed methodology was tested in four different areas and concluded that it allowed obtaining the optimal system configuration without using commercial programs developed for this purpose. A schematic representation of the methodology is given in Fig. 2.41 (Tenghiri et al., 2019).

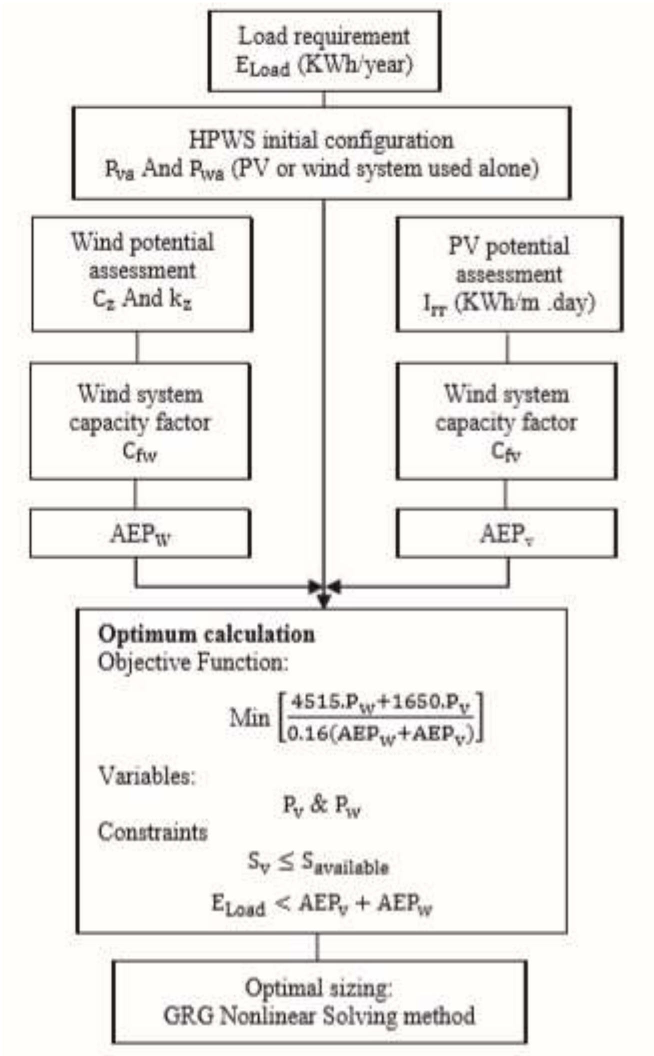


Fig. 2.41. Calculation of the optimal solar-wind hybrid system configuration

2.4.5. Use of geothermal energy

Geothermal energy is heat that is found inside the earth and consists of a) energy flow through the earth's crust, b) heat flow as a result of the thermal conductivity of rocks, c) energy stored in the rocks and liquids of the earth's crust. Geothermal resources can be considered renewable on the time scale of technological/social systems because they do not require the renewal time required for fossil fuels (e.g., coal, oil and gas). Therefore, geothermal energy is included in renewable energy sources and can be used to provide electricity, heating and cooling in households, commercial and industrial buildings, as well as other equipment.

Geothermal energy is divided according to the temperature range a) high temperature (> 90 °C), b) low temperature (25-90 °C) and C) shallow geothermal energy (<25 °C). The use of shallow geothermal energy is realized using heat pump technologies (Karytsas & Choropanitis, 2017).

Heat pumps use relatively constant temperatures in the soil or water to provide heating, cooling and hot water preparation throughout the year. Heat pump systems consist of three main elements (Fig. 2.42):

- Heat absorption from or to the ground;
- A heat pump that converts this heat to a suitable temperature level;

- Distribution system inside the building for heating, cooling and hot water. In the case of hot water, the system also includes a hot water tank.

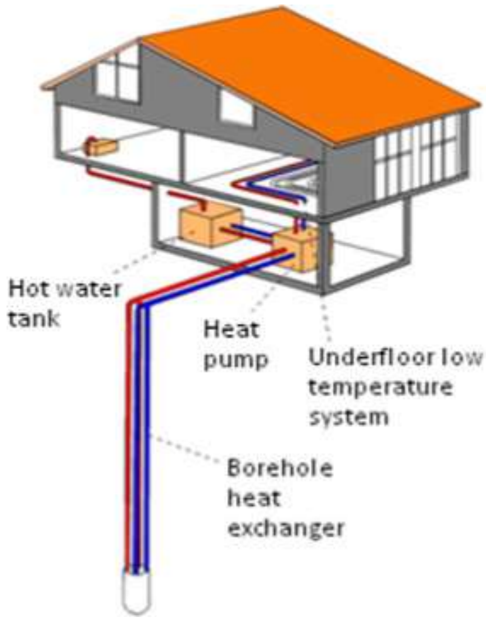
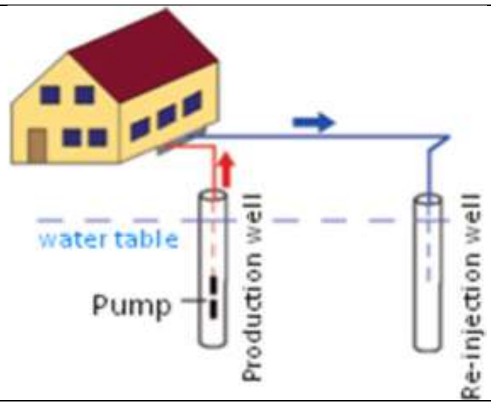


Fig. 2.42. Heat pump system

The heat pump is considered to be a refrigeration unit and contains the same main components as refrigerators and air conditioners. It is a device that causes heat to flow from a lower temperature environment to a higher temperature area. The heat pump requires additional power to reach the temperature increase. Electricity is usually used for this purpose (thermal energy is rarely used). This additional energy supply drives the compressor. The required energy input is less than the output heat energy, the less extra energy is required, the more economically advantageous the heat pump. Heat pumps with a heat output between 5 and 20 kW are typically used in the residential sector.

Geothermal energy utilization systems can be of several types (Karytsas & Choropanitis, 2017) Fig. 2.43.

Open-loops with heat pump	

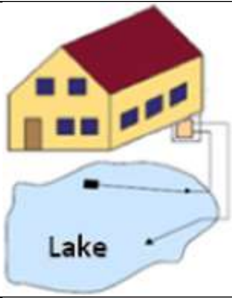
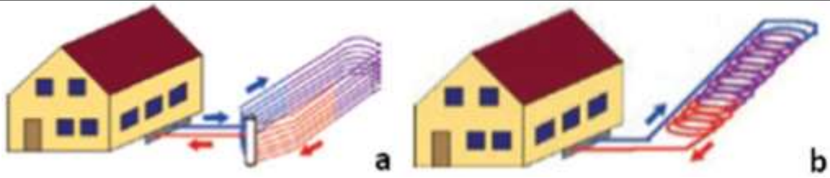
Open loops using surface water	
Closed-loop horizontal systems a) in parallel b) serial	
Closed-loop horizontal systems with a spiral arrangement a) in the trench b) spiral	
Vertical systems	

Fig. 2.43. Types of the geothermal energy system

Although geothermal energy poses specific challenges compared to other renewable energy technologies, it has significant potential to reduce the environmental impact and greenhouse gas emissions from energy production. The advantages of geothermal energy are not only the production of electricity in various configurations, but also the direct use of heat in industry and households, regardless of meteorological conditions. From a technical point of view, energy saving potential is due to the fact that replacing direct electric heating with heat pumps reduces the amount of energy supplied. In many countries with colder climates, heat pumps are considered part of future energy systems, however, as seen in many other energy efficient technologies, the real energy savings expected from heat pumps are not fully realized (Hannsen et al., 2017).

Greece

According to the study, the main barriers to the spread of heat pump technologies in households are related to the lack of information on installers/engineers/architects and other service providers to be involved in the design and installation of the individual system. It is also related to the lack of public awareness of the technologies and its benefits. In order to remove the barriers mentioned before, actions should be taken, to raise public awareness and understanding of the technologies to be installed by organizing information events on the benefits of the technology (public authorities, research centres, distribution projects, etc.) as well as training installers.

The second category of obstacles includes the installation process and in particular, the difficulty of adapting the system to an existing household, as well as the discomfort caused by the installation process in the dwelling. The legal framework for the use of heat pump technology in Greece has improved in recent years, but various measures should be taken to increase the use of technology. For example, changes in installation specifications (reducing the mandatory distance from elements such as main underground pipelines, the property of other residents, etc.) (Hannsen et al., 2017).

Heat supply using geothermal energy as an energy source is perceived in many parts of the world as a sustainable solution for heat production, which can provide heating independently of heat suppliers. Fig.2.44 is given information on which countries have the largest heat capacity using shallow type geothermal energy as an energy source in different periods.

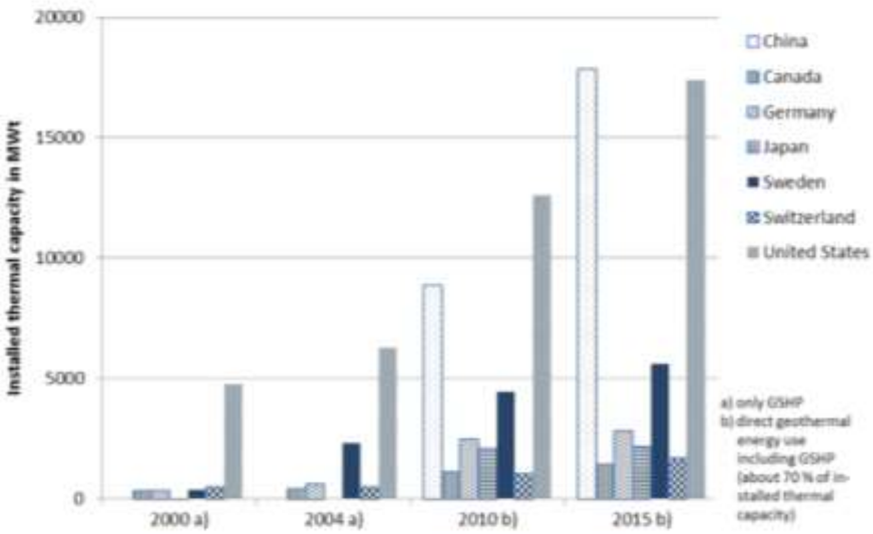


Fig. 2.44. Heat energy capacity of the installed shallow geothermal energy equipment in the period 2000 to 2015

Germany

In Germany, the share of geothermal energy in households is increasing, driven by investment in the development of building insulation technologies that have made heat pumps more efficient for domestic use as a heating source. The heat supply is identified in the Energy Policy Guidelines as a strategic priority for reducing greenhouse gas emissions and ensure stable and secure energy supply. Studies have estimated that there are also cases where cost reductions were not achieved after the installation of heat pumps after the first winter (Bleicher & Gross, 2016).

2.4.5.1. Heat pumps in combination with other types of RES

The climate change mitigation potential of heat pumps is estimated to increase when used in combination with other types of RES, such as solar PV and solar thermal energy.

2.4.6. Possibilities of using hydropower in the household sector

Of the renewable energy sources, hydropower has been assessed as the world's largest resource for generating electricity (Kadier et al., 2018). Norway is estimated to have the largest hydropower resources as well as the largest storage capacity for the electricity generated (Askeland et al., 2019).

2.4.6.1. Small hydropower plants

In households, in contrast to the industrial sector, where it is necessary to provide large amounts of energy, more and more small-scale and high-capacity hydropower plants are used to provide electricity to households.

Italy

In study case, The Regio Parco mini-hydropower plant in Turin, Italy, was designed to provide electricity to around 600 households in an environmentally friendly way, while reducing CO2 emissions by almost 900,000 tonnes while renovating the historic dam (Comino, 2020).

2.4.6.2. PHP hydropower equipment

The adverse effects on the environment and the investment required in the installation of large-scale hydropower plants have led to the search for new solutions for obtaining electricity from water resources in a more environmentally friendly way. This has led to a focus on Pico-type hydropower plants, which can reduce the environmental impact of large-scale hydropower plants. Pico hydropower plants have been rated as the best option on the market with the lowest price for electrification outside urban areas or remote areas in developing countries. PHP systems are used to provide electricity in rural and mountainous regions. PHP is suitable for individual households to generate a maximum power of up to 5 kW. PHP equipment is estimated to have one of the lowest construction and operating costs for providing electricity outside centralized grids compared to other technologies.

Using PHP hydropower facilities can provide rural communities with about 30 households that consume relatively small amounts of electricity daily to power household appliances and provide lighting. In some countries, PHP devices are rated as functionally suitable for families in individual households. The principle of operation of PHP equipment is shown in Fig. 2.45 (Kadier et al., 2018).

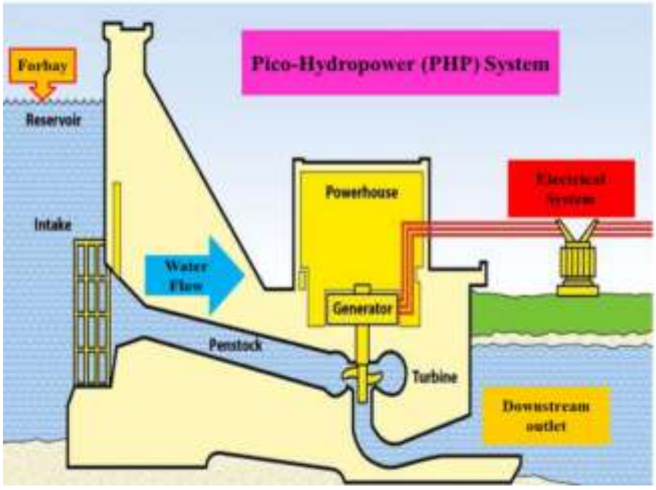


Fig. 2.45. PHP system operation principle

2.4.6.3. Advantages of PHP equipment

Many low-income households around the world are choosing for PHP equipment as a more appropriate and secure solution comparing with wind or solar PV panels to providing electricity for everyday use.

One of the main advantages of PHP is its ease of use. Therefore, PHP turbines are rated with relatively low installation and operating costs compared to other technologies. Compared to solar, wind, hybrid or other fossil fuel-based processes, the PHP system is considered to be a cost-effective source of electricity for households. The latest PHP turbines have a lifespan of about 15 to 20 years with a short payback period. Unlike PHP installations, such as solar PV panels or wind turbines, no battery is required. It is estimated that PHP units have the lowest tariff - 15% less than PV solar panels. Also, one of the main advantages is that PHP turbines do not harm the environment, as there is no need to build dams, like this in the case for large-scale hydropower plants.

In rural areas, to provide electricity and share costs, the division of PHP equipment into communities with one equipment providing electricity to several household households was assessed as one of the advantageous options. In this way, it is possible to jointly install the most efficient turbines possible, dividing all costs by the number of people in the community and ensuring a stable and secure, equal supply of energy to all residents of the community.

PHP devices also have some drawbacks in their use, such as during periods of heavy rain, PHP devices can be damaged and flushed, and PHP devices are easily portable, so there are risks of theft (Kadier et al., 2018).

2.4.7. Possibilities of using biomass in the household sector

In the household sector, biomass resources offer opportunities reaching the Europe 2020 climate and energy goals. Through their policies, various EU countries are encouraging citizens to take action, such as replacing boilers with more efficient boilers and increasing the use of renewable energy. One of the most classic types of biomass used for energy production is wood. If the area under wood fuel felling is below the annual growth rate, then the stock of wood biomass is not depleted, and the harvest is considered sustainable. If the annual felling volume exceeds the increase, then it is not regarded as sustainable, leading to a decrease in wood biomass, forest degradation and net carbon emissions. The use of biomass for energy production is closely linked to the thermochemical processes of fossil fuel conversion. It is possible using incineration, pyrolysis, gasification and liquefaction processes or biochemical transformation-fermentation processes for the production of energy resources. The type of process used depends on the type and amount of biomass resources, the type of energy required and consumer requirements (Piwowar et al., 2019).

Based on 2017 data on biomass used for energy in all EU Member States, it was estimated that most solid biomass was used in households and the energy sector (Malico et al., 2019).

It is recognized that throughout the European Union, wood resources are used in households and for individual heating, as well as for district heating.

There are several existing plants in the United Kingdom that use biomass residues from agriculture and biodegradable waste as raw materials. Several small-scale pilot plants and stations have been installed in the several EU Member States, using different energy crops as raw materials, together accounting for 76% of the biomass consumed in the EU (Robina & Loncˇarevic, 2017).

<u>Turkey</u>

In rural Turkey, almost all biomass for energy is used by households for heating, hot water and cooking. Combustion wood is the largest source of energy in rural areas and the fourth largest source of energy in Turkey (Robina & Loncˇarevic, 2017).

2.4.7.1. Use of biomass residues

Studies estimated that there is vast potential in Turkey, transforming biomass residues into energy resources. In Turkey, the energy equivalent of agricultural residues is about 16 Mtoe per year. It is known that grain residues, wheat straw, hazelnut shells can be used as energy sources because they have a high energy production potential. Approximately 3,5 x 105 tonnes of hazelnut shells are produced in Turkey each year and would, therefore, be a suitable raw material for further energy production. It is estimated that the highest heat of combustion of hazelnut shells is 19,2 MJ/kg. Hazelnut shells can be converted into gaseous products rich in hydrogen using the steam gasification method.

Using biomass, it is possible obtaining both - electricity and heat through heat treatment by converting raw materials into charcoals or gas. Wood has been identified as the main fuel for 6,5 million households in Turkey (Robina & Loncˇarevic, 2017).

2.4.7.2. Technologies that can be used to reduce the negative impacts of using solid biomass

In biomass combustion plants, where electricity is generated from steam turbine generators, the conversion efficiency is in the range of 17 to 25%. It is estimated that efficiency can be increased by up to 85% using cogeneration.

One of the most common methods of thermal conversion of biomass is pyrolysis, through which it is possible to treat different types of biomass or biomass residues, it is estimated that the greatest heat capacity can be achieved using cellulose.

Gasification is considered to be one of the alternatives for the combustion of biomass or its residues using thermal conversion methods. The advantages of gasification are associated with higher efficiency compared to incineration. For example, 40% efficiency can be achieved through gasification and 26-30% efficiency through combustion methods.

Another way to generate energy using biomass as a source is co-incineration. Combustion of biomass with any of the fossil fuels (e.g. lignite, coal) is widely used, especially in the United States or the Netherlands. Biomass can be mixed with coal in various proportions by mixing from 2 to 25% or more. One of the advantages of co-incineration is that co-incineration requires less investment compared using only a biomass incineration plant. Co-incineration has been estimated to be more efficient in converting biomass to electricity. Table 2.29 provides information on all the biomass conversion methods discussed above for further energy production.

Table 2.29

Conversion technologies for biomass

Conversion techology	Biomass Type	Example of Fuel used	Main product	End-use	Technology status
Combustion	Dry biomass	Wood logs, chips and pellets, other Solid biomass	Heat	Heat and electricity (steam turbine)	Commercial
Co-firing	Dry biomass	Agro-forestry Residues (straw)	Heat/electricity	Electricity and heat (steam turbine)	Commercial
Gasification	Dry biomass	Wood chips, pellets and solid waste	Syngas	Heat (boiler) and electricity (engine, gas turbine)	Commercial
Pyrolysis	Dry biomass, and biogas	Wood chips, pellets and solid waste	Pyrolysis oil	Heat (boiler) and electricity (engine)	Commercial
CHP	Dry biomass	Straw, forest residues, wastes and biogas	Heat and electricity	Combined use of heat and electric power (combustion and gasification)	Commercial
Etherification/ Pressing	Oleaginous Crops	Oilseed rape	Biodiesel	Heat (boiler), electricity (engine) and transport fuels	Commercial
Fermentation/ hydrolysis	Sugar, starches, and cellulosic material	Sugarcane, corn, and woody biomass	Ethanol	Liquid fuels and chemical feedstock	Commercial
Anaerobic Digestion	Wet biomass	Manure, sewage sludge, and vegetable waste	Biogas and by-products	Heat (boiler) and electricity (engine, gas turbine)	Commercial

It is estimated that in the short and medium-term, biomass and adapted biomass combustion technologies will dominate in the supply of electricity and heat, and that biomass residues will be used more (Toklu, 2017).

One of the advantages of using biomass is that the use of biomass is not affected by weather and can be provided equally throughout the year. Also, it is easy to store, and it is possible to obtain competitive energy from biomass residues, especially through cogeneration pellet combustion plants in private households. According to one model of studies and projections, biomass will be recognized as the most competitive energy source in the household sector over the next three decades, from 2040 to 2045 (Jordan et al., 2019).

Studies on the projections for the use of renewable energy sources until 2040 estimate that the highest efficiency can be achieved by using a wood pellet gasifier (cogeneration) in combination with PV solar panels and installing a heat pump as an additional element. The main motivator for the competitiveness of these systems is the further development of energy prices. With rising energy prices, the use of wood chips from biomass residues and energy crops is estimated to be the most cost-effective way to reduce greenhouse gas emissions by 95% by 2050 (Jordan et al., 2019).

2.4.7.3. Biomass combustion

Spain

Spain has been one of the most energy-dependent countries in Europe. The use of biomass is considered an essential driver for reducing energy dependency. The existence of technical, economic and even market barriers has limited the development of the use of thermal biomass. The main findings of the study on the use of biomass boilers for heating and hot water in Spain can be summarized as follows:

- Replacing fossil fuel boilers with biomass boilers, while increasing final energy consumption, led to significant reductions in non-renewable fossil resources and CO_2 emissions. On average, replacing a massive fuel oil boiler increased final energy consumption by 7,19%, reduced the share of non-renewable energy sources by 92,28% and reduced CO_2 emissions by 93,78%. By replacing the LPG boiler, energy consumption increased by 7,19%, non-RES consumption decreased by 92,42% and CO_2 emissions by 92,39%. By replacing the natural gas boiler, energy consumption increased by 30,92%, non-RES resource use decreased by 90,66% and CO_2 emissions reduced by 9,63 %. Although CO_2 emissions significantly reduced, other emissions, in particular CO, NMVOC and PM_{10}, increased considerably.
- Biomass boilers generated significant savings throughout the life of the plant, despite the significant investments required.
- All the benefits of biomass boilers were greater in regions with more severe winter climates. In climate zones with milder winters, the introduction of biomass boilers was less economically attractive, despite obvious improvements in energy and environmental levels (Casas et al., 2018).

Poland

Poland (along with Bulgaria) is one of the countries with the highest level of air pollution in Europe - especially for high PM_{10} content (above 50 μg/m^3). The highest expectations for the use of renewable energy are related to biomass (Casas et al., 2018).

2.4.7.4. Production of gaseous fuels from biomass

The Netherlands

The Netherlands household sector has a natural gas monopoly for heat production. As a result, there is a risk of depleting public reserves and even causing earthquakes in the production area. The Dutch government and key players in the natural gas industry have expressed an interest in significantly promoting biogas production. It could be used in existing infrastructure.

Biomass processing for gas can take place through biological and thermochemical treatment. In the Netherlands, the path of biological development - anaerobic digestion - is better developed and more widely used. In 2016, approximately 13 PJ of biogas was produced in this way, of which 2,6 PJ was processed, purified and fed into the common gas grid. Unlike anaerobic digestion, biomass gasification technology for green gas production is not widely implemented. Coal gasification for the production of synthetic natural gas is a proven technology, and biomass gasification is still subject to technological challenges that need to be addressed.

As a result of the work of various companies, research institutes, universities and their mutual cooperation, several test stands and demonstration plants have been created. The biological raw materials used range from wood for the production of lignocellulosic biomass, gaseous and liquid fuels (such as syngas) and waste (waste fuels). The final products produced are both electricity and heat. The resulting gaseous fuels are biogas, synthesis gas and synthetic natural gas (LPG). LPG is a "green gas" suitable for injection into the natural gas grid. The liquid fuels are dimethyl ether (DME) and Fisher-Tropsch diesel (FT Diesel), which is a renewable transport fuel.

Various companies, research institutes, universities and collaborations between them encourage trials and demonstrations of plants. Biological feedstocks range from wood lignocellulosic biomass, gaseous and liquid fuels (e.g. synthesis) and waste (waste fuels) (Miedema et al., 2019).

Biomass gasification in the Netherlands is still subject to technological challenges that need to be addressed. One of the most critical issues is the lack of alternative heating infrastructure. The infrastructure is owned by both private owners and housing corporations. From the public point of view, large-scale green gas production through biomass gasification has an advantage over other RES alternatives. The use of green gas is hampered by social and economic barriers on the demand side. Housing corporations claim to have limited financial resources for investment and find it challenging to persuade tenants to accept higher rents to generate financial resources for investment. The transition to another technology requires large investments, and the household sector does not feel the economic incentive to replace natural gas with another heating technology. The current target is B and C energy performance certificates, which could have an impact on the property housing community and the private sector, as they could alleviate resistance to change. On the supply side, the technological barrier is to increase the scale of biomass gasification technologies. This increase is hampered by high investment risk and unpredictable biomass prices. There is no clear policy on the expected role of biomass gasification for green gas. The leading players in the natural gas market have expressed apparent hopes for "green" gas, but are reluctant to take risks by investing in gasification technologies on a large scale. Consequently, this technological limitation can be seen as the result of an economic and political barrier. A possible solution to overcome this status quo could be public-private partnerships or joint ventures. Such partnerships could reduce risks for individuals and could link technology to the market or demand side needs.

In addition to the introduction of biomass gasification technology, the availability of biomass for energy production remains an uncertain factor. Domestic biomass shortages are projected as early as 2030, so biomass imports will be needed. The potential market for "green" gas from biomass gasification in the residential sector may be large enough to create the need to develop such international biomass supply chains. Given the expected shortage of domestic raw materials and potentially high demand, such international supply chains require specific energy crop production systems (Miedema et al., 2019).

It was concluded that there are four constraints on the use of biomass gasification for green gas production, which are systemic barriers mainly related to institutional problems and financial and knowledge infrastructure. Energy efficiency measures would reduce gas demand in the residential sector, and the pace of change related to energy efficiency is lagging behind the government's planned timetable. In the rented housing sector, this is due to limited financial resources, the lack of a market model and policy agreements. As a result, it is challenging to overcome tenants' resistance to change due to a lack of interest in energy efficiency and/or uncertainty about their monthly costs.

In the private sector, a lack of mandatory policies and a lack of awareness are hampering changes in energy efficiency and RES use. Besides, for both housing corporations and private owners, the lack of infrastructure poses technical risks and negatively affects the implementation of renewable heat technologies and energy efficiency. The lack of a market model creates barriers on both the demand and supply side (Miedema et al., 2018; Schipfer et al., 2019).

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2.5. POSSIBILITIES FOR THE USE OF RENEWABLE ENERGY IN THE TRANSPORT SECTOR

According to the Energy Information Administration (EIA) in 2015, the transport sector accounted for 40% of total global energy consumption and 29% of total carbon dioxide emissions that year. An alternative to the replacement of fossil fuels is the replacement of conventional vehicles with electric vehicles with internal combustion engines, which has been assessed as one of the solutions to reduce energy consumption and transport emissions.

In the transport sector, greenhouse gas emissions are affected by a number of factors, such as population growth, increasing car numbers, limited public transport options, and relatively cheap fuel (gasoline or diesel) (Settou et al., 2019). This sector is one of the biggest emitters of greenhouse gases, and the best alternative to fossil fuels must be found to reduce emissions.

Electrification of both transport and heating can reduce CO_2 emissions by about 25 to 30%. Another solution could be smart charging, which makes it possible to manage electricity demand for transport more efficiently. Both increasing the share of electricity generation from renewable energy sources and wider electrification, as well as smart technologies, are now considered vital tools to build and secure a more sustainable energy system (Bellocchi et al., 2020).

Italy

Italy is estimated to have one of the highest rates of renewable energy production, as well as one of the largest hydropower plants. According to the Italian National Energy and Climate Plan, one of the goals is to gradually but significantly increase the share of renewable energy sources. The share of electric cars is expected to increase until the complete replacement of traditional vehicles.

Fuel used in private vehicles is estimated to be more carbon-intensive than carbon-free electricity (Bellocchi et al., 2020).

2.5.1. Hydrogen

The use of hydrogen in transport has been identified as one of the essential ways of reducing emissions from transport. The process of hydrogen production is considered to be complicated, but according to experts, renewable energy sources can be used for the production of pure hydrogen (Bellocchi et al., 2020; Anguita et al., 2018).

Greater efficiency in the transport sector could be achieved by using hydrogen as a fuel. Nevertheless, the disadvantages of using hydrogen in the transport sector are associated with high investment costs (Ajanovic & Haas, 2018).

2.5.2. Electricity

One of the advantages of electric vehicles is that they can be charged while driving and storing energy from regenerative braking. The use of electric cars does not lead to emissions, but the production of electricity itself can generate significant emissions if renewable energy sources are not used.

The disadvantages of electric vehicles are related to that they need 12 hours to charge fully. It is possible to drive from 160 to 500 km by electric car.

2.5.3. Biofuels

Most biofuels are generally classified as first, second and third-generation depending on the type of biomass used as feedstock - food, non-food and algal biomass. Liquid biofuels are ethanol, more than

80% of which comes from maize and sugar cane. Biofuels are usually used blended with fossil fuels (Sydney et al., 2019).

In the study, comparative analysis has shown that the introduction of electric cars is the best alternative from energy supply, but a biofuel strategy could provide maximum benefits to consumers (Shafiei et al., 2015).

Currently, most of the hydrogen produced is mainly used for oil refining and the ammonia production process. Hydrogen can be used for various purposes, but the use of hydrogen in the transport sector is still low (Ajanovic & Haas, 2020).

It has been estimated that using hydrogen instead of fuel could lead to greater efficiency in the transport sector. Nevertheless, the disadvantages of using hydrogen in the transport sector are associated with high investment costs (Ajanovic & Haas, 2018).

Greece

The study proposed two scenarios for reducing energy consumption and CO_2 emissions. The analysis showed that the Greek road transport sector could be decarbonised using various alternative technologies and fuel combinations. In the study, the best-case scenario combined the increased use of biofuels, electric vehicles, and gasoline vehicles, assuming that electricity is generated from renewable energy sources.

Electrolysis - the use of hydrogen as a fuel in transport has been assessed as the most energy-efficient solution (Tsita et al., 2017).

China

It is estimated that the transport sector is the primary source of CO_2 emissions and oil consumption in China. The transport sector in China accounts for about 37% of China's total oil consumption and accounts for a significant share of carbon dioxide emissions (Wang et al., 2019).

Nicaragua

Nicaraguan studies estimated that there are three possible options for introducing cleaner energy in the transport sector:

1. Liquid biofuels. Liquid fuel is obtained using raw materials or biomass (biomass - liquid fuel (BTL)) as raw materials. It is estimated that biofuels are already effectively integrated into the common fuel system.
2. Biofuels can be blended and used together with petroleum derivatives (petrol and diesel).
3. Biogas or biomethane. Up to a certain extent, purified biogas is called biomethane, and it can be integrated with natural gas in the grid or with natural gas in vehicles or dual-fuel vehicles.
4. Transport electrification (Vanegas Cantero, 2019).

2.5.4. Possibilities of using solar energy in the transport sector

2.5.4.1. Solar roads

Algeria

The study evaluated the supply of energy from solar energy using solar road technology. The results of an Algerian study showed that road-integrated solar PV panels can produce more than 804 GWh per year, equivalent to 13778 tonnes of hydrogen per year, and that solar road technologies can save 41.10^3 litres of fossil fuels, usually petrol, and reduce greenhouse gas emissions in the transport sector as whole emissions by 216 tonnes per year.

2.5.4.2. Electric vehicles

There are identified six types of energy transmission configurations that are differentiated by energy source: electric vehicles (BEVs), fuel cell electric vehicles (FCEVs), and fuel cell hybrid electric vehicles (FCEVs) (Settou et al., 2019).

The use and increase of the share of fuel cell hybrid electric vehicles (FCHEV) are more focused on the development of electricity and/or hydrogen refuelling infrastructure to provide more support for energy supply.

Disadvantages of using electric cars are mainly related to the availability of charging stations that provide electricity and/or hydrogen. One of the solutions to the problem of the availability of charging stations can be the introduction of solar road technologies.

The use of solar road technology can be an essential tool in creating a decentralized energy supply through charging stations. Solar road technologies consist of solar PV panels that are installed on the road converting solar energy into electricity.

The concept is based on the idea of replacing asphalt roads with solar PV panels that are able to collect and store solar energy and convert it into electricity. Each PV panel consists of at least three bottom layers - surface layer, electronics layer, base layer. The solar PV panel for road use is made of polycrystalline silicon. The electricity generated by solar PV panels is used to provide power to Plug-in-FCEV charging stations (Fig. 2.46).

Hydrogen available at charging stations is obtained through an electrolysis process, and hydrogen is stored in storage tanks (Settou et al., 2019).

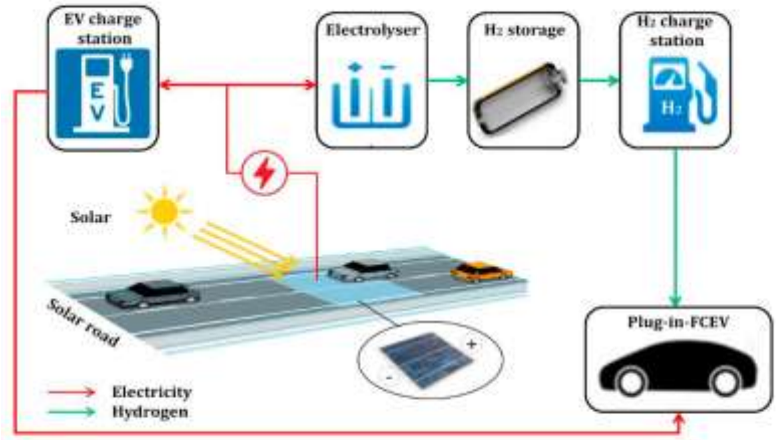

Fig. 2.46. Schematic diagram of solar road technologies

One example of the use of solar road technologies is the French company BTP COLAS, which in 2016 developed new solar PV panels for installation in roads (Watt-Ways) in sections from 10 m² to 50 m².

The advantages of solar road technologies are related to the fact that solar PV panels can be placed in any type of road infrastructure, for example, highways, parking lots, bicycle lanes. Solar panels can also be installed on the existing surface without prior engineering reconstruction or other road adaptation works before the panels are installed. It is forecasted that the produced electricity can reach 280 MWh per year, but in summer - 1500 KWh per day.

In China, with the introduction of solar road technology, various improvements have been made, such as the introduction of a solar emergency lane on the roads in the nearby capital of Shandong Province, Beijing. It is estimated that solar road technology can produce up to one million kWh of energy, which is enough to supply about 800 households in China.

The study conducted in Algeria identified three main calculation steps for estimating electricity and hydrogen production using solar PV panels as an energy source, based on Geographic Information System (GIS) model data.

One data set consisted of road names, lengths, geographical coordinates of each segment, as well as traffic information. The second data set consisted of meteorological information on the annual solar thermal radiation intensity (KWh/m²year) (Fig. 2.47).

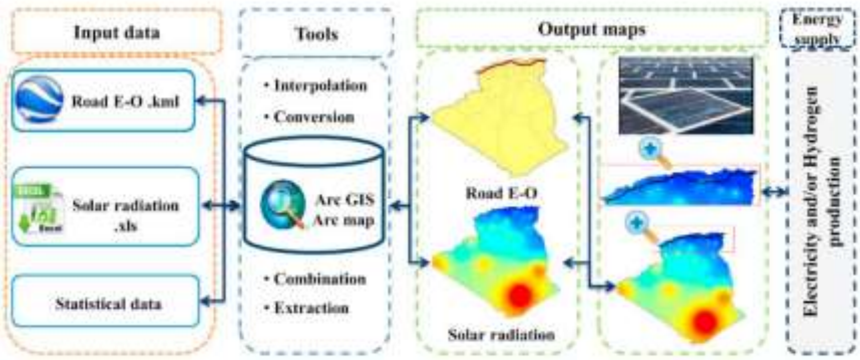

Fig. 2.47. Geographic information system model data

The study used the inverse distance weighted (IDW) method to estimates the available solar energy potential in Algeria. To assessed the potential of solar energy, a solar map was used, where each cell contained quantitative information about the intensity of solar radiation in a particular area.

2.5.4.3. Hydrogen

The electrolyzer uses solar energy to control the electrolysis processes, which results in the production of hydrogen, which can be further used as an energy source in vehicles. The study estimated that the renewable hydrogen produced using a proton exchange membrane electrolyser (PEM) is about 75% efficient – 53.2 kWh was consumed in the study to produce one kg of hydrogen using the electrolyser (Settou et al., 2019).

The aim of the study was assessing the possibilities of introducing solar road technologies in the Algerian transport sector. The study also evaluated and demonstrated the potential for hydrogen production using solar panels on the roads to provide electricity. The study assessed that the hydrogen produced can be used in hydrogen charging stations.

According to the results of the study, 804 GWh of electricity was generated on-road E-O during the year using solar road technologies. Using the obtained electricity, it was possible to extract 13778.39 tons of hydrogen per year. This resulted in significant reductions in CO_2 emissions and fuel savings. The study estimated that CO_2 emissions were reduced by 216 tonnes using the Plug-in-FCEVs vehicle. Vital issues for the development of a further investigation would be, for example, the choice of the location of hydrogen stations, the impact of the seasons on hydrogen production, the amount of electricity required in electric cars charging stations (Settou et al., 2019).

2.5.5. Possibilities of using wind energy in the transport sector

2.5.5.1. Wind - hydrogen

Sweden

Compressed and stored hydrogen produced from wind energy can be used as a fuel in the transport sector, reducing fossil fuel imports and at the same time reducing greenhouse gas emissions. Therefore, hydrogen produced from wind energy can be one of the crucial solutions for replacing fossil fuels with renewable energy sources in the transport sector.

In recent years, wind energy has been increasingly used in the transport sector for generating electricity for hydrogen production and further as an alternative to fossil fuels in electric vehicles. It is estimated that in Sweden, using local wind energy resources to convert electricity into electricity (approximately 860 TWh) can produce about 25580 kilotonnes per year.

Studies show that using 530 kilotonnes of hydrogen produced from wind power can reduce fossil fuel consumption and CO_2 emissions by up to 50%.

The disadvantages of using wind energy are related to the periodicity of wind energy. Nevertheless, the potential of wind energy available in Sweden is assessed as high and thus the potential for the production of hydrogen for vehicles. Hydrogen production and storage using wind energy as an energy source are considered to be an effective solution to increase the integration of wind energy into the overall national energy system (Siyal et al., 2015).

The hydrogen produced can be used not only in the transport sector but also for the grid, providing electricity, heating to local or remote places. Hydrogen generated by wind energy can be used as an energy carrier to compensate for wind energy interruptions in cases where sufficient wind speed (m/s) cannot be ensured.

The hydrogen produced acts as an energy carrier, and the benefits of its use are also linked to the security of energy supply, energy security in rural areas, as well as rural development itself, as well as economic and social benefits.

Currently, according to the existing trends, the produced hydrogen is used in the industrial sector, paying less attention to the supply of electricity to households and the use of hydrogen in the transport sector. Studies showed that the United States produces between 10 and 11 million tonnes of hydrogen a year and that this could fill up to around 20 to 30 million cars. Hydrogen from industrial processes is used in refineries for crude oil processing, as well as in the food industry to provide a hydrogenation process, as well as for metal processing and in ammonia production processes.

The Swedish energy policy specified that the use of fossil fuels for heating must be phased out by 2020, while the use of fossil fuels in the transport sector must be phased out from 2030 so that hydrogen produced from wind energy can be an effective alternative.

2.5.5.2. Summary of the advantages of using hydrogen

Hydrogen can be used as a fuel in methane (CH_4) vehicles. Hydrogen can use in the production of synthetic fuels in the same way as methane or other hydrocarbon fuels. One of the advantages of using hydrogen is a significant reduction in fuel consumption. Using 530 kilotonnes of hydrogen per year can reduce petrol consumption, even about 50%, from 2900 kilotonnes to 1450 kilotonnes, at the same time reducing CO_2 emissions from 8700 kilotonnes to 4350 kilotonnes, respectively.

The advantages of using hydrogen from wind energy are also related to economic benefits. In the United States, replacing gasoline with renewable hydrogen fuel is estimated to save a total of $ 4249 million a year, based on a gasoline price of $ 2930.

The wind-hydrogen energy potential is influenced by the power of the wind turbine used, the height of the hub and the efficiency of the proton exchange membrane electrolyzer.

2.5.5.3. Disadvantages and solutions related to the use of hydrogen

The use of natural gas, in combination with hydrogen, is estimated to be highly efficient. In order to ensure better combustion efficiency in vehicles, it is possible to use a mixture of compressed natural gas and renewable hydrogen in the proportion of 20% hydrogen and 80% natural gas.

Studies have calculated that if hydrogen gas is produced as an energy source using one of the renewable energy sources capable of generating electricity, then the use of natural gas and hydrogen as a fuel can reduce total CO_2, THC and Nox emissions from vehicles by 10%, respectively. 18%.

Despite the benefits, hydrogen production also generates emissions. It is estimated that 970 g CO_2/kg H_2 is formed during the hydrogen conversion process. Emissions from the operation of turbines and the electrolysis process, as well as from the compression and storage of hydrogen, account for part of the CO_2 emissions generated.

One of the significant disadvantages of wind energy is that, in the event of insufficient wind speeds, the corresponding load for hydrogen production cannot be fully met. The disadvantages of using hydrogen as a fuel are also due to the fact that the possibilities for supplying and using hydrogen in existing gas turbines are limited due to technological reasons.

One of the most effective solutions for ensuring a stable load is to use hybrid energy systems in addition to wind energy using another energy source for electricity generation, and such a solution can provide a stable supply of electricity in the connected grid and outside the grid (Siyal et al., 2015).

Germany

In Germany, the use of wind energy is estimated to play a vital role in reducing greenhouse gas emissions. According to data from 2017, 56,100 MW of capacity was achieved using wind energy. One of the disadvantages or limitations of wind energy is its availability, depending on geographical location, climatic and regional differences.

Along with the extensive supply of wind energy, wind surpluses are also formed. One of the solutions for the sustainable use of wind energy without creating surpluses is the storage of energy by producing hydrogen using renewable wind energy as an energy source. Despite the vast potential of wind energy, large amounts of fossil fuels are still used in the transport sector. In Germany, the use of stored and compressed hydrogen gas instead of fossil fuels has been identified as a possible solution to reduce wind energy surpluses and GHG emissions in the transport sector.

Another advantage of hydrogen gas in the German context is the provision of protection against short-term supply disruptions because all crude oil is imported from Russia.

The wind speed-wind shear mathematical model (WSWS) was used in the study to estimate the wind speed. The study assessed the potential for reducing fossil fuels in Germany using wind energy and hydrogen as an energy source, also taking into account meteorological, technical and geographical aspects and constraints. The potential for reducing wind - hydrogen and fossil fuels were assessed based on PEM calculations.

According to a German study, the technical wind - hydrogen potential for electricity generation was 780 TWh per year, potentially replacing 80.1% of the fossil fuel currently used in the transport sector.

2.5.5.4. Proton exchange membrane electrolyser for hydrogen production

The advantages of using a proton exchange membrane electrolyzer in hydrogen production processes are associated with high efficiency, the ability to perform or continue to operate in wind power outages, as well as the advantages associated with low greenhouse gas emissions.

Studies have estimated that the lowest heat of combustion associated with hydrogen production is 0.0333 MWh/kg, which is higher than the heat of combustion of gasoline - 0.0120 MWh/kg. It is also estimated that 1 kg of hydrogen can replace about 2,75 kg of fossil fuels (petrol or diesel).

There are several cases where hydrogen cannot be produced in areas with the highest fossil fuel consumption because wind energy resources are limited. German studies estimated that an additional 25026 new wind turbines would need to be installed to replace 25% of current fossil fuel volumes (Jung et al., 2018).

2.5.6. Possibilities of using hydropower in the transport sector

The hydropower potential depends directly on the flow velocity and the altitude gradient between the two water layers. As with wind energy, hydropower resources can also be used to produce hydrogen, which in turn is used as a fuel for vehicles.

2.5.6.1. Hydrogen production using hydropower resources

Ecuador

In a study to assess the potential of hydrogen gas to replace fossil fuels, a comparison was made based on information on the consumption of three fuels and the production of hydrogen using hydropower as an electricity source.

One of Ecuador's cities, Cuenca, located near the existing hydropower complex, which supplies most of the city's electricity, was chosen as the study site. The study concludes that hydrogen production from unused hydropower or its surpluses is one of the untapped niches that could move Ecuador towards a hydrogen-friendly and supportive economy. Hydrogen extraction by electrolysis has been assessed as one of the most environmentally friendly solutions with one of the lowest environmental impacts if hydropower is used as an energy source. Also, one of the lowest costs has been estimated for this type of energy production.

The study estimates that 1.5% to 8.5% of the surplus hydropower produced in Foz de Iguazu is needed to produce enough electrolytic hydrogen to run public transport (Posso et al., 2015).

Nepal

Studies have estimated and predicted that by 2050, the share of electric vehicles should reach 35%, and hydropower capacity should increase to 495 MW by 2050, while the annual amount of electricity produced should increase by 7.86 TWh. One of the main tools for increasing and promoting the sustainable use of local hydropower resources in the transport sector is the policy of transport electrification by expanding the capacity of electricity generated by hydropower to 495 MW by 2050 (Shakya & Shrestha, 2011).

2.5.7. Possibilities of using geothermal energy in the transport sector

The use of geothermal energy depends to a large extent on geographical location, climatic and regional characteristics. Geothermal energy is primarily thermal energy, but in the transport sector, it is necessary to use electricity to operate vehicles. Consequently, geothermal energy is not widely used in the transport sector, which is also confirmed by the reviewed scientific literature.

Iceland

It is estimated that the actual share of geothermal energy in Iceland is 27% of the total energy produced in Iceland.

A study in Iceland assessed the linkage between the dynamics of geothermal resources in the context of the establishment and development of a sustainable energy system in Iceland. The research included an assessment of electric vehicles as Iceland's decarbonisation strategy in the transport sector.

According to the results or research viewed, it was identified that the dynamics of geothermal resources is an essential component in the assessment of the energy system. The energy and transport system model (UniSyD_IS), which was related to the geothermal resource dynamics model, was used to perform the assessment, develop forecasts and evaluated the impact of the use of geothermal resources on electricity generation.

It was estimated that the inclusion of geothermal resource dynamics offers an opportunity to expand the electrification of Icelandic transport. The study assessed that electrification of transport has a small impact in terms of emissions, costs and availability of resources, and measures for introducing electric cars can be assessed as sustainable (Spittler et al., 2020).

2.5.8. Possibilities of using biomass in the transport sector

The Renewable Energy Directive (RED-1) has imposed an obligation European Union countries to achieve a 20% share of renewable energy by 2020, stipulating that 10% of total final energy consumption must be achieved in the transport sector (Banja et al., 2019).

Finland

In Finland, it is estimated that bio components already account for a proportion of all transport fuels and that blending thresholds for bio components are set according to specific quality criteria. The human factor also has a significant impact on increasing the share of biofuels. In Finland, a study was carried out on which type of fuel people choose best and for which they would be willing to pay the most. According to the results of the study, people chose biofuels as best option compared to fossil fuels (Moula et al., 2017).

2.5.8.1. Opportunities for the use of biofuels in the transport sector

It is estimated that in the European Union as a whole, the transport sector accounts for about 30% of total final energy consumption. The increased use of biofuels has been identified as a solution for reducing carbon emissions in the transport sector and to meet the European Union's target of replacing 10% of fossil fuels with biofuels. Biofuels from biomass are considered to be the main possible solution to reduce the use of crude oil.

Greece

It is estimated that Greece has a high potential for energy crops. Liquid biofuel can be obtained, for example, from rapeseed or sunflower - for the production of biodiesel, as well as barley, beets, corn, sweet sorghum - for the production of bioethanol. According to research, next-generation biofuels using lignocellulose and waste as raw materials do not have the same restrictions as first-generation biofuels.

Different types of biomass resources can be used to produce biofuels - different sectoral residues, waste, algae, to obtain fuel that can be burned with a higher degree of purification and without mixing restrictions, for example, to obtain hydrotreated vegetable oils (HVO).

2.5.8.2. Promotion of support for the use of biofuels

Support for increasing the share of biofuels is encouraged, for example, by issuing biofuel certificates certifying compliance with sustainability criteria for each tonne of oil equivalent of biofuel produced (Tsita et al., 2020).

2.5.8.3. Hydrogen as an alternative to reducing the need for biomass resources

The study estimated that first-generation ethanol with a total capacity of 120 Mt per year is the most widely used biofuel, which accounts for 4% of total fuel demand in the transport sector. The study estimated that the use of electrolytic hydrogen after pyrolysis and rapid catalytic pyrolysis could reduce the need for biomass by 48.2% and 61.2%, respectively (Onarheim et al., 2020).

There are several biological, thermochemical and chemical conversion processes to convert biomass to biofuels to produce bioethanol, biohydrogen and biodiesel.

2.5.8.4. Possibilities of using biogas and biomethane in the transport sector

Sweden

In Sweden, the policy instruments used have made significant investments in promoting support for renewable energy in the transport sector. The Swedish government has set a target of making the transport sector independent of fossil fuel resources by 2030.

In order to achieve the targets set, Sweden has identified five different categories of resources in which feedstocks can be used efficiently as components for further biogas production, taking into account all sectors where waste or unused by-products could be used as feedstock—in this way ensuring the prudent and sustainable use of waste, residues, by-products. Five categories of resources can be divided into food waste, sewage sludge, industrial residues, agricultural residues or waste, and energy crops. Policy support is a crucial factor in promoting biogas for reducing fossil fuel consumption. For achieving the goals set, it is necessary to strengthen and promote the established waste management policy so that the biogas obtained from the above-mentioned residues can be used as an energy source in vehicles (Lönnqvist et al., 2015).

In Sweden, not only political instruments set by the government but also economic instruments like reduced fuel tax on biofuels used in vehicles or tax discounts are important for promoting biogas support (Lönnqvist et al., 2019).

2.5.8.5. Possibilities of using biomethane in the transport sector

Sweden is currently assessed as the leading actual user of biomethane. In the transport sector, there are gaseous fuels that can be used as fuel in vehicles - biomethane and electromethane. According to the studies reviewed, the use of biomethane in the transport sector can offer significant cost savings. It is estimated that the cost savings from using electromethane are lower because a large proportion of liquid electric fuels have lower costs.

One of the advantages of biomethane is that biomethane can also be used in commercial vehicles, buses, as well as in some heavy-duty trucks (Korberg et al., 2020).

2.5.8.6. Possibilities of increasing the methane content in biomethane

Gas with a methane content of 97% (biomethane) is the only biofuel that has better properties than fossil fuels and can reduce dependence on fossil energy sources. By removing CO2 and other impurities from the gas, the resulting biomethane has similar chemical properties to fossil gas, and the resulting biomethane can be transported directly through the centralized gas grids (Oyyum et al., 2020).

Crop residues are considered to be the largest source of lignocellulosic biomass. The use of lignocellulosic biomass, together with nitrogen-rich feedstocks, can create the necessary optimal carbon-nitrogen ratio and increase the yield of biogas produced. Despite the high methane potential of lignocellulosic biomass, high-quality biogas production is often not ensured (Abraham et al., 2020).

Various technologies can improve the quality of biogas for producing biofuels consisting of 95-99% methane and 1-3% CO_2. Biomethane can replace fossil fuels in, for example, transportation, electricity generation, and the chemical industry (Worawimut et al., 2019).

Although it is possible to use various methods to promote lignocellulose degradation and higher methane yield, biomass pre-treatment methods are considered to be one of the most effective (Abraham et al., 2020).

2.5.8.7. Pre-treatment of lignocellulosic biomass to increase methane content in biogas

The inclusion of a pre-treatment step for raw materials can increase the efficiency of lignocellulosic biomass for further processing into biogas. Separation of hemicellulose and lignin from cellulose is another way to improve the quality of the biogas produced. The pre-treatment efficiency varies depending on the biomass used and the treatment method chosen. Biomass pre-treatment methods are generally divided into physical, chemical, physicochemical and biological methods.

Using physical pre-treatment methods, it is possible to increase the surface area of biomass by reducing the particle size and promote more efficient decomposition of biomass in the further biogas production process (Abraham et al., 2020).

Mechanical pre-treatment methods

It is estimated lignocellulosic biomass shredding is widely used and shredding techniques depend on the moisture content of the biomass, but the efficiency of the method depends on the raw materials used. Mechanical pre-treatment has been assessed as effective in reducing biomass particle size. In the study, the yield of methane produced by mechanical pre-treatment of rice straw increased from 3% to 10%. Another study evaluated the effectiveness of mechanical pre-treatment of meadow grass, and the results showed an increase in methane production of 25% compared to untreated samples. In another study, six different types of lignocellulosic biomass were mechanically pre-treated, and the resulting in methane production for each type of biomass used increased by 22%.

Pre-treatment methods using irradiation

Using the microwave irradiation pretreatment method, the biomass is heated. In the process of microwave irradiation, due to dipole orientation deviations of polar compounds, the solubility of lignocellulosic biomass increases. The study evaluated the yield of methane produced by pretreating wheat straw and Panicum virgatum using the microwave method at a temperature of 150 ° C. The results showed that the methane content of wheat straw increased by 30%, but no increase of methane was observed for the pretreated Panicum virgatum, which in turn proved the selectivity of the method depending on the type of raw materials used.

Chemical pretreatment methods

Chemical pretreatment methods are mainly classified as treatment with alkali, use of acid, use of organic solvents. The main acids used in the pretreatment of biomass process are sulfuric acid, hydrochloric acid, formic acid and nitric acid. The study estimated that pretreatment of wheat straw at high temperatures with sulfuric acid increased the yield of methane produced by 16%.

Compared to other pretreatment methods, alkali has been evaluated as the most efficient chemical treatment method. Sodium hydroxide and ammonia are mainly used for the alkaline pretreatment of lignocellulosic biomass. During the treatment with alkali, lignin-carbohydrates are broken down, which increases the surface area and porosity of the treated biomass. The study evaluated the quality of the produced biogas before anaerobic digestion of wheat straw by treatment with NaOH. The results showed that the biogas yield increased by 88%, while the methane yield increased by 112%.

In addition, the yield of methane produced was increased by 38% when 5% of NaOH was used for grass silage pretreatment. Another study evaluated the efficiency of the use of $Ca(OH)_2$ in the pre-treatment of extruded biomass. The results showed that the methane yield increased by 37% when 7,5% $Ca(OH)_2$ was added (Abraham et al., 2020).

It is estimated that using a chemical method with oxidation, it is possible to decompose lignin and hemicellulose in lignocellulose biomass. Oxidation mechanisms have been assessed as less selective for the type of biomass. Fenton, ozone in combination with $H2O_2$ and Fe (II) was used in the pretreatment of agricultural residues. The results showed that the maximum increase in methane production was 30%. Another study evaluated the efficiency of pretreatment of rice straw using $H2O_2$, and results showed an 88% increase in methane content.

Organic solvents in biomass processing are used to separate high purity cellulose from the rest of the lignocellulosic biomass. Although several types of organic solvents can be used in the pretreatment of lignocellulose, N-methyl morpholine-N-oxide monohydrate (NMMO) is the most widely used. Wheat straw treated with NMMO before biogas production showed a 47% increase in methane content compared to control conditions. It was estimated that a 98% increase in methane production can be achieved by pre-treating water hyacinth with 1-N-butyl-3-methyl imidazolium chloride.

Physical-chemical pretreatment methods

Physicochemical pretreatment is characterized by a combined approach to the degradation of hemicellulose or lignin polymers before further biogas production. During Physicochemical pretreatment, the hydrogen bonds between the complex polymers are broken down by heat, increasing the available surface area for the efficient action of enzymes or bacteria on the biomass.

Pre-treatment with steam explosion. The structure of lignocellulosic biomass can be changed by steam explosion - under high pressure conditions (5-50 bar) the steam is in the temperature range of 160-250 ° C. A study on the efficiency of straw pretreatment estimated that the methane content produced by steam blasting increased by 16%. Another study evaluated the efficiency of steam pretreatment of reed biomass. The results showed that the steam treatment at 200 °C for 15 minutes increased methane production compared to the raw biomass by 89%.

Another Physico-chemical treatment method is the pre-treatment of biomass using extrusion. During pre-treatment with the extrusion method, lignocellulosic biomass is subjected to a number of different types of treatment, like heating, mixing, pressure changes. The pressure drop causes the release of intracellular water from the raw materials and structural degradation, which can improve the further process of anaerobic decomposition of biomass. The main parameters influencing extrusion are reaction time, pressure and biomass moisture content. It was estimated that extrusion treatment of wheat straw and litter increased the yield of methane produced by 1 to 16% 90 days after the anaerobic digestion process. Another study estimated that the yield of methane produced increased by about 35% after pre-extrusion treatment of maize silage.

The hydrothermal treatment method is used as another pre-treatment method for the pretreatment of lignocellulose biomass. During the hydrothermal process, the water is heated to 200 °C and used for high-pressure biomass treatment. It was estimated that prior treatment of Napier grass with a hydrothermal method at 175 °C for 15 minutes, incubation resulted in a 35% increase in methane yield compared to untreated samples. In another study, the optimum temperature for hydrothermal pretreatment for biogas production from wheat straw was 180 ° C, resulting in a 53% increase in methane yield over untreated samples.

Biological pretreatment methods

During biological pretreatment, the lignin fraction in the biomass is separated using bacterial enzymes that promote its decomposition. The advantage of biological pre-treatment is easier application of process conditions compared to chemical methods, however, using biological methods requires longer pre-treatment time.

Compared to chemical or physicochemical methods, biological pretreatment methods are considered to be environmentally friendly, and processes require less energy consumption. Fungi or bacteria are used in biological treatment methods. It has been estimated that several bacterial cultures have a high potential for degradation of lignocellulose biomass, and one of the advantages of bacterial treatment is a faster growth rate compared to fungi. The study estimated that Bacillus sp. rice straw significantly reduced the lignin content and this resulted in a 76% increase in methane yield. It has been estimated that the quality of biogas can be improved by pre-treating wheat straw with several groups of bacteria, resulting in a 41% increase in methane content (Abraham et al., 2020).

Several types of fungi can be used in the treatment of lignocellulosic biomass, one of the most widely used is white-rot fungus due to its high potential to degrade lignin and part of hemicellulose, however, research is increasingly looking at the effectiveness of other fungi. One of the studies estimated that using the fungus *richoderma reesei*, it is possible to achieve 23.6% lignin degradation and an increase in the methane content of ~ 78.3%.

Another biological treatment method that has been evaluated as effective is enzyme treatment, the advantage of the method is related to the short reaction time, but the disadvantages are related to the high cost. Lignin-degrading enzymes can hydrolyze lignin monomers, making other lignocellulosic biomass components more accessible and easier to degrade. It was estimated that treatment of maize residues with Laccase and peroxidase contributed 25% and 17% to the yield of methane produced compared to the untreated samples.

Taking into account the considered methods, it can be concluded that different pretreatment methods can change the structure of biomass, separate lignin and hemicellulose, increase biomass surfaces, thus promoting more efficient anaerobic digestion for further biogas production and each method is applicable and its efficiency depends on raw materials used (Abraham et al. 2020).

Post-treatment of the obtained biogas to obtain a methane content corresponding to biomethane

If it is not possible to use pretreatment methods for the biogas production process to increase the methane content for producing high-potential biomethane, then it is possible to apply biogas post-treatment methods. The obtained biogas after-treatment improvement methods can be divided into 1) physical methods using high-pressure washing, cryogenic separation, pressure fluctuation absorption and 2) chemical methods, for example, using chemical absorption. To improve the quality of biogas, the study designed a two-stage carbon membrane system to increase the selectivity of CO_2/CH_4 and the purity of the obtained methane, as well as to reduce methane losses. The results showed that the developed carbon membrane could lead to higher CO_2 / CH_4 selectivity and methane purity of about 98%, as well as lower methane losses of 2%, thus meeting the quality requirements of biomethane. The most crucial for determining the quality of biogas produced and the potential of biomethane is the methane content, and the amount of methane recovered, as they have the greatest impact on biogas efficiency. Studies have shown that the chemical absorption method can achieve high purity potential of biomethane, high gas separation selectivity and high methane recovery, but the disadvantages of the method are related to high energy consumption and use of chemicals. The methane content of the obtained biogas shows the degree of purity of methane (Worawimut et al., 2019).

The study evaluated the possibilities of improving the quality of biogas (using pig manure as a raw material) using conventional absorption, modified absorption using water and diethanolamine (DEA) solution as absorbents. The effect of different pressure levels on the methane content in biomethane was evaluated using conventional absorption and modified absorption with 30 wt% DEA and water as absorbent. The results showed that using conventional and modified absorption, the methane content in biomethane increased with increasing pressure. The DEA solution absorbed more CO_2, and thus the methane content of the biomethane increased. The study estimated that it was not possible to achieve a methane content of 95% or more by conventional absorption and therefore concluded that it was not applicable to biomethane production. The study estimated that the modified absorption could achieve a methane content of 95% or more and CO_2 content of less than 3%.

The literature review concluded that both the use of biogas feedstock pre-treatment methods and the resulting biogas after-treatment methods could be solutions to increase the methane content and achieve quality indicators corresponding to the biomethane production potential, however, the efficiency of the methods mainly depends on the feedstocks and costs (Worawimut et al., 2019).

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2.6. Comparison of sectoral renewable energy use

2.6.1. Common, speed of technological development, advantages and disadvantages of using renewable energy sources

Table 2.30

	Common in RES using and technology production development						**Summary of the most important common in RES development and production technologies.**
	Sectors						
No.	**Energy resource**	**Industry sector (characteristics)**	**Service sector (characteristics)**	**Agriculture sector (characteristics)**	**Household sector (characteristics)**	**Transport sector (characteristics)**	
	Solar power	Uses both - collectors and solar panels at the same time providing electricity and heat. Solar energy technologies are mainly used to reduce energy consumption, prices, reduce environmental pollution, and improve market competitiveness	Uses both - collectors and solar panels. Solar PV panels - for electricity generation, solar collectors for hot water production, and heat pumps. Use of solar panels in combination with smart scheduling, load reduction to reduce grid energy consumption, carbon emissions, the maximum load on the	Uses both - collectors and solar panels at the same time providing electricity and heat. In recent years it is increasingly being used smart farming methods where solar energy systems used as an energy source.	Uses both - solar collector and panels. The use of smart systems and smart meters is increasing, and the share of use is expected to increase in the future. Also, in recent years, more and more households are using smart lighting, smart plugs, smart washing machines and often solar energy systems	More and more research is related to the use of solar road technologies through solar PV panels to obtain the necessary electricity for charging. The concept is based on the idea of replacing all asphalt roads with solar PV panels that are able to collect and store solar energy and convert it into electricity.	Uses both - collectors and solar panels. Solar energy PV panels - for electricity generation, solar collectors for hot water production. Solar energy technologies have a wide range of potential and potential for even greater use in the future in all the sectors considered. Solar energy systems are used, for example, to provide water pumping, battery charging, in

			institution's electricity bills.		can be used as a source of heat. It is estimated that the introduction of smart grids in the household sector would promote sustainable RES integration and implementation of the micro grid concept. Solar collectors can be integrated into various building constructions. Energy storage function. Solar collectors can be used in conjunction with rock bed systems to store energy. Studies have assessed a number of criteria that are important for zero-energy buildings that use solar energy	Solar road technologies are used to provide electricity to electric car charging stations and to solve the problem of charging station availability. The hydrogen available at charging stations is obtained through an electrolysis process. The electrolyzer uses solar energy to control the electrolysis processes, which results in the production of hydrogen, which can be further used as an energy source in vehicles.	various processes like - refrigeration, cooling, heat and electricity generation, swimming pool heating systems, hydrogen production process. In many research, it is estimated that The use of PV panels and solar collectors can significantly reduce electricity and heat consumption. In the case of solar energy gaps, one of the main solutions are combined systems using additional renewable energy sources, as well as heat, can be transferred to heat pumps or excess energy can be temporarily stored in accumulation tanks. In recent years solar energy systems are increasingly being used together with smart technologies, smart schedules that can

					systems as an energy source. One of the most important indicators was assessed: functional location, microclimate management, solar PV systems, heating, ventilation and cooling systems, industrial production systems and payback time. Such buildings are widely integrated into both passive and active technologies. Zero energy buildings often integrate PV panels for electricity generation, collectors for heat generation, heat pumps.		reduce load and total energy consumption, reduce electricity bills. Using solar energy technologies it is possible to provide various temperatures for relevant industrial processes to reach medium and high temperatures, which are suitable for electricity generation, industrial use, hot water production, or cooling, as well as, for example, for desalination. In many research, it is estimated that solar energy technologies have a high potential for use now and in the future and are mainly used to reduce energy consumption, prices, environmental pollution, as a solution to reduce greenhouse gas emissions as well as are

							used for improving market competitiveness. As the intensity of production of technologies increases, the prices for solar energy technologies become lower, and the payback period shorter.
	Wind energy	Less information on wind use can be found in publications. Wind energy can be used for specific industrial processes like ammonia production. In wind energy deficit, combined energy systems must be used in addition to other renewable energy sources and energy storage systems to cover peak loads.	Less information on wind use. The publications provide information on both the positive and negative impact of wind energy on the development specific of tourism.	Uses wind energy to generate electricity for agricultural processes.	There is a growing interest related to possibilities of installing individual low-capacity microgeneration wind turbines on the roofs of houses to generate electricity. In recent years, a significant number of household-type wind turbines have been installed to provide electricity to non-urban households where it is not possible to provide it in any other way. Hybrid solar and wind systems are used.	Wind energy in the transport sector is used as an energy source in the production of renewable hydrogen, which in turn is used in vehicles to replace fossil fuels. Hydrogen production through electrolysis and PEM is resistant to wind energy interruptions. Studies have calculated that if hydrogen gas is produced as an	More or less, but all of the viewed sectors use wind turbines to generate electricity. To use wind energy and to provide the efficiency of the system, uninterruptible power generation also during wind shortages one of the main solutions is using combined systems with an additional renewable energy source such as solar energy, biomass, or use energy storage systems. Another solution is smart technology, which detects when there is enough wind energy

						energy source using one of the renewable energy sources capable of generating electricity, then the use of natural gas and hydrogen as a fuel can reduce total CO_2, THC and NO_x emissions from vehicles by 10%, respectively. %, 18%.	and then provides its further transmission, reducing transmission losses.
	Hydropower	Mainly large scale hydropower plants are used to provide electricity for industrial processes which requires a considerable amount of energy.	Hydropower energy for the service sector is used mainly from large hydropower plants to generate electricity.	In the agricultural sector, hydropower is used as a source of electricity for irrigation systems.	More and more households are using small hydroelectric equipment to provide electricity to individual households. Pico hydropower small capacity plants have been rated as the best option on the market with the lowest price for electrification outside urban areas or remote areas in developing countries.	The potential of hydropower depends on the flow rate and the altitude gradient between the two water layers. As with wind energy, hydropower resources can also be used to produce hydrogen.	The industrial and service sectors use energy from large-scale hydropower plants to generate electricity. There is a different trend in the agricultural industry. Hydropower in the agriculture sector can be used for example to manage the irrigation system. **Use of combined systems** Hydropower, like other renewable energy

							sources, can be combined with other renewable energy sources to generate stable electricity for example with wind energy or solar panels - using combined systems.
	Biomass (including biomethane)	Solid biomass is used in industrial processes as an energy source. Solid biomass is used more in industries where biomass resources are generated as waste or residues in processes, for example, wood processing, forestry. In the industrial sector biomass residues - agricultural residues, organic municipal waste, are lately more used as raw materials.	Organic kitchen waste generated by the catering sector is used as a raw material for energy production. In other service sectors, the proportion of biomass use is assessed as relatively small.	Agricultural residues are increasingly being used in agriculture for energy purposes, to enrich biogas and, in addition to manure, using agricultural waste as a raw material to provide quality requirements for biomethane production. The use and treatment of biomass residues for energy production reduce the disposal of organic waste amounts.	In the household sector, solid biomass is used for heating and hot water production, which also causes air emissions during combustion. As in other sectors considered, an alternative to solid biomass could be biomass residues, biodegradable waste with high energy potential. The treatment of biomass residues using gasification has been evaluated as an efficient way of energy production. Thermal conversion methods	Biomass can be widely used to produce biogas, biomethane, biofuels, biodiesel and vehicles. Liquid biofuels can be obtained, for example, from rapeseed or sunflower - for the production of biodiesel, as well as barley, beets, corn, sweet sorghum - for the production of bioethanol. According to research, next-generation biofuels using lignocellulose and waste as raw	In all viewed sectors, biomass more or less is used in the form of solid biomass, which is limited. Therefore more and more agricultural residues or process by-products or organic kitchen waste from the catering sector are used for energy production. **Using biomass, it is possible to achieve the temperature range required for industrial processes efficiently**. **In all viewed sectors, biomass residues are more or less used as raw materials - agricultural residues, organic waste.**

					using incineration have been assessed with less efficiency.	materials do not have the same restrictions as first-generation biofuels.	
	Geothermal energy	The use of geothermal energy has a wide range of possibilities of use.	Geothermal energy is more used in the recreation sector and tourism, where it has a wide range of possibilities of use.	Geothermal energy in the agriculture sector can be used in aquaculture to provide the necessary temperature conditions for trout growth in farms.	Heat pumps use relatively constant temperatures in the soil or water to provide heating, cooling and hot water preparation throughout the year.	Geothermal energy is thermal energy, while the transport sector needs more electricity. A small amount of literature related to the use of geothermal energy in the transport sector. The use of geothermal energy depends to a large extent on geographical location, climatic and regional characteristics.	**The use of geothermal energy has a wide range of uses**. It is estimated that geothermal energy (with a temperature <100 C) connected to a heat pump in the system can be used for heating and cooling of buildings, storage of surface energy, hot water preparation, icing, and snow melting, as well as for heat storage and reuse in industrial processes, in households. It is also estimated that geothermal energy can be used in freshwater extraction and water desalination processes. **The rate of use depends on the availability of the resource**.

							The possibilities of using a geothermal resource are influenced by geographical conditions and resource availability.

1. Is there a faster technological development of any RES in any of the sectors?

5 - the fastest development
4 - the second-fastest development, there are limiting factors
3 - slower / restrictive development
2 - slow development
1 - no development

Table 2.31

No.	Energy resource	Industry sector	Service sector	Agriculture sector	Household sector	Transport sector
	Solar energy	**5 – the fastest development** **The proportion of the use of solar energy technologies is expected to increase in the future.** In recent years China has experienced a major shift from fossil energy resources to cleaner energy sources, including in the industrial sector	**5 – the fastest development** Development and demand for solar energy technologies are affecting the low payback period and smart technologies development anticipating the time when the maximum solar energy will be reached and when it will be necessary to cover the solar energy gaps.	**4 – the second-fastest development** Depending on the chosen technology and the installed device's capacity, the invested investment in solar panels can be repaid in less than ten years. **Increasing the use of smart technologies. Smart**	**4 – the second fastest development, the fastest development is possible in the future, however, it should be taken into account that RES technologies are introduced by only a part of households**	**4 – the second fastest development, in future - 5** The use of solar road technologies using solar PV panels continues to develop, and it is expected that with

		using PV solar panels and wind turbines. An increase in the share of use and rapid development of solar energy technologies are also associated with more intensive production of renewable energy technologies reducing costs and the payback period of the invested investments. Example: *By 2030 it is possible to provide approximately 15 EJ of solar thermal energy and in this period the proportion of these technologies in the industrial sector could reach 33%.* Solar energy as a primary energy source is more and more used in the food and beverage industry, for example in the United States, where manufacturing plants are already equipped with large-scale solar thermal systems to provide production processes The food industry is also globally assessed as the dominant industry, with the	By choosing the appropriate capacity and technology, it is possible to repay the invested investments in 5 years. **By using solar energy technologies in combination with smart technologies, it is possible to achieve faster technological development and efficiency. The following energy-saving methods are more widely used.:** Solar energy technologies combined with a regulated smart schedule are used to reduce huge load and energy consumption in public institutions, for example, in schools. It is estimated that in addition to the smart schedule, a biothermal heating mechanism can also be used in combination with solar PV panels. In research, it is estimated that limiting energy demand in combination with solar PV energy and a bi-thermostat is evaluated as an effective energy-saving method that controls electric	**agricultural monitoring using the Internet of Things.** Regarding technological development, the use of smart technologies as a source of energy and energy storage in solar PV panels should be mentioned as a leader in technological development. Smart technologies in recent years are more and more being used in the agricultural sector, especially in monitoring measures, such as dosing of nutrients needed for crops and various parameters control, for example, soil moisture control. Smart technologies are being used combined with solar energy technologies, and further technological development and proportion growth are expected in the future.	The household sector is increasingly using smart grids and smart meters, often using solar energy systems as RES, and it is expected that in the future The use of smart technologies will increase and they will be used by people who think more about energy savings and energy efficiency measures. Reduced PV panel prices facilitate the installation of technology in households. It is estimated that the installation of solar thermal energy equipment is currently experiencing rapid development due to the growing interest of engineers, architects and individual consumers in renewable energy	the increase in the share of electric cars, the use of solar road technologies will also increase due to the need for charging stations. In the future, the use of solar road technology is expected to be an important tool in creating a decentralized energy supply through charging stations. One of the leaders in the development of solar road technology is China, which is constantly making various improvements. Example: *A solar emergency lane has been introduced on the*

		increasing use of solar thermal systems. **It is estimated that more and more industrial companies use solar panels and collectors to reduce fuel costs, reduce environmental pollution, and improve market competitiveness.** Studies have estimated that the highest potential for the use of solar energy is for example for motor vehicle plants, textiles, printing, metal products, paper, rubber, plastics, chemicals, food and beverages, and electrical equipment. Example: According to the information in the publications, it is estimated that the use of solar-powered equipment can save 12,9 kilotonnes of diesel and reduce CO2 greenhouse gas emissions by 41 kilotonnes per year. *It is estimated that using solar energy in pharmaceutical production processes can save about 30% of the annual diesel*	water heaters so that they do not affect the total maximum monthly energy consumption of the specific building. **The possibilities of technological use of solar energy are being developed more in recent years and solar energy as an energy source are widely being used in the wastewater sector**. The use of solar energy technologies involves the recovery of heat from mainly previously treated wastewater. Heat pumps are used to recover energy from wastewater, electricity is generated using solar PV panels.		sources. This is partly due to global warming and the need to replace traditional energy sources with RES technologies. In the household sector, zero-energy buildings using solar energy systems as an energy source are increasingly emerging as an emission reduction solution. Faster development of zero energy buildings is also planned in the future, therefore it can be concluded that the share of solar energy use in the household sector is expected to continue to increase, as collectors, PV panels and heat pumps are often used in zero energy buildings.	*roads in the provincial capital of Shandong, near Beijing. It is estimated that solar road technology can generate up to one million kWh of energy, which is enough to supply about 800 households in China.*

		consumption previously used for providing industrial processes. *The electroplating plant in Zhejiang Province, China, uses solar energy as the primary energy source for electroplating processes, and the installation of solar thermal devices is estimated to reduce CO_2, SO_2, and NO_x emissions by 390 tonnes, 1.400 tonnes, 45 tonnes and 22 tons.* Solar collectors and an air heat pump were installed in an area of 129.6 m^2 in one of China's cement plants in Jiangsu Province. As a result it was estimated that each year CO_2 emissions decreased by 558 tonnes, SO_2 emissions by 1.47 tonnes, NO_x emissions by 0.76 tonnes, and particulate matter emissions by 5.03 tonnes. Lately, large scale research is focused on solar drying devices for agriculture and the food sector.				

	Wind energy	**3 – limited development, in the future - 4** It is estimated that in recent years China is the dominant country in the production of wind turbines and the use of wind turbines in the industrial sector continues to grow.	**3 – limited development** The development of wind energy is influenced by the human factor and people's prejudices about wind generators and their negative impact on the environment, change of visual landscape.	**3 – limited development** The development of wind energy is influenced by the human factor and people's prejudices about wind generators and their negative impact on the environment, change of visual landscape.	**3 – limited development, in future – 4 – second fastest development** Growing interest in the possibilities to provide individual electricity - using low-power turbines and installing them on the roofs of houses. Consequently, an increase in the share of use is also expected in the future. In recent years, a significant number of household-type wind turbines have been installed to provide electricity to non-urban households, and energy independence issues are expected to be just as important in the future, and the number of microgeneration wind turbines used will increase.	**4 – the second fastest development or 5 - fastest development in future** The use of wind energy is one of the solutions to replace fossil fuels and reduce fuel imports. The use of wind energy has been shown to have a high potential for hydrogen production and It is expected that with the increase in the share of cars that use renewable hydrogen to run, the need to use wind energy resources to produce hydrogen will increase at the same time. Along with the requirements set by the EU, by 2050

						there will be more and more thinking about how to decarbonise the transport sector and one of the solutions will be a GHG-neutral fuel. Consequently, the share of wind energy use for hydrogen production is expected to increase in the future.
	Hydropower	**3 – limited development, in future – 4 – second fastest development** It is estimated that China has great potential for development in the use of hydropower resources. **The potential and use of hydropower are primarily dependent on the different availability of hydropower resources.** In developed countries, the use of hydropower is estimated as	**3 – limited development** The use of hydropower in hydropower plants is hindered and influenced by people's opinions about hydropower plants and their impact on the environment and landscape, as well as the use of hydropower is influenced by the availability of water resources.	**3 – limited development** The use of hydropower is influenced by the availability of water resources and the human factor. Lack of information to provide information on the stage of development	**4 – second fastest development** There is an increasing trend in individual households to use independently supplied electricity as a small-scale hydroelectric plant as an energy source. One of the most advantageous is the PHP system, the share of which could increase in the future as well,	**3 – limited development, in future could be – 4 – the second fastest development** The potential of hydropower depends directly on the flow rate and the height gradient between the two water layers.

		high reaching on average 60% - 95% in contrast in developing countries, the use of hydropower is assessed as low. Example: *Related to Ecuador Strategy until 2025, one of the main scope of activity is the development of strategic energy-intensive industries like oil refineries, petrochemicals, aluminium, copper, and steel production which require a huge amount of energy which can be provided from large scale hydropower plants. Related to Ecuador's development strategy the use of hydropower is now considered to be a key solution for energy security, reducing electricity prices, and greenhouse gas emissions.*			because using the PHP system does not require the construction of dams and thus also reduces the negative environmental impacts traditionally associated with hydropower plants.	In Ecuador, the extraction of hydrogen by electrolysis has been assessed as one of the most environmentally friendly solutions with one of the lowest environmental impacts when hydropower is used as an energy source. In Nepal, it is estimated that one of the main tools in the transport sector to increase and promote the sustainable use of local hydropower resources is the transport electrification policy by increasing the capacity of electricity generated by

						hydropower to 495 MW by 2050. The development of the use of a resource is also influenced by its availability. It is expected that the share of resource use will increase in the future along with the increase in the share of electric cars.
	Biomass (including biomethane)	**4 – Second fastest development, expected in future too** Based on 2017 data, it is estimated that solid biomass was the only source of renewable energy in the 28 countries of the European Union with a significant share of energy use - 93% of the renewable energy used in the industrial sector A further increase in the use of biomass is also forecast in the future.	**3 – in other sub-sectors, 4 – the second-fastest development in catering service** Biomass is not limited by energy shortages, and energy can be provided equally throughout the year, in the service sector, it is more relevant to the treatment of kitchen waste from the catering sector for energy.	**5 – fastest development, expected in future too** In recent years, more attention has been paid to biogas and its quality improvement as an alternative energy source to replace fossil fuel. The use of agricultural residues has a high potential for use, and it is estimated that in the future the proportion of agricultural residues for energy production will increase. The	**4 – the second-fastest development and perspectives in future – 5** Throughout the European Union, wood is used in households for both individual heating and district heating. Several small-scale pilot plants have been set up in several Member States of the European Union, using	**5 – fastest development and perspectives in future** There is a rapid development of biomass use, which is also expected in the future, due to the search for solutions that can replace fossil fuels, and biomass resources offer opportunities for

		Most biomass amounts are used in sectors where biomass residues are directly generated to provide the temperature conditions necessary for processes and heat energy. Most solid biomass for thermal energy processes is consumed in sectors where biomass residues are formed in production, for example - pulp, paper production, printing, wood processing plants. It is estimated that the total biomass used for energy in these sectors was about 85% of the total energy consumption of industrial biomass. Based on 2017 research data, it is estimated that 69% of the proportion of primary energy production was produced using solid biomass **The use of % biomass depends on each specific country or region**. Based on 2017. year data it was estimated that in almost all		use of agricultural residues is linked to the production of energy for processing into biogas and the improvement of the quality of made biogas to provide requirements of biomethane, which are used as a fuel for vehicles. It is Estimated that lately particularly rapid development in the use of agricultural residues has been in Sweden. The Swedish International Renewable Energy Agency has calculated that by 2030, 13-30 EJ $y-1$ of agricultural residues should be used for energy production to reach specific sustainable energy targets of doubling the proportion of renewable energy by 2030. It is also estimated that the use of cereal and sugar cane residues for energy production will make a considerable contribution to achieve the set goals. One of the priorities in the agricultural sector-related	different energy crops as raw materials. Modelling scenarios for the future use of biomass and the results show that biomass is recognized as the most competitive energy source in the household sector for the next three decades until 2040-2045. According to the results of the study, it was identified that the dynamics of geothermal resources is an important component in the assessment of the energy system.	expansion or combination of fossil resources in the transport sector. The increased use of biofuels has been identified as a solution to reduce carbon emissions in the transport sector and to meet the European Union's target of replacing 10% of fossil fuels with biofuels. In Finland, it is estimated that biocomponents already account for a proportion of all transport fuels. In the Scandinavian countries, the development of faster use of biomass in the transport sector has been assessed with the aim of decarbonising it in accordance with the

		European Union countries, the proportion of solid biomass in the total energy consumption of the industrial sector in 2017 was more than 30%, but In Belgium, Denmark, Ireland, and Luxembourg, this proportion exceeded 70%. Other research shows that in Ireland, more than half of solid biomass (53%) is used in the industrial sector for processes, but in Finland, Sweden, Slovakia, and Portugal the proportion of solid biomass is over 40%.		biomass is the production of biomethane from biogas using manure combined with agricultural residues as a raw material for biogas to enrich biogas quality and provide requirements for biomethane. In recent years more and more research is focusing on which type of agricultural residues have the greatest potential to provide biomethane quality requirements. Biomass is not limited by renewable energy shortages and energy can be provided equally throughout the year, more and more biomass being used as a stable source of additional energy in hybrid systems, compensating, for example, wind and solar energy interruptions.		goals and objectives set by the EU. Biofuels derived from biomass are currently and for the foreseeable future considered to be the main possible solution to reduce the use of crude oil. Support for increasing the share of biofuels is promoted by issuing biofuel certificates certifying compliance with sustainability criteria for each tonne of biofuel produced.

	Geothermal energy	**3 – limited development, faster development is expected in the future – 4** It is estimated that the actual use of geothermal energy is considered as low even though the use of geothermal energy has several advantages. It is estimated that Medium enthalpy geothermal energy has great potential as a source of central heating and cooling, and the use of geothermal energy is expected to increase in the future. The share of use can be increased by using geothermal energy in combined systems, for example, in solar energy systems by providing power in case of solar interruptions. The use of geothermal energy is increasing lately, and combined systems are being used more and more.	**4 – second fastest development of resource use in recreation and tourism, which could increase in the future** The development of the use of geothermal energy in the recreation and tourism sector can be assessed as the second fastest with the potential to grow in the future as well. In other sectors of the service sector, the use of geothermal energy can be assessed as low. This can be partly explained by the heterogeneous availability of geothermal resources, the possibilities of wider use have been assessed in those regions where geothermal energy sources are more widely available.	**3 – limited development** It is estimated that geothermal energy use affects geographic location, resource availability.	**4 – second fastest development** In Germany, rapid development in the use of geothermal heat pumps in households has been assessed, thus providing heat independently. In many countries with colder climates, heat pumps are considered part of future energy systems. Many passive houses use heat pumps.	**3 – limited development** There is a small amount of information in the literature on the use of geothermal energy, which essentially provides heat, but in the transport sector, there is more need to provide electricity. Influenced by development Geographical location, climatic and regional differences. Greater development in places where resources are widely available, such as Iceland. A study in Iceland assessed the relationship between the

						dynamics of geothermal resources in the context of the establishment and development of a sustainable energy system in Iceland. The study included an assessment of electric vehicles as Iceland's decarbonisation strategy in the transport sector. The study estimates that the inclusion of geothermal resource dynamics provides an opportunity to expand the electrification of Icelandic transport.

2. Which RES resource has the greatest use of advantages?

5 - the most promising

4 - the second most promising

3 - less perspective, there is some serious limiting factor
2 - Even less perspective, several limiting factors
1 - least perspective or no perspective

Table 2.32

Which RES resource has the greatest advantages of use?						
No.	Energy resource	Industry sector	Service sector	Agriculture sector	Household sector	Transport sector
	Solar energy	**4 or 5 in the future – second most promising and in the future could be most promising.** **It is estimated that using solar thermal technologies, it is possible to cover 50-70% of the total energy consumption generated by the industrial sector** The required temperatures correspond to processes for which the required temperature is below 100 ° C and which can be provided using solar thermal technologies**.** Thus creating favourable conditions for the use of solar energy in industrial processes.	**4 or 5 – the most or the second most promising** **By installing PV panels and solar collectors, it is possible to obtain electricity and heat at the same time.** **Solar systems do not generate greenhouse gas emissions, but can significantly reduce them.** **Solar heating systems are suitable for use at the low and medium temperatures required for processes in the service sector.** **Wide range of use in the service sector** - Sollar energy can be used in the tourism sector, office service buildings, it is possible to find information on the	**5 – Most promising** **The wide use of smart technologies using solar energy as an energy source**. The advantages of smart farming are related to the higher quality of cultivated crops, higher productivity, efficiently managed, and monitored agricultural system and it is estimated that the functioning of this kind of system increases the incomes of the population. **Possibilities of using smart agricultural monitoring using the Internet of Things**. Solar energy PV panels are used as a solution to increase	**4 or 5 – the most or the second most promising** Uses both - solar collector and panels. Reduced CO2 emissions. Promotes diversification of energy supply and regional, national energy independence. Solar collectors can be integrated with the building structure in various ways: as a facade element, roof or balcony, as well as in rainwater gutters or compact systems. Studies have evaluated stone bed systems as an effective	**4 – second most promising** Solar road technology is a solution for the availability of electric car charging stations. Road-integrated solar PV panels can generate significant amounts of electricity and reduce emissions. Studies estimate that they can produce more than 804 GWh per year and that solar road technology can save 41 000 litres. The advantages of solar road technologies are

		It is possible using different solar energy technologies and specific modes to provide different temperatures for relevant industrial processes. Average temperatures which are up to 200 ° C - are achieved by using ultra-high vacuum plate collectors and vacuum tube collectors with concentrators, but solar concentrators like parabolic, *Fresnel* collectors, can generate pressurized steam at temperatures up to 400 ° C. Flat plate collectors and tube-type collectors (ETCs) are suitable for processes that require low temperatures while parabolic collectors for production processes with higher temperatures (above 250 ° C). According to the publications reviewed modern designs have been developed for flat plate collectors (FPCs) and pipe collectors (ETCs), for example, flat plate collectors are equipped with transparent insulation material to ensure high-	use of solar energy systems in public institutions, including providing heat and electricity to schools. In the hotel industry from renewable energy sources, mostly solar energy technologies are used and especially solar energy PV panels for electricity generation and solar water heating systems for heat. Research estimate that people prefer as the best option solar panels installed on the roof rather than those installed on the ground. Example: 50 kWp PV panels installed on the roof using EPC mechanisms, which allowed the hotel complex to save til 21% of electricity consumption and evaluated payback period was 5 years. Taking into account the installed maximum capacity and solar radiation conditions, the annual energy savings for the hotel complex using solar energy PV panels were calculated til 75,000 kWh /year.	the life of the sensor network and to store energy. The energy required to operate the IoT sensor unit is obtained and stored from solar energy PV panels and can be used directly to charge the sensor unit. Excess solar energy can be stored in the battery so that the Internet of Things (IoT) node can also be operated at night. **Precise farming methods can be used**. If the Internet of Things (IoT) and wireless sensor networks (WSN) are used in agriculture, where solar energy technologies are used as an energy source, then it is possible to apply precise farming methods and provide precise control parameters measurements of crops and livestock. By using precision crop monitoring technologies, it is possible to reduce costs and increase production efficiency,	solution for solar energy storage. It is possible to use different types of solar collectors, such as a concentration type collector, which uses direct sunlight and can provide high temperatures. It is possible to reduce heat loss while maintaining the smallest size of the solar collector and heat accumulator.	related to the fact that solar PV panels can be adapted to any type of road infrastructure, for example, highways, parking lots, bicycle lanes. It is also possible to install on the existing surface without prior engineering reconstruction or other pre-installation work. Electricity generated by solar road technologies can reach 280 MWh per year, in summer - 1500 KWh per day. Example: *Chinese studies estimated that solar road technology could generate up to one million kWh of energy, which is enough to supply about 800 households in China.*

		temperature conditions up to 150 ° C. Estimated that for flat plate collectors, it is also possible to use multiple glazing, which allows reaching temperatures up to 110 ° C, also it is possible to use inert gas or extremely high vacuum, which allows maintaining a temperature of up to 150 ° C. **Depending on the type of use and the temperature required for the specific processes, it is possible to provide the following type of use of solar energy industrial systems:** use of solar energy to provide water in production processes; use of solar energy for steam generation in production processes; drying using direct or indirect solar energy systems (greenhouse type, collector type, combined greenhouse and collector type drying systems); desalination of seawater using solar energy; use of solar energy in refrigeration devices.	**Solar energy advantages are also related to solar energy use for cooling processes.** Example: Biomass and oil burners replacement or in case of biomass partial replacement by heat pumps to provide necessary cooling functions and ensure requirements for hot water preparation. As a result of technology change electro energy consumption necessary for cooling processes decreased by about 30%, but hot water consumption - by 89%. Combined with a heat recovery system, this has reduced biomass consumption for hot water by 70%. In Greece, there are solar-powered cooling systems with a total installed cooling capacity of approximately 1.500 kW. By installing additional solar collectors for existing solar collectors, it is possible to significantly increase heat energy savings and provide the necessary hot water, at the same time in addition to installing solar	because necessary plant nutrients are precisely dosed, and the relevant doses of for example herbicides can be determined more precisely. Smart farming systems are used as one of the solutions in areas outside cities. **Solar energy can be used in installations of different capacities**. Solar energy technology advantages are also related to solar energy flexibility and it is possible to use for low-voltage devices and high-power equipment. The use of solar energy does not cause atmospheric pollution and the duration of solar energy technologies - several years. **The obtained solar energy has a wide range of use**. Solar photovoltaic panels are also increasingly being used as an alternative energy source of electricity, for example for the treatment of electrochemical wastewater and contaminated		

		Solar systems are a solution to reduce greenhouse gas emissions as well as other pollutants emitted. Example: *Estimated that several European countries and also China, South Africa, and the United States are making a significant contribution to reducing CO_2 emissions from breweries production processes using solar energy as an energy source.* *According to the viewed research using the potential of solar-powered devices can save 12,9 kilotonnes of diesel per year and reduce greenhouse gas emissions by 41 kilotonnes per year.* *In one of the Chinese industrial plants, it was estimated that an effective way how to reduce CO_2 emissions by 3100 tonnes and SO2 emissions by 350 tonnes is to install a glass tube type collectors on roofs in the area of 7460.*	energy PV panels it is possible to provide electricity savings. Example: In recreation complex in addition to existing installed solar panels in the area of 144 m2 which covered approximately 22,5% of hot water requirements additional solar energy PV panels in the area of 170 m2 were installed, covering 50% of the hot water demand in the complex. Example: As a result of installing solar energy panels on the roof of the office building, energy savings were 86,700 kWh, which is about 11% of the total annual energy consumption with a payback period of 6 years. **For greater efficiency solar energy sources can be used combined with other RES.** In cases of solar energy shortages as a solution can be combined energy systems using additional renewable energy sources, as well as heat from sollar devices can be transferred to heat pumps or excess energy can be temporarily stored in storage tanks.	soil from herbicides and heavy metals. Example: *According to the research conducted using solar panels as a source of electricity in soil treatment plants after 15 days of treatment with herbicide-contaminated soil achieved 73,6% soil treatment efficiency.* The obtained energy can be used to provide drying processes in the agricultural sector. Research showed that the use of solar-based drying systems can improve product quality The advantage of solar-powered dryers is that the dryers do not emit carbon monoxide, carbon dioxide, nitrogen oxides, and other substances that are released during combustion processes. **It is possible to use hybrid drying systems, which are rated with higher drying efficiency**, improve product quality, where solar energy		

		One of the research estimated that the installing of solar panels in the Indian textile industry could reduce CO_2 emissions by approximately 1420 kt per year, which is 0,06% of India's total emissions. *According to research solar collectors and an air source heat pump were installed in one of China's cement plants in Jiangsu Province to replace the combustion plant area of 129,6 m^2. As a result of the changes 210 tonnes of coal per year, CO2 emissions by 558 tonnes, SO2 emissions by 1,47 tonnes, NOx emissions by 0,76 tonnes were saved and PM particulate matter emissions by 5,03 tonnes.* *In China, Henan Province solar energy and an air heat pump were combined to provide the necessary temperature conditions for tobacco drying and estimated that combination results as reducing CO_2 emissions by 450 tonnes.*	Using smart schedules combined with the use of solar energy technology can reduce water, heat, and electricity consumption. Solar energy PV panel combined with smart schedule, load reduction is already being used to reduce grid energy consumption, carbon emissions, peak load, and, for example, school electricity bills. Produced solar energy or excess energy can be transmitted to other devices like electric water heaters, heat pumps, or storage tanks. PV solar energy panels can be used in addition to other renewable energy devices, smart schedules, smart technologies - reducing energy consumption, and increasing cost savings. In South African schools using solar energy systems the maximum monthly energy consumption was reduced by 24%, with minimal energy losses Example: The smart planner was adjusted to heat the water needed for school, at the same time shifting the excess solar	technologies are used combined with other renewable energy sources. Solar thermal energy can be used as an effective solution to provide necessary temperatures for greenhouses as well as in some cases to increase productivity. For raising the temperature and as heat storage material are being used water storage systems, rock bed storage systems, or soil collectors. Example: *In research estimated that the stone bed system has a positive effect on tomato yields, which had improved by 22% compared to conventional greenhouses.* **The use of solar PV panels in irrigation systems is cost-effective for electro energy.** Solar energy technologies are increasingly being used as an energy source in water irrigation systems to provide water pumping, and it also has been estimated that it is more cost-effective to use solar energy in irrigation systems, saving up to		

		Viewed research estimates that using solar panels can save 18,15 million dollars a year and achieve a total CO_2 reduction of approximately 76 kt. **Short payback period - less than ten years**. *Example*: *In China, Luohe cigarette factory was installed solar collectors and air source heat pump to provide specific industrial processes, It was estimated that the payback period of the investments was six years.* **Solar thermal energy from collectors can be used to recover energy from wastewater and for the treatment of polluted wastewater** using a chemical oxidation wastewater treatment system that is operated by using solar thermal energy and can promote the degradation of persistent organic matter, promoting efficient wastewater treatment and which need low energy consumption.	energy to the water heaters to take advantage of the energy savings and increasing the school's energy bill savings to 26% per month. In addition to the smart schedule, a biothermal heating mechanism can also be used in combination with solar PV panels. Example: A bi-thermostat is heated to a temperature of 50 ° C to provide heat for transmission in the network and a temperature of 90 ° C to provide heat using excess solar energy. Example: Using a demand-limiting control scheme and limiting the maximum energy consumption of electric water heaters, the annual cost savings were about 30% less than the original school costs. Short payback period of fewer than 10 years.	60% of the cost of electricity consumed. **Electro energy from solar energy can be used to convert biomass residues into biochars**. Excess energy from the produced solar energy is transferred through the electrical grid to the friction pyrolysis plant for an electric motor operation which provides the mechanical energy required for the heat treatment process. **Short payback period of fewer than 10 years**.		

	Wind energy	**3 – limited advantages, 4 – in the future if combined systems are used.** **Wind energy can be used in combined systems with other renewable energy sources or in energy storage systems**. **Wind energy can be used as an energy source for specific processes**. Wind energy can be used as an energy source for the ammonia production process. Estimated that at the time when electricity demand is low, for example at night, wind energy can be used to produce hydrogen for further ammonia production and it provides higher revenues than electricity sales	**3 – limited advantages.** Wind energy is used more in the hotel industry, where the main focus is on sustainable thinking. “Green hotels” use “green” tariff energy - they use electricity from the electricity grid obtained from renewable resources, which often also is wind energy The use of wind energy is influenced by the positive or non-efficient human factors.	**3 – limited advantages, 4 – if hybrid systems are used to cover the wind energy deficit.** The use of wind energy is an efficient way of obtaining electricity if other renewable energy sources which balanced and ensure stable energy production for compensating wind shortages. Solar PV panels or biomass are often used as an additional source of electricity. Example: *In research estimated that the combined system with an installed capacity of 1.5 MW, where wind energy combined with biomass is used as an energy source, can operate without limitations and the obtained electricity can be transmitted in the centralized grids.* Wind energy can also be used as an energy source in water	**4 – the second most promising** Hybrid wind energy systems are used, like combined wind and PV panel systems, which are rated for higher efficiency and are able to compensate for energy shortages from other energy sources and provide greater stability in renewable energy production. The right combination of wind and solar photovoltaic (PV) systems can create optimal configurations that increase annual energy production. Hybrid systems have also been assessed as more cost-effective. Hybrid systems can be integrated with energy storage technologies to provide energy reserves. It is possible to use low-power microgeneration wind turbines to provide electricity at the household level.	**4 – the second most promising, in future – 5 – most promising** Compressed and stored hydrogen produced from wind energy can be used as a fuel in the transport sector, reducing fossil fuel imports and at the same time reducing greenhouse gas emissions. *Example: Studies have estimated that fossil fuel consumption and thus CO2 emissions in Sweden can be reduced by up to 50% with 530 kilotonnes of hydrogen.* In Germany, the use of stored and compressed hydrogen gas instead of fossil fuels has been

				pumping systems, as well as an energy source for soil for electrochemical treatment.		identified as a possible solution to reduce wind energy surpluses and GHG emissions in the transport sector. Example: *According to a German study, the technical potential for wind - hydrogen electricity generation was 780 TWh per year, potentially replacing 80.1% of the fossil fuels currently used in the transport sector*. The hydrogen produced can be used not only in the transport sector but also in the grid, providing electricity, heating to local or remote settlements. Hydrogen produced with wind energy can be used as an energy carrier to compensate

						for wind energy interruptions. The produced hydrogen acts as an energy carrier, and the advantages of its use are also related to the security of energy supply, energy supply opportunities in rural areas. The benefits of using hydrogen from wind energy are also linked to the economic benefits. Example: *In the United States, replacing gasoline with renewable hydrogen fuel is estimated to save a total of $ 4249 million per year based on a gasoline price of $ 29*
	Hydropo wer	**3 – limited advantages** Most of the energy required for the processes is provided by large-scale hydropower plants that can provide the capacity for	**3 – limited advantages** Energy from large hydropower plants is mainly used.	**3 – limited advantages** The possibilities of using hydropower are limited by the geographical location and availability of water resources, the attitude towards hydropower	**3 – limited advantages in cities, in rural areas – 4** Pico hydropower equipment is rated as the best option on the market with the lowest price.	**3 – limited advantages, in future could be 4** Similar to wind-generated electricity, hydroelectric power

		the processes which require a huge amount of energy.		plants, and their impact on the environment.	PHP systems are used to provide electricity in rural and mountainous areas. Using PHP hydropower facilities to provide rural communities with about 30 households. The advantages of PHP equipment are cheap maintenance, easy installation. Many low-income households around the world are choosing for PHP equipment as a more appropriate and secure solution compared to wind power or solar PV panels.	can be used for electrolytic power. **Hydrogen production**. Example: A study estimated that 1.5% to 8,5% of the surplus energy produced is needed to produce enough electrolytic hydrogen to operate public transport in Foz de Iguazu. In Nepal, it is estimated that one of the main tools for increasing and promoting the sustainable use of local hydropower resources in the transport sector is the transport electrification policy until 2050, increasing the capacity of electricity generated by hydropower to 495 MW. In the reviewed literature, information

						on the possibilities of using hydropower in the transport sector is limited.
	Biomass (including biomethane)	**4 – the second most promising Using biomass, it is possible to provide the temperature range required for industrial processes.** **Biomass is not limited by energy shortages, and energy production from biomass can be provided equally throughout the year.** **Wide possibilities for extraction of biomass or its residues**. Solid biomass for energy can be obtained from organic residues f from forests and uncultivated land, energy crops, organic waste and residues from industry, waste from agriculture and organic residues from raw materials or products, waste from food and drink sector, organic municipal waste.	**3 – limited advantages or in future – 4** Kitchen waste is collected from the catering sector and processed for further biogas production. The amount of discarded and untreated waste is reduced. Cogeneration technologies based on solid biomass have been assessed as advantageous in cases where it is necessary to provide processes that require large amounts of energy, for example to provide heat for indoor swimming pools.	**5 – the most advantages in the future too, if more agricultural energy is used to produce energy.** **Biomass can be transformed into chemical products to produce electricity, heat, and fuel.** Agricultural residues such as cereal straw, rice husk, animal manure are produced at different processes of agriculture and can be used in energy production processes, also agricultural residues do not compete with food production how it is in case of solid biomass **The use of agricultural residues for energy production has been assessed as efficient, especially in rural areas, where agricultural residues are produced in agricultural processes**.	**3 – limited advantages in cities, 4 – the second most advantages of using biomass if residues are used as an energy resources** Using biomass, it is possible to obtain both electricity and heat raw materials by converting raw materials into charcoal or gas through heat treatment. By replacing fossil fuel boilers with biomass boilers, a significant reduction in fossil resources and CO_2 emissions is achieved. Example: *The study estimated that the replacement of boilers from heavy fuel oil to biomass reduced the share of non-renewable energy sources by 92.28% and reduced CO_2 emissions by 93.78%.* Biomass efficiency can be increased by thermal and	**5 – the most promising in the future too, if more agricultural energy is used to produce energy** Can be used in all five resource categories, agricultural residues are increasingly being used as feedstock for high methane biomethane. Different types of biomass are used for biofuel production - residues from different sectors, waste, algae with the aim to obtain such fuel that can be burned with a higher degree of refining and without mixing restrictions. Biomethane is the only biofuel that has better properties than

		Estimated that It is possible to use both - raw biomass and heat-treated biomass. Solid biomass can be used both without thermal conversion and thermally modified biomass. Heat-treated biomass has higher efficiency and density compared to raw biomass. **Wide possibilities of using biomass as an energy source.** Biomass is used to recover chemicals and produce steam for industrial processes. It is estimated that fossil energy resources used in cement production processes can be replaced with biomass. The high temperature in the cement kilns makes the biomass residues suitable for combustion for energy obtain. Biomass is also used in the production of biofuels and electricity, in the last years more and more biomass is used as a raw material in the chemical industry, replacing fossil fuel with biomass.		**In research, it was estimated that the use of agricultural residues for energy production could improve the total CO_2 balance.** **Agricultural residues use has the potential to generate sustainable energy if biomass is transformed appropriately, however, biomass can also be used without treatment** **Synthesis gas can be obtained from agricultural or forestry biomass residues**. It was estimated that biomass residues can be converted into synthesis gas to produce electricity or heat or chemicals. Using biomass and its residues In addition to synthesis gas, biogas, hydrogen, biomethane, bioethanol, and biodiesel can also be obtained **By enriching biogas with agricultural residues and organic kitchen waste, it is possible to obtain gas that**	other conversion methods - pyrolysis, co-incineration or biological methods such as gasification, anaerobic digestion. Biomass efficiency can be increased by increasing the efficiency of cogeneration by up to 85%.	fossil fuels and can reduce dependence on fossil fuels. According to the studies reviewed, the use of biomethane in the transport sector offers significant cost savings. The enclosure obtained using electromethane is smaller. Biomethane can also be used in commercial vehicles, buses, as well as some heavy-duty trucks. The inclusion of a pre-treatment stage for raw materials can increase the efficiency of lignocellulosic biomass for further processing into biogas. Various technologies can improve the quality of biogas to produce biofuels consisting of

		High potential for the use of torrefied biomass has been assessed lately. Example: *In one of the research was assessed the potential for the use of torrefied biomass in the steel industry in Finland, where about 92 PJ of steel is produced per year. The results showed that powdered coal could be completely replaced by charcoal made using torrefied biomass*.		**meets the quality of biomethane**. **Energy can be stored by converting agricultural waste into bio-coal using friction pyrolysis.** In recent years, methods for thermal treatment of biomass have been increasingly used. As one of the most broadly methods used is friction pyrolysis which can be used to thermally transform agricultural residues into bio-coal. Method of friction pyrolysis provides that electricity obtained using renewable energy sources, where agricultural residues are used as a raw material, can be used to transform biomass into bio-coal. The conversion of agricultural residues (for example maize residues) into biofuels using friction pyrolysis can be used to transform raw materials into high carbon products		95-99% methane and 1-3% CO2.

				Biomass is used in hybrid systems as a solution to compensate wind and solar energy shortages.		
	Geothermal energy	**3 – limited advantages or 4, if wider usages in different sectors are developed** **Using geothermal energy, it is possible to reduce costs, provide production processes that require high load conditions**. By using geothermal energy, it is possible to reduce energy costs, including part of the total production costs and to provide the supply of energy in one place and to carry out production processes in heavy load conditions. **It is possible to use geothermal energy in the industrial process for heat conservation and reuse.** **It is estimated that from industries geothermal energy nowadays is most used in the**	**4 – the second most promising advantages** Geothermal energy is broadly used in the tourism sector and recreation, the use of geothermal energy does not require large investments compare to other renewable energy sources. .	**3 – limited advantages** **Geothermal energy in the agricultural sector can be used in aquaculture to ensure the necessary temperature conditions for trout growth in farms**.	**4 – the second most promising advantages** Geothermal energy does not require the recovery time required for fossil fuels (such as coal, oil and gas). Provides both electricity, heating and cooling in households. Energy saving potential - replacing direct electric heating with heat pumps reduces the amount of energy supplied. Electricity generation in various configurations, direct use of heat in industry and households regardless of meteorological conditions. The climate change mitigation potential of heat pumps increases when used in combination with other	

		agriculture industry and winery. Low enthalpy geothermal energy can be used in wine production processes – grape cooling, fermentation cooling processes. **To provide greater efficiency of stored energy, it is possible to use combined systems that reduce the gaps of other renewable energy sources like solar or wind energy**. Shallow (at a depth of 100-200 meters) geothermal energy systems are integrated into combined solar thermal systems and geothermal energy is often used in solar energy interruptions			types of RES. For example, solar PV and solar thermal.	

3. Which RES have some limitations and specific shortcomings?

5 - least limitations/shortcomings or no limitations
4 - almost the least limitations/shortcomings
3 - there are shortcomings to be considered that limit the use of the energy source
2 - serious shortcomings that temporarily limit the use of the resource
1 - the most disadvantages and limitations of the use of RES.

Table 2.33

	Which of the RES use opportunities in any of the sectors are limited and have specific shortcomings and why?					
No.	**Energy resource**	**Industry sector**	**Service sector**	**Agriculture sector**	**Household sector**	**Transport sector**
1	**Solar power**	**4 – almost the least limitations** Solar energy shortages in the months of the cold period of the year, the solar energy resource must be used with other energy sources - combined energy production.	**4 – almost the least limitations** Associated with solar energy shortages that can be compensated using combined systems or heat pumps, accumulation tanks, which provide energy and compensate solar interruptions. In the service sector, unlike from agriculture, less biomass is used, including biomass residues, but more used are solar energy, insufficient use of combined systems creates fewer opportunities to cover the shortfall of solar energy during the cold season. Lack of solar energy in the months of the cold season of the year so combined energy production with other energy sources should be used, for example, estimated that geothermal energy is broadly	**5 – the least limitations, can be compensate** Solar energy shortages in the months of the cold period of the year are compensated by using combined renewable energy sources systems - combined energy production in addition to other energy sources. It was estimated that the disadvantages of solar energy production are related to solar energy shortages affected by weather conditions and the efficiency of solar panel conversion. There are several solutions to compensate for solar energy interruptions. Solutions for solar energy gaps can be smart systems, and monitoring because thanks to	**4 – almost the least limitations** The disadvantages of using solar energy are related to the need to provide an additional source of energy in the conditions of insufficient solar radiation - using hybrid systems or using reserves from energy storage systems. Solar energy technologies can be installed more efficiently in the design phase of building structures than in existing structures.	**5 – the least limitations, can be compensate** The disadvantages are related to solar energy interruptions, which can be compensated by installing an additional energy source - hybrid systems.

			used to compensate solar shortages. Estimated that crucial is the human factor - ground-based panels compared to other renewable energy sources, rated as least desirable by the consumer perspective.	smart systems solar energy are used at the same time when it is produced. The drying system's biggest disadvantage, where solar energy technologies are used as an energy source, is related to the decreasing product quality when there are solar power shortages. One of the solutions can be hybrid systems, solar accumulation tanks that can increase the quality of the final product. In the agricultural sector, the efficiency of the irrigation systems is influenced by geographical location, the availability of water as well as user habits.		
2	**Wind energy**	**3 – there are shortcomings** Wind energy interruptions. Despite the actual and potential use of wind energy, the potential for wind energy use is influenced by its periodic character and wind energy interruptions in	**3 – there are shortcomings** Limitations on wind use are related to human factors and the reluctance to have wind turbines near their residence. In the service sector, the use of wind is also associated with a	**3 – there are shortcomings, in future – 4** Possibilities to use wind energy are partly influenced by local communities and cooperatives.	**3 – there are shortcomings, in future could be 4** Deficiencies can be compensated by using combined systems, using solar PV panels and wind energy systems, one energy	**3 – there are shortcomings, in future could be 4** The disadvantages of using wind energy are related to the periodicity of wind energy, but

		conditions of insufficient wind speed. Wind energy for industrial processes that require high energy consumption can be used if combined systems are used. In addition, another energy source must be used, such as biomass, the use of which is not limited by weather conditions, or additional energy storage systems	negative impact on the development of tourism. One of the main advantages of is related to wind power interruptions during periods of windless or insufficient wind	To provide stable electricity generation during wind energy gaps, should use combined renewable energy systems. Often, in the agricultural sector, wind PV panels or biomass resources are used in addition to wind energy.	source compensates other during periods of insufficient energy.	nevertheless to wind energy the potential for use has been assessed as high for hydrogen production. The wind – hydrogen energy potential is influenced by the power of the wind turbine used, the height of the hub and the efficiency of the proton exchange membrane electrolyzer. One of the most effective solutions for ensuring a stable load is to use bibrated energy systems in addition to wind energy using another energy source for electricity generation, and with such a solution

						it is possible to ensure a stable supply of electricity in the connected network and also outside the network. Another disadvantage of resource use is the availability of resources due to their geographical location, as well as climatic and regional differences.

3	Hydropower	**3 – there are shortcomings, 4 – depending on the specific country and resource availability** Flexibility and ability to compensate wind energy in case of its variability and interruptions.	**3 – there are shortcomings** The use of hydropower is highly influenced by the availability of water resources, people's attitude related negative impact of hydropower plants on the environment, and the landscape.	**3 – there are shortcomings** Lack of information on the possibilities of using hydropower in the agricultural sector. The proportion of resource use depends on the geographical location and availability of resources in a particular region.	**3 – there are shortcomings, outside cities in households – 4** Large hydropower plants have a negative impact on the environment and require large investments. Small-scale PHP is mostly suitable for use in rural areas or mountainous areas Suitable for individual households to generate a maximum power of up to 5 kW. Use is affected by the availability of water resources. PHP Equipment can be damaged and washed away by floods, and they are easy to move, so there is a risk of theft.	**3 – there are shortcomings** Restrictions are related to the availability of water resources. The reviewed scientific literature does not indicate a wide range of applications in the transport sector.
4	**Biomass (including biomethane)**	**3 – there are shortcomings, in future for the food industry could be – 4, if residues are used** The use of biomass is limited unless agricultural residues are used for energy.	**3 – there are shortcomings or in future in the catering industry – 4** The use of biomass in the service sector is influenced by that, except for the catering sector, the service sectors do not generate	**5 – the least limitations** Disadvantages related to the use of solid biomass in agriculture, which is related to limited biomass when residues are not used, disadvantages can be compensated if more	**3 – there are shortcomings, in future – 4, if biomass residues are used** The use of solid biomass as the only energy source causes emissions to air, but a significant reduction in emissions can be achieved	**5 – the least limitations** The quality of biomethane depends on the raw materials used, pre-treatment, as well as biogas post-treatment methods,

			raw materials that can be used for further energy production. The use of solid biomass is affected by the processes emissions	agricultural residues, organic waste will be used for energy production. The moisture content of certain types of agricultural residues greatly affects their energy recovery potential. If appropriate types of agricultural residues with appropriate moisture content are selected for energy production, then it is possible to obtain higher energy potential, if inappropriate - then lower.	by switching from fossil fuels to biomass boilers. Biomass residues are underused for energy production, although their high energy potential has been estimated.	their efficiency and cost.
5	**Geothermal energy**	**4 – almost the least limitations** The disadvantages of using geothermal energy are related to the availability of resources. A geothermal energy resource is used more as an additional renewable source in combined systems providing energy during solar or wind gaps.	**4 – almost the least limitations** The disadvantages of using geothermal energy are related to the availability of resources and dependence on geographical and regional differences.	**3 – there are shortcomings** The disadvantages of using geothermal energy are related to the availability of the resource, which depends on the geographical location and climate.	**3 – there are shortcomings** The heat pump requires additional power to reach the temperature increase. Geothermal energy can pose specific problems compared to other renewable energy technologies, such as difficulties in adapting the system to an existing household. There are cases that in the household after the first winter, after the installation	Almost no use in the transport sector, exception could be underground transport - metro. Geothermal energy can produce, but in transport sector electricity is required.

					of the heat pump, the cost of electricity is significantly higher. Can provide both - heating and cooling, or just heat.	

2.6.2. RES evaluation matrix and choice of criteria

The assessment consists of qualitative information within the sector and the obtained information on quantitative indicators, which together make up 1 to 5 points.

- qualitative assessment (from 1 to 5 (most promising)) - using the obtained information on the achieved results and real and potential possibilities of using RES, the extent to which RES is used in each sector (Table 2.35).
- quantitative assessment (1 to 5 (most promising) - payback period of invested investments (years) (for solar energy), energy savings (%), cost reduction by introducing RES technologies (Eur) (Table 2.34).

Based on the qualitative and quantitative criteria, a RES evaluation matrix was created, as well as a comparative analysis of RES use possibilities was performed (Table 2.36).

Table 2.34

Criteria to be used for quantitative assessment

Factor	Unit of measurement
Repayment time	years
Cost savings	Eur, %
Energy savings	kWh, MWh, %

Table 2.35

Criteria to be used for qualitative assessment

Factor
People's wished to use RES technologies
Potential future opportunities for technology
Possibilities of real/actual use of technologies
Technology gaps and limitations
Advantages of technology
Whether and how technology gaps can be addressed (for example, combined systems)

Table 2.36

No.	Energy resource	Sectors				
		Industry sector	**Service sector**	**Agriculture sector**	**Household sector**	**Transport sector**
	Solar energy	**4 or 5** (if combined systems are used). Solar power is used to improve market competitiveness, reduce energy consumption, and the price for required energy. Solar energy technologies have lower prices and shorter payback periods, which increases the proportion of their use.	**4 or 5** (if combined systems are used to cover peak loads during the cold period of the year). Already perspective possibilities of use and potential use in the future.	**5** Lack of solar and wind energy can be compensated with biomass, including agricultural residues, smart technologies that compensate for solar energy shortages and using energy when it is produced, and smart agricultural monitoring. The Internet of Things is increasingly used in agriculture, where the energy required to operate the Internet of Things sensor unit is obtained and stored from solar energy PV panels and used for charging the sensor unit. The obtained solar energy has a wide range of possibilities of use - it can be used, for example, in	**4** Uses smart grids and smart meters, other smart technologies, where solar energy can be used as an energy source. The use of solar energy promotes regional and national energy independence. Solar collectors can be integrated into various building construction elements. The share of zero-energy buildings is growing, and since both collectors and PV panels are often used in passive buildings, the use of these technologies is expected to increase in the future.	**4 and in future 5** Solar road technologies are increasingly being used, which is also important for increasing the share of electric cars, as there is a solution to the problem of the availability of charging stations. The use of solar road technologies can be an essential tool in creating a decentralized energy supply. Can be used as an energy source in hydrogen production. The electrolyzer uses solar energy to control the

				irrigation systems, drying processes, higher efficiency can be achieved by using hybrid drying systems, which combine several renewable energy sources, wastewater treatment, soil for removal of heavy metal and herbicide. The proportion of solar energy use is expected to increase in the future with the development of technologies. By using hybrid drying systems, it is possible to cover solar energy shortages, improve drying efficiency, and product quality. The use of heat storage systems (TES) can compensate for solar energy shortages during energy shortages (8.lp).		electrolysis processes, which results in the production of hydrogen, which can then be used in vehicles.
	Wind energy	**3 and in future 4** Related wind energy use in the industrial sector there are fewer sources of information. Because of its periodic nature, wind energy is used in combined	**3** Less information from publications about this sector can be found. The proportion of energy resource use is influenced by human factors and attitude that wind turbines	**4** Wind energy has the potential to be used to provide electricity to agricultural processes, the human factor is important in the installation of wind	**3 and in future 4** It is possible to install small-capacity microgeneration turbines for daily household electricity generation, energy independence	**5** Compressed and stored hydrogen produced from wind energy can be used as a fuel in the transport sector,

		systems with other energy sources to compensate for wind gaps. Wind energy can be used as an energy source for specific production processes, like ammonia production. With other renewable energy sources using combined systems, the proportion of wind energy has the potential to increase in the future.	could be with a negative impact on the service sector.	turbines, as well as the development of combined systems during wind energy interruptions, for example in combination with biomass residues.	issues have become more and more important and the share of such turbines is expected to increase in the future. Microgeneration turbines can also be used at the community level through cost-sharing and the installation of more efficient wind turbines. Higher capacities are used in hybrids, such as wind-PV or wind-biomass systems, which compensate for the periodicity of the wind, the hybrid system can be integrated with energy storage technologies, providing backups. Wind energy capacity is also partly influenced by geographical location.	reducing fossil fuel imports and at the same time reducing greenhouse gas emissions.
	Hydropower	Large hydropower plants are used to provide huge energy required for specific industrial processes. Hydro energy, like other renewable energy sources, can be used in combined systems, for example for	**3** There is a small amount of information from publications on the use of hydropower resources in the service sector which could be largely related to the human factor and their	**4** Hydropower is used in the necessary processes in agriculture, for example, for irrigation, and there are also opportunities for future use.	**3 – in cities, 4 – rural areas** Using PHP's low-power hydropower facilities to provide rural communities with about 30 households. Not suitable for urban use.	**3, in future 4** Similar to wind energy, it is possible to use renewable hydrogen production as an

		cover solar and wind energy shortages. The advantages of hydropower are related to its flexibility and ability to compensate wind energy gaps in case of its variability and interruptions.	perceptions of the adverse environmental impact of hydropower plants as found in publications.		Many low-income households around the world are opting for PHP equipment as a safer solution compared to wind power or solar PV panels.	energy source, which is used in vehicles. Advantages in places with abundant water resources, hydrogen production, has been assessed as an efficient way to use energy surpluses sustainably. An instrument for the implementation of electrification policy.
	Biomass	**4** Estimated that there is a great potential for use in the food and beverage industry sectors, where the residues or other organic waste generated and can be used for energy production in the company to provide other industrial processes. In other sub-sectors of the industrial sector, the real and potential uses are assessed as smaller.	**3 or 4** (based on the catering sector). There are more possibilities of use in the catering sector for the treatment of biodegradable kitchen waste in biogas plants. Organic kitchen waste used to enrich biogas to produce biomethane, which can then be used as fuel for vehicles. The treatment of waste generated in the catering sector has great potential for energy	**5** Agricultural residues in combination with manure, provide wide possibilities for biomethane production. Biomass and its residues in the agricultural sector have been assessed as one of the dominant renewable energy sources with a high perspective in the future. Estimated that biomass residues can effectively	The use of solid biomass in households is associated with emissions from the fuel used. The advantages of using biomass are that the use of biomass is not affected by weather and can be provided equally throughout the year, it is easy to store and it is possible to obtain competitive energy from	**5** Extensive use in all five resource categories, agricultural residues are increasingly being used as feedstock for high methane biomethane. Biomethane can also be used in commercial

		Extensive opportunities for obtaining raw materials from biomass.	production, but for the other service sectors, there is not enough information to provide an assessment.	cover solar or wind shortages using combined systems.	biomass residues, especially through cogeneration pellet combustion plants in private households. Nevertheless, biomass is projected to be the most competitive energy source in the household sector over the next three decades, from 2040 to 2045.	vehicles, buses, as well as some heavy-duty trucks.
	Geothermal energy	**3, in future 4** By using geothermal energy sources, it is possible to reduce energy costs, provide stable energy supply, and carry out production processes under high load conditions. Geothermal energy has a wide range of possibilities of use. It is estimated that medium enthalpy geothermal energy has great potential as a source of central heating and cooling and the proportion of geothermal energy use will increase in the future.	**4** Extensive use in some countries where geothermal energy is available does not require large investments. It is possible to use heat pumps. Currently more used in tourism and recreation. Extensive use with potential in the future depends on the availability of resources.	**3** Viewed publications contain a small amount of information on the possibilities of geothermal use in the agricultural sector. The proportion of resource use partly depends on location. In research, it was estimated that geothermal energy in the agriculture sector could be used in aquaculture to provide the necessary temperature conditions for trout growth in farms.	**3, in future, could be 4** Geothermal heat pumps are still used as heat energy sources in households, but their operation is sometimes associated with specific problems. One of them is the difficulty of adapting the system to an existing household. Replacing direct electric heating with heat pumps reduces the amount of energy supplied. One of the advantages is the direct use of heat in households, regardless of meteorological conditions.	**3** The use depends on the extent on the geographical location, which determines the availability of geothermal resources. Favourable use opportunities, for example, in Iceland.

Conclusions

1. Hydropower and wind energy have the most factors that limit their use a proportion of use highly depends on the human factor.
2. Solar power and biomass agricultural residues have the least limiting factors that limit their use.
3. Solar and wind energy shortages can be compensated using combined systems, estimated that biomass and geothermal energy are suitable for cover the peaks.
4. In recent years installation of solar collectors or PV panels payback period in less than 10 years.
5. In the agricultural sector most promising energy sources are biomass if biomass residues are used and solar energy with a high perspective in the future too.
6. In the service sector most promising energy source is geothermal energy, which is highly used in the recreation and tourism sector and solar power energy which is used for electricity, heating, and cooling processes.
7. For the industrial sector most promising is solar power using both – solar panels for electricity and collectors for heating.
8. Based on information about all tree sectors it can be concluded that solar energy combined with smart technologies, smart schedules are the most perspective solution for the future.

2.6.3. The comparison of RES sustainable development in the main sectors of economy

In the scope of this chapter the comparison of the sustainable development tendencies of renewable energy sources (RES) between all the sectors analysed in the study such as the industrial, services, agricultural, transport and household sector is performed. The aim of the analysis is to *find out which of the RES types is the most perspective and sustainable in each of the sectors and what are the circumstances that impact that.*

The content of the chapter is structured in the following way. At first the applied methodological approach that was used in order to perform the analysis and obtain the results is described in detail. Then the results are demonstrated for each of the sectors by describing the main factors influencing the results.

2.6.3.1. Description of the methodological approach

The analysis includes utilization of versatile methodology that includes the combination of both qualitative and quantitative method to obtain as objective and descriptive results as possible. Fig. 2.48 illustrates the main chronological steps of the applied methodology.

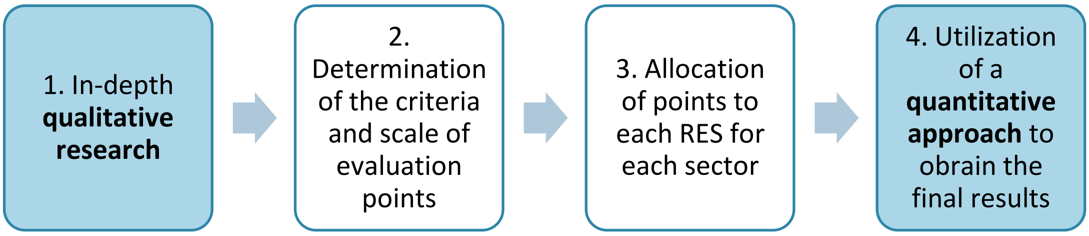

Fig. 2.48. The chronological stages of the analysis

At the beginning, an in-depth qualitative analysis is performed based on the scientific literature, previously executed studies, researches, reports and available information sources about the utilization of RES, their development tendencies and utilization specifics in each of the sectors studied. In order to obtain a sufficient analysis, three main criteria and aspects were determined that were further studied separately for each RES in the particular sectors. These criteria are the following –*technology development tendencies of RES, utilization benefits of RES and specific limitations of RES*.

For each of the defined criteria a point scale in a range from 1 to 5 was assigned, where 1 being the lowest and 5 – the highest grade. The points are assigned for each type of RES and sector according to the conclusions obtained as a result of the qualitative analysis. Table 2.37 summarizes the determined categories and criteria according, as well as the explanation of the defined point scales.

Table 2.37

The categories and evaluation methodology of RES sustainable development analysis

Name of the criteria	Research question	Scale of the points
Development	Is there observed faster technology development and advancement in any of the RES?	5 – the fastest development 4 – second fastest development, there exist limiting factors 3 – slower/limited development 2 – slow development

		1 – no development observed
Advantages	Which of the RES has the greatest utilization benefits?	5 – the most perspective 4 – second most perspective 3 – less perspective, there exist a significant limiting factor 2 – even less perspective, there exist several limiting factor 1 – the least perspective or no perspective
Limitations	Which of the RES has specific disadvantages or limitation in any of the sectors?	5 – no limiting factors or least limiting factors are observed 4 – almost with the least limitations 3 – there exist some disadvantages that limit the utilization of the energy source 2 – there exist serious disadvantages that at the moment limits the utilization of the source 1 – with the most disadvantages and limitation for the utilization of this RES

The assigned points were summarized in the tables of the qualitative analysis that allowed to get acquainted with the explanation of the justification for the assigned grades for each of the RES in the particular sectors. Afterwards, the points were gathered in a common table and data processing activities were further performed. A mathematic model in MS Excel program was developed to execute all the necessary calculations and obtain the results.

During the data gathering process it was observed that in some parts of the qualitative analysis the assigned points were in the range from, for example, 4 or 5, by explaining that the grade 4 represents the current situation and grade 5 will be potentially achieved in the nearest future or the grade has been achieved in one of the sub-sectors. In such cases as explained in this example, the average value, i.e. 4,5 was taken (in this particular example).

In addition, it was observed that in 3 places there were no grade assigned in the qualitative analysis due to insufficient information about specific type of RES in the particular sector. As a result, it led to the missing value identification in the overall data set. For example, in the analysis of the agricultural sector very limited information about the development tendencies and utilization disadvantages for hydropower was available. In such cases, in the model it was assumed to assign the grade of 3 points, that in the scale of the points is the most neutral value. Moreover, insufficient information about a particular type of RES utilization in a sector indicates that a possible explanation for lack of information in the sector means that there exist limitations in the development of RES. Therefore, the grade of 3 points represents the situation that there exist some limitations that hinders a sustainable development of RES.

After the data gathering and replacement of the missing values, data processing and normalization was performed. The obtained points in each category for each RES in particular sectors were normalizes in a way that, *the range of the obtained points are from 0 to 1, where 0 is the lowest and 1 – the highest value*. Assuming that each criteria has an equal influence on the sustainable development of a particular RES, equal weight categories were assigned to the obtained number of points. The mentioned data normalization technique is frequently used in sustainability analysis studies and researches, in order to obtain comprehensive and representative results. The range of the results from 0 to 1 allow to easily interpret the obtained results and obtain valuable conclusions about the existing performance level of sustainable development of a particular RES in a sector.

The obtained aggregated results of each RES show its long-term sustainable development performance tendency and potential. The closer the result is to the value of 1, the higher evaluation of its long-term development and potential in a sector is achieved.

2.6.3.2. Industrial sector

Comparison of RES development potential in the industrial sector is illustrated in the Fig. 2.49 According to the obtained results between different types of RES. It can be observed that in the industrial sector the energy utilization potential of solar energy and biomass is dominating. In other words, both of the energy sources are the most perspective and suitable for the industrial sector. Solar energy with the obtained 0,83 points reached the highest grade that was achieved due to the rapid development and higher technological advantages of the source. Solar energy for industrial processes is already widely utilized abroad and also in Latvia a rapid increase in the share of solar energy utilization among the industrial companies is observed. Increasing number of manufacturing companies invest in the installation of solar panels and collectors, as well as in the other solar energy systems, which allows to save up to 50%-70% from the total energy consumption. Technological development and potential of solar energy in the recent years have increased rapidly. At the moment various technological advancements of solar energy systems are observed such as the technological solutions with the integrated regimes that allow to regulate the necessary temperature for the industrial production processes which ensures that the solar energy is supplied to the significant manufacturing processes, for example, heating of the hot water, steam generation, drying and many others.

However, there exist a significant disadvantage that limits the utilization of the solar energy in industry. In the periods of cold weather, possible shortages in solar energy production might be observed, therefore it should be used together with the other RES, as a result it is necessary to ensure the combined energy production. Due to this reason the total results for solar energy did not achieve the maximum possible grade of 1. As it can be observed in the Fig. 1.2 the limitations criteria make up the lowest contribution to the total number of normalized points for solar energy. However, these limitations do not significantly hinder the utilization potential of the source due to the rapid pace of solar energy technological development and utilization advantages, as well as decreased investment repayment time. Moreover, there has already been introduced solutions to compensate the solar energy limiting factors, which in the long term will help the industrial companies to achieve even greater energy savings, become more energy efficient and reduce the GHG emissions from the production processes, as a result, reducing the produced impact on the environment.

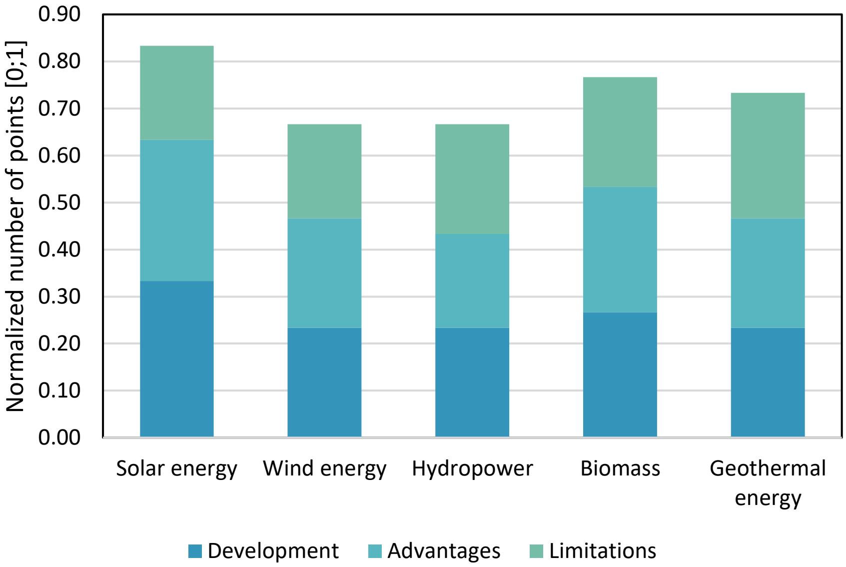

Fig. 2.49. Comparison of RES development potential in the industrial sector

High potential was identified for biomass utilization in order to produce energy for the industrial processes. Biomass obtained the second highest grade reaching a value of 0,77. A rapid development for biomass utilization potential has been already observed and projected to rapidly develop also in the future. Larger amounts of biomass utilization are observed in the sectors where biomass waste is produced from the manufacturing processes, for example in the cellulose, paper and wood manufacturing sectors. The use of biomass has the second highest advantage as an energy source. Technological solutions such as achieving the required temperature range for efficient industrial processes are listed as the most important advantages of biomass. The biggest advantage of using biomass is the equal provision of energy throughout the year, without creating energy shortages, which, in turn, is mentioned as the most significant limitation of resource utilization for solar energy. In addition, biomass has a wide range of extraction opportunities. It can be obtained from various types of organic waste, that occurs in forests, uncultivated land, and from agricultural and forestry activities. As the most significant disadvantage of the use of biomass is the shortages of biomass unless agricultural waste is used for energy production.

At the moment the use of geothermal energy has not yet achieved an equally high level of sustainable development evaluation result to compete with the potential for using solar or biomass energy, however, also this type of RES has number of advantage that contribute to the reaching a higher utilization of the resource in the future. The total results for utilization of the geothermal energy for the industrial processes is 0,73. At the moment, the development of this energy resource is slower compared to, for example, the rapid technological development of solar energy, however, it is expected that the technological solutions of geothermal energy will also develop at a rapid pace in the future. The current use of geothermal energy in the manufacturing sector is considered to be relatively low, however, it has a number of the following technological advantages, which can significantly reduce production costs, especially in high-capacity plants. Geothermal energy makes it possible to store heat and reuse it, which significantly optimizes production processes under high load conditions. Geothermal energy can be used in combined systems, ensuring energy supply to the plant in situations of solar energy shortages. The use of geothermal energy has almost the least number of disadvantages. Its limitation is related to the availability of the resource.

The grade of the evaluated potential for sustainable development of wind energy and hydropower is equal to 0,67, which is the lowest value among the analyzed types of RES in the industrial sector. Both resources are currently experiencing a limiting and slower development, which is influenced by the relatively low utilization possibilities of these resources for sufficient energy production for industrial processes. The potential and utilization of hydropower depends on the availability of different hydropower resources. However, despite the current limited developments, both types of resources are expected to develop increasingly in the future. The utilization of wind energy, like solar energy, has limited benefits due to changing weather conditions. However, this type of energy can be used in combined systems, where wind energy shortages can be compensated by another RES. Hydropower also has limited advantages due to the need for high technological capacity for energy production. However, it is able to adapt and compensate for wind energy shortages and interruptions.

2.6.3.3. Service sector

Comparison of RES development potential in the service sector is illustrated in the Fig. 2.50. Also in the service sector, the potential for the utilization of solar energy has gained a leading position with an overall grade of 0,90. In the service sector, the pace of development of solar energy technologies in recent years can be assessed as rapid, which has also been influenced by the demand of service sector companies for technology solutions of solar energy. In the service sector the combination of solar energy technologies with smart technologies accelerates the technological development and growth in the use of this RES. For example, solar energy technologies with integrated smart meters are widely used to control the load and consumption of energy in a various of public organizations, including in education institutions and other service sector organizations. The tourism sector is also experiencing a rapid increase in the installation of solar energy technologies, which are able to supply the required energy consumption on an almost full scale.

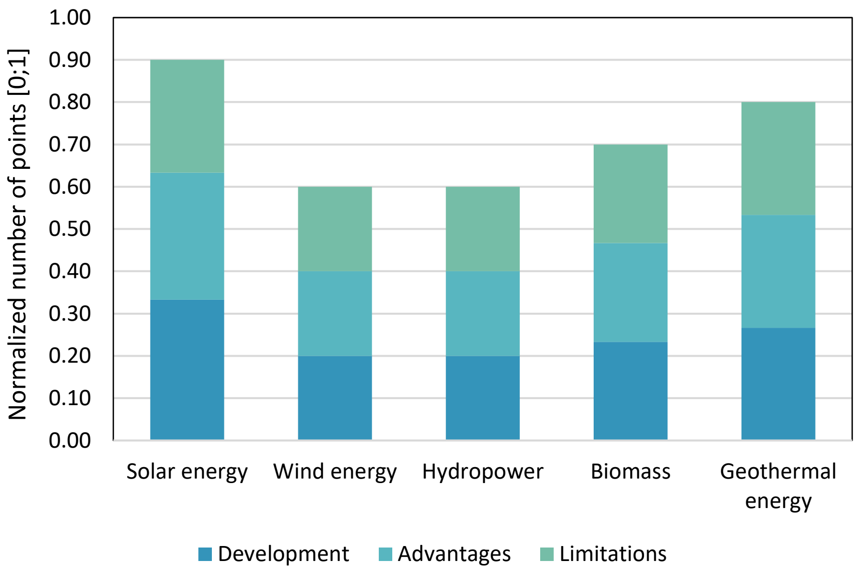

Fig. 2.50. Comparison of RES development potential in the service sector

More and more new technological solutions based on solar energy technologies are emerging in the market, such as heat recovery from wastewater, where the heat produced by PV panels is used in the heat pumps. In addition, the installation of PV panels and solar collectors generates not only electricity, but also heat. As a result, it is possible to provide the maximum amount of energy required for the necessary processes. The advantage of solar energy is its suitability for the low and medium temperatures required for most processes in the service sector. By combining solar energy technologies with smart solutions, companies in the service sector are able to significantly reduce water, heat and electricity consumption, thus also increasing their competitiveness. In addition, it is important to mention that solar energy technologies have a relatively short payback period, on average it is less than 10 years. This aspect serves as an important incentive for the introduction of these technologies in service sector companies.

Also in the service sector, the only limitation of solar energy is the shortages of energy during periods when it is not possible to produce it in the required amounts. However, solar energy shortages can be compensated by combined systems, heat pumps or storage tanks. The service sector is more grateful for the potential use of solar energy compared to, for example, with the industrial sector, as it does not require such intensive energy capacity and it is much easier and more cost-effective to compensate for energy shortages. The high results in the service sector has achieved the utilization of geothermal energy that has achieved the second highest value of 0,8 in total. Higher development of geothermal energy utilization is observed in the recreation and tourism sector. Although geothermal energy is not yet widely used in other service sub sectors, in general, the development of this type of RES is expected to increase in the future. In the qualitative analysis, geothermal energy is valued to have the second highest advantage, which is based on the fact that no large investment is required for the use of this energy source. Also, geothermal energy has almost the least disadvantages. The disadvantages of its utilization are related to the availability of resources and dependence on geographical and regional differences. The value of sustainable development and potential utilization of biomass in the services sector reached the third highest result or a value of 0,7. At the moment, the development of biomass utilization in the services sector has been slower than in other sectors, but the development has been rapid in the catering sector. Organic waste and food residues from the catering sector are collected and passed for further processing in biogas plants. This significantly reduces the amount of waste thrown away and unprocessed. The advantage of biogas is that it is not limited by energy shortages and can be supplied all year round. The most significant limitation of biomass in the service sector is the fact that, with the exception of the catering sector, other sectors of the service sector do not generate sufficient organic waste or raw materials that could be used for further energy production.

As it was observed in the industrial sector, the potential for sustainable development of wind and hydropower utilization in the service sector can be assessed as the lowest among the different RES considered. Both of these resources in the service sector evaluation scored 0,6 points for each in the services sector.

The development of both wind energy and hydropower in the services sector is influenced by general public's opinion and prejudices about wind turbines and hydropower plants and their impact on environment and landscape. In the service sector, the use of wind energy is associated with a negative impact on the development of the tourism industry. In turn, it is assumed in the society that the construction of hydroelectric power plants produce adverse effects on the environment and landscape. However, the sector has also seen the benefits of using wind energy. For example, in the hotel and accommodation sector, which focus on corporate social responsibility and sustainable activity, electricity is generated from electricity grids derived from RES, which are often wind energy grids. However, given the impact of the overwhelming views and prejudices of the general public on the use of wind and hydropower, these RESs are characterized by significantly slower development.

2.6.3.4. Agricultural sector

Comparison of RES development potential in the service sector is illustrated in the Fig. 2.51. The absolute leader among the analysed RES is for the utilization of biomass for energy production processes, that has achieved the maximum value of 1. Therefore, exactly this energy source in the agricultural sector achieved the most competitive and highest possible grade in each of the analysed subcategories. Such a result is natural and justified for the agricultural sector in particular. As a result of agricultural activities, a large amount of biomass waste is generated - useless agricultural product residues and organic waste, which can be used as energy sources. The use of biomass in the agricultural sector is experiencing the most rapid development and future prospects. With the growing interest and requirements for replacing fossil fuels with alternative energy sources, both the use of biogas and the implementation of its quality improvement activities are growing rapidly.

Agricultural waste such as grain and sugar cane residues, as well as manure, that are enriched with agricultural residues, are already in high demand among biogas production factories and the demand is projected to increase rapidly in the future. This This opens up additional production realization opportunities for farmers, providing a possibility to generate additional economic value. In addition, it is important to note that biomass, compared to other RES, does not show seasonality that would affect its development or stability. Respectively, biomass is not limited by energy shortages, which allow energy to be supplied throughout the year through the use of biomass in hybrid systems to compensate for periods when, for example, wind and solar energy are unable to produce the required energy amounts due to unsuitable weather conditions.

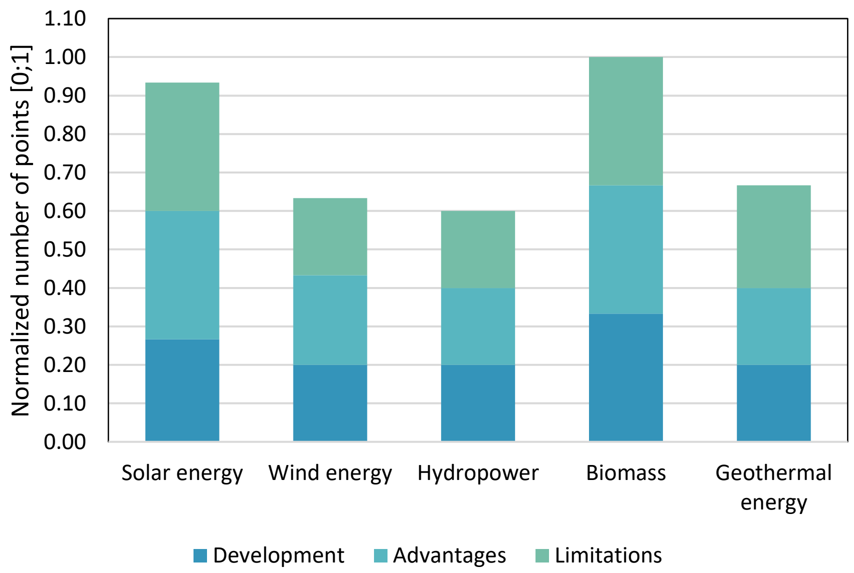

Fig. 2.51. Comparison of RES development potential in the agricultural sector

The second highest value in the agricultural sector with an overall grade of 0,93 was reached by the potential for the utilization of solar energy. The development of solar energy technologies are growing at the second fastest pace in the agricultural sector. In recent years, an increase in the share of solar energy technology utilization in the sector has been observed. Therefore, it ensures a detailed monitoring of energy consumption. In the agricultural sector, smart technology mechanisms integrated in solar energy technologies are used for such agricultural activities as, for example, dosing of protective equipment and nutrients, various parameters, incl. for controlling of soil moisture, etc. Further development of solar energy technology solutions is also projected in the future. In addition, depending on the installed capacity of the technology and equipment, the investment in solar panels and collectors can be repaid in less than 10 years, which provides additional incentives for farmers to invest in sustainable solar energy solutions. In addition, these technologies also have a longer service life.

There are numerous benefits for the utilization of solar energy technologies in the agricultural sector. Combined with the Internet of Things (IoT) and wireless sensor networks (WSN), where solar energy technologies are used as an energy source, it is possible to ensure precise control and management of crops and livestock. In addition, solar energy can be used in installations of different capacities due to its flexibility and ability to adapt to both low-voltage and high-capacity installations. The produced solar energy in agriculture can be used to provide a variety of agricultural activities - to operate drying systems, to provide the required temperature in the greenhouses, to operate various electric motors, etc. In addition, solar energy in agriculture has the least disadvantages. As already mentioned in other sectors, the lack of solar energy is the disruption of energy production due to unsuitable weather conditions. However, it does not have such a significant impact on agricultural activities, as they are often carried out at times and in seasons when solar energy is at high intensity and can fully cover the production of necessary energy amounts. In addition, smart systems can be used to prevent shortages. They can also be compensated by combined heat and power systems.

The assessment of the sustainable development of geothermal energy utilization in the agricultural sector reached a value of 0,67, which is the third highest result among the analysed RES, however, it lags significantly behind biomass and solar energy that have the leading positions. Compared to other RES, the use of geothermal energy in the agricultural sector has shown limited development in recent years. It is mainly affected by its limited use. Geothermal energy in the agricultural sector can be used in the aquaculture sector to provide the necessary temperature conditions for trout growing in farms. In other sectors, the use of energy is not as productive as, for example, the use of solar energy. Also, an important consideration is that the disadvantages of using geothermal energy are related to the availability of the resource, which depends on the geographical location and climatic conditions.

The assessment of the sustainable development and potential of wind energy and hydropower utilization achieved a value of 0,63 and 0,60, respectively, which are the lowest grades among the analysed RES in the agricultural sector. The development of both resources in the agricultural sector has been hampered the attitude and prejudices of general public about the impact of wind turbines and hydropower plants on the environment and the landscape. The potential of wind energy is greatly influenced by local communities and cooperatives. When assessing the advantages of wind energy, it can be concluded that wind energy currently has disadvantages that limits its utilization, which are affected by the dependence of weather conditions(periods of windless and insufficient speed of wind), which causes interruptions in energy production. However, if cogeneration is used to cover the wind energy deficits, the resource as a whole could be considered to have almost the least disadvantages. In agriculture, wind energy can be used to support and provide various activities, such as energy supply in water pumping systems, as well as energy sources for soil electrochemical treatment. The possibilities of using hydropower in the agricultural sector are also limited by the geographical location and the availability of water resources, as well as the public attitude towards the construction of the hydropower plants. However, it is important to mention that there is a lack of information on the possibilities of using hydropower in the agricultural sector, which indicates the limited development of this RES utilization, which makes it difficult to make accurate projections of future resource development tendencies.

2.6.3.5. Household sector

A comparison of the sustainable development of different RES in the household sector is illustrated in Fig. 2.52. According to the summarized results on RES sustainable development tendencies in the household sector, it can be observed that in general the obtained results fluctuate in a very similar range, however, solar energy is dominating. Solar energy achieved the highest number of points, which is equal to 0,83. This can be explained by the fact that in recent years in households there has been an increase in the installation of various smart grids and meters based on solar energy systems. The installation of solar energy technologies in households is stimulated by the reduction in the price of PV panels every year, as a result of which the total payback time of the technology is reduced and this solution is made more attractive. The development of solar energy technologies has been influenced both by the growing interest in RES and due to the rapid development in the construction of zero energy consumption buildings. In addition, solar energy has a number of significant advantages in its utilization, as it is possible to use both solar collectors to produce heat and panels to generate electricity, thus supplying the household with all the necessary energy and promoting the energy independence of households. Solar energy technology solutions allow to integrate them into the overall structure of the building, using them as facade elements. The high range of different solar energy technologies makes it easy to apply household-specific solutions to strive for higher energy efficiency. Solar energy is considered to have almost the least disadvantages. Existing disadvantages of solar energy utilization are related to periods when, in case of insufficient solar radiation conditions, it is necessary to use hybrid systems that would provide additional energy supply when necessary, or to use energy from installed energy storage systems.

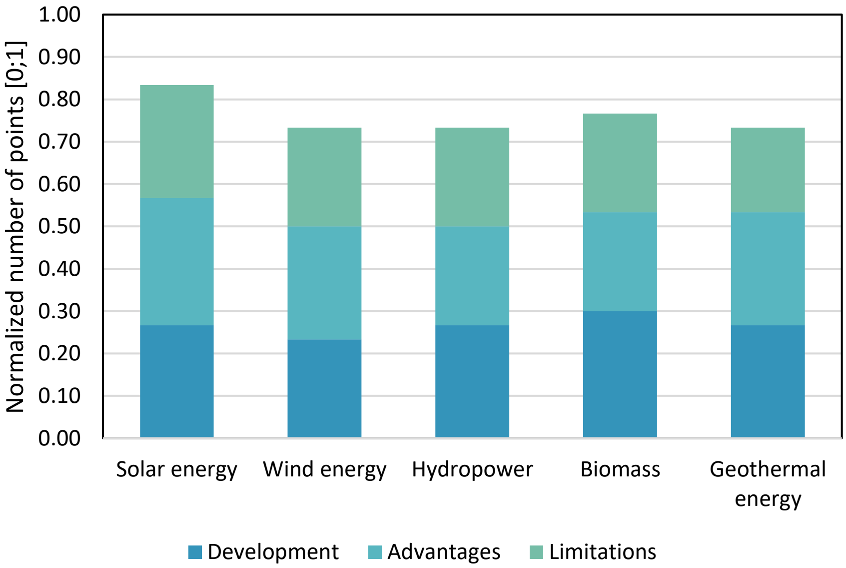

Fig. 2.52. Comparison of RES development potential in the household sector

The second highest estimated RES utilization potential was obtained for biomass, with the total obtained normalized grade of 0,77. This is justified by the use of wood to produce heat in the households in both individual heating and district heating systems. According to the results of the research, it is projected that the utilization of biomass to supply households with necessary energy has the fastest future development prospects and the highest competitiveness among other types of RES in the household sector. When assessing the advantages of the biomass utilization, it can be concluded that currently the use of biomass has limited advantages in the urban areas, however it has the second highest advantage if biomass residues are used as an energy source, from which it is possible to obtain both electricity and heat through thermal processing. The disadvantages of using biomass, or limitation on the use of this energy source, are related to the current insufficient use of biomass residues for energy production, despite their high energy potential. However, in the future, the utilization of biomass residues is expected to increase more rapidly and to accelerate the developments of its usage in energy production.

The other types of RES considered - wind energy, hydropower and geothermal energy, received the same number of points in the assessment, i.e., 0,73 points. Thus, equal prospects for sustainable development in the future are assessed for these resources. There is a growing interest in the use of wind energy in the household sector, which is associated with an increase in the installation of low-capacity wind turbines on household rooftops, thus making households more energy independent. In addition, wind energy has the second major utilization advantage, where hybrid wind energy systems, which are combined from both wind systems and PV panels, have the potential to achieve higher technological efficiencies in energy production and provide energy compensation for energy deficits. There is also a growing interest and development potential in the use of hydropower. In addition, there is also a growing trend in households to install hydraulic equipment to ensure the supply of the necessary energy. PHP systems, which do not require the construction of dams, have become more popular, as a result of which the share of hydraulic equipment utilization is expected to increase in the future as well. Moreover, with PHP systems it is possible to supply energy to rural communities and villages which consist of approximately 30 households. However, the use of hydropower is also subject to various restrictions on its utilization, such as the need for high investment and the impact on the environment it creates. The use of the resource is also influenced by the availability of water resources, and PHP systems are more suitable for its utilization in regions or mountainous areas, where there is a risk of faster depreciation and damage of equipment. Similar development trends can be observed for the potential of geothermal energy utilization in households. In Western Europe, there is already widespread use of geothermal heat pumps in households and it is predicted that in countries with colder climates, the installation of heat pumps will be put forward as an essential component of the future energy system. Geothermal energy has the second biggest utilization benefits in terms of energy saving potential, where geothermal energy systems make it possible to replace direct electric heating with heat pumps, thus reducing the amount of energy supplied. Disadvantages of using geothermal energy include the provision of the necessary capacity to provide the necessary temperature increase for heat pumps. Also, the installation of geothermal energy systems requires a higher degree of complexity compared to other types of RES.

2.6.3.6. Transport sector

Comparison of RES development potential in the transport sector is illustrated in the Figure 2.53. In the transport sector, leading position was achieved by biomass and its utilization potential that obtained the highest possible grade, i.e., a value of 1. Therefore, this resource in the transport sector, compared to other RES, has higher development tendencies and advantages, as well as with less usage limitations.

In general, rapid development of biomass use is projected in the future, with a rapid increase in the share of biofuel utilization. The transport sector is increasingly looking for the solutions to replace fossil fuels in order to reduce carbon emissions from the transport sector and achieve the ambitious climate goals set by the EU. As a result, biomass-derived biofuels are seen as the most significant solution for replacing crude oil. This is stimulated by the introduction of various support mechanisms for biofuel producers and consumers. In addition, biomass has the highest advantages in its utilization in the future if different types of biomass is utilized such as agricultural residues, waste, algae and others. The high concentration of methane puts biofuels in competitive positions in the future, which will also allow to achieve higher costs savings for the fuel consumers in the long term. The use of biomass in the transport sector is considered to have the lowest disadvantages, where one of the main disadvantages is the quality of biomethane, which depends on the composition of the raw material used, pre-treatment and post-treatment processes.

The second highest potential for sustainable development of RES in the transport sector was assessed for solar energy, which achieved a grade of 0,90 points. The use of solar energy in transport was observed to be second fastest growing and is expected to grow even faster in the future. It is expected that as the share of electric cars increases, so will the use of solar PV panels in road technologies. It is projected that in the future the use of solar roadways will serve as an important tool for the decentralized supply of energy through charging stations. Moreover, it is estimated that solar energy has the second highest utilization advantages that are related to the adaptability of PV panels to different types of road infrastructure and the ability to generate significant amounts of electricity. The most significant limitations of solar energy in the transport sector are the energy interruptions, however, they are relatively easy to compensate by installing additional energy sources, such as hybrid systems.

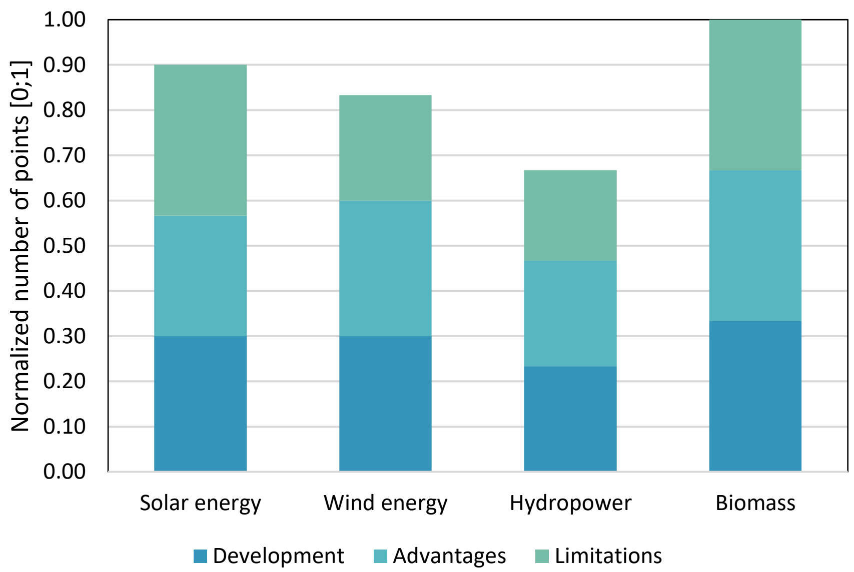

Fig. 2.53. Comparison of RES development potential in the transport sector

The third highest estimated sustainable development potential for RES use was obtained for wind energy, which showed a total value of 0,83. In the future, the rapid development of wind energy is projected, which is related to the possibilities of using wind energy in hydrogen production. As the number of hydrogen-powered cars increases, so will the share of wind energy utilization in the transport sector. In order to reduce the use of fossil fuels in transport, compressed and stored hydrogen from wind energy will be used as an alternative fuel in the future, thus also reducing greenhouse gas emissions. In addition, the produced hydrogen can be used not only in the transport sector, but it can also be transported in the grid to provide electricity and heat to nearby communities. However, it is important to mention that the use of a wind energy source has also some disadvantages that are related to the shortages of the wind, which can lead to energy interruptions. The efficiency of wind energy production is also affected by the capacity and stability of the installed wind turbines.

The potential for the use of hydropower in the transport sector reached a value of 0,67 points. Similarly as for the electricity generated from wind, electricity generated by hydropower plants can be used in the production of electrolytic hydrogen. Hydropower's potential depends closely on the flow rate and altitude gradient between the two water layers. Hydrogen extraction from energy produced in hydropower plants can be assessed as one of the most environmentally friendly methods, however, the development of resource use is influenced by the availability of water resources, which also significantly limits the use of energy sources.

Given that the use of geothermal energy in the transport sector has not yet been sufficiently investigated and invented, therefore, geothermal energy is not included in the comparison of the sustainable development potential of RES in the transport sector.

2.6.3.7. The comparison of sustainable development potential of different types of RES between the sectors

In addition to the separate comparison of types of RES in the sectors, a common sectorial comparison was performed to identify the differences in the development tendencies among the sectors studied. The comparison is illustrated in the Fig. 2.54. In the comparison for each RES the total normalized number of points is included in that way ranking the types of RES according to the highest development potential in the future. Additionally, Table 2.38. summarizes the total obtained normalized number of points for each RES in the division by sectors.

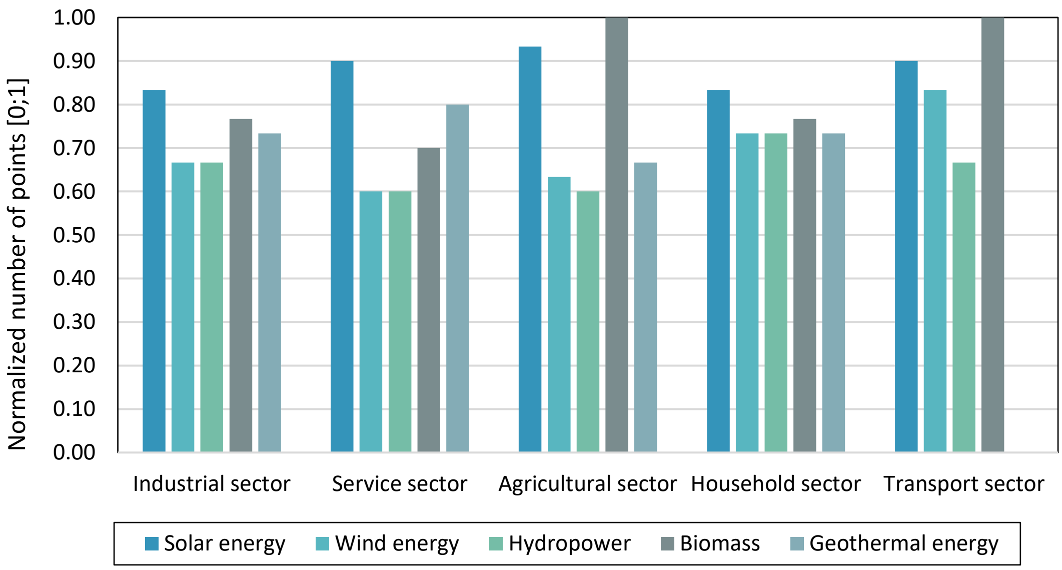

Fig. 2.54. Comparison of RES development potential tendencies between sectors

The highest sustainable development evaluation grade was reached by the biomass utilization potential in the agricultural and transport sectors. For both of these sectors biomass obtained the maximum possible number of points, i.e. 1. Therefore, in both – agricultural and transport sector a rapid development in the energy production from biomass has already been observed and projected in the future. Biomass utilization potential in the industrial and household sectors obtained the second highest evaluation of the potential.

High evaluation was achieved also by the solar energy and its utilization potential in the future. Solar energy was determined to be with the highest perspectives compared to other RES in the industrial, service and household sectors. In addition, it is ranked as the second most perspective among the analyses RES in the agricultural and transport sectors.

According to the average values, solar energy achieved the highest grade compared to the other types of RES with the average number of points of 0,88. It is followed by the biomass with the average value of 0,85. In total for both – solar energy and biomass a high development potential is projected in all the analysed sectors which in turn also is reflected in the higher average values in the total results.

Table 2.38

Summary on the normalized points for each RES in each sector

	Solar energy	Wind energy	Hydropower	Biomass	Geothermal energy
Industrial sector	0,83	0,67	0,67	0,77	0,73
Service sector	0,90	0,60	0,60	0,70	0,80
Agricultural sector	0,93	0,63	0,60	1,00	0,67
Household sector	0,83	0,73	0,73	0,77	0,73
Transport sector	0,90	0,83	0,67	1,00	0,00
Average values	0,88	0,69	0,65	0,85	0,59 (0,73*)

*Average value among 4 sectors (excluding the transport sector)

Lower energy utilization potential evaluation results were obtained by the wind energy, hydropower, and geothermal energy that compared to the rapid development tendencies of the solar energy and biomass, is developing at the lower pace.

However, substantially higher energy utilization potential is observed in the service sector, where it is ranked as with the second highest perspectives from the types of RES, right after the solar energy. Development tendencies of the wind energy in the transport and household sectors rank it as the third most perspective RES in the mentioned sectors.

According to the obtained results, it can be observed that the normalized number of points in the household sector are less distributed compared to the other sectors, where there clearly dominates a certain type of RES.

2.6.4. Conclusions

1. Hydropower and wind energy have the most constraints on their use. The use rate largely depends on the human factor.
2. Solar energy and agricultural residues from biomass have the least restrictive factors limiting their use.
3. Solar and wind energy shortages can be compensated by using combined systems, in accordance with the calculations, biomass and geothermal energy could be used to cover peak loads.
4. In recent years, the payback time of installation of solar collectors or PV panels is less than 10 years.
5. In the agricultural sector, the most promising energy source is biomass, if biomass residues are used, and solar energy has great prospects for the future.
6. In the service sector, the most promising energy source is geothermal energy, which is widely used in the leisure and tourism sector, and solar energy, which is used in electricity, heating and cooling processes.

7. The most promising energy source in the industrial sector is solar energy, using both solar panels for electricity, and collectors for heating.
8. Based on the information by sectors, it can be concluded that solar energy combined with smart technologies, smart schedules is the most promising solution for the future use of RES technologies.

APPENDICES

Appendix 1

Survey questionnaire for manufacturing enterprises

My name is Edgars Kudurs and currently, I am a student at Riga Technical University working on my thesis with the subject: "Promotion of the use of renewable energy resources in the manufacturing enterprises". In the course of work, it is planned to carry out an evaluation of the renewable energy source technologies, as well as to develop policy recommendations to ensure wider use of renewable energy in manufacturing enterprises. In order to obtain information on the current state of the use of renewable energy in manufacturing enterprises, please complete the survey.

Completing the survey will take up to 5 minutes of your time. The survey is anonymous and responses will only be analysed in aggregate form.

1) Are renewable energy technologies used in your company?

☐ Yes
☐ No

2) Please specify which of renewable energy sources is/are used? (Multiple answers are possible)

☐ Biomass (wood, straw, biogas, biofuel)
☐ Geothermal energy
☐ Hydropower
☐ Renewable part of waste
☐ Solar energy (for electricity)
☐ Solar energy (for heat energy)
☐ Tidal energy
☐ Wind energy

3) In your opinion, what limits the use of renewable energy sources? (Multiple answers are possible)

☐ Existing infrastructure constraints
☐ Legislation shortcomings
☐ Long payback period
☐ No faith in technology
☐ No in-depth expertise on these resources
☐ Other investment priorities
☐ Other (please specify)

4) In your opinion, what would facilitate the use of renewable energy sources? (Multiple answers are possible)

☐ Aim of reducing environmental impact
☐ Better understanding of technology
☐ Energy independence
☐ Fines and policy pressure

☐ Grant/subsidy
☐ Improvement of legislation
☐ Increase of tariff
☐ Opportunity to position yourself as a corporately responsible company
☐ Public and customer pressure
☐ Tax credit

5) Which three renewable energy source technologies in your opinion could have the most potential in your company: biomass (wood, straw, biogas, biofuel); geothermal energy; hydropower; renewable part of waste; solar energy (for electricity); solar energy (for heat energy); tidal energy; wind energy? Please, specify starting with the technology for which you see the greatest potential.

☐ 1st: ________________________
☐ 2nd: ________________________
☐ 3rd: ________________________

6) What is the approximate monthly electricity consumption of your company?

☐ Please specify as ________ kwh/month
or
________ euro/month

☐ I can not specify exactly

7) Is energy consumption one of the top three cost positions in your company?

☐ Yes
☐ No
☐ I can not specify exactly

8) Would you be interested in the results of this survey and learning more about renewable energy source technologies?

☐ Yes
☐ No

Your response has been received.
Thank you for taking the time to complete the survey!

Prioritization of policy recommendations

Policy recommendation	Funding	Measure will have impact on main barriers indicated by enterprises	Measure is in line with the incentives deemed necessary by the enterprises	Time and effect of implementation of the measure	Total	Priority
Collective marketing platform	1	3	2	2	8	MEDIUM
Reduction of administrative burden	2	3	1	3	9	HIGH
Funding of science at national and transnational level	1	0	3	2	6	MEDIUM
Transition to biomass use for high value-added products	0	0	0	1	1	LOW
The action of state institutions as an example of good practice	1	3	3	2	9	HIGH
A website dedicated to RES issues	1	3	3	2	9	HIGH
Training course for specialists in the involved sectors	1	3	3	3	10	HIGH
Training course for enterprise energy managers and employees	1	3	3	3	10	HIGH
Pension fund for financing “green” energy	2	3	0	1	6	MEDIUM
Raising excise duties	2	0	1	1	4	LOW
Real estate and corporate tax credit	2	2	2	3	9	HIGH
Review of environmental requirements	2	3	1	2	8	MEDIUM

Changes in the regulations governing the support programs	2	3	1	3	9	MEDIUM
Changes in the process of energy audits in enterprises	2	0	1	2	5	LOW
Expansion of the range of net payment system users to entrepreneurs	2	3	1	3	9	HIGH