Environmental and Climate Technologies

2019, vol. 23, no. 2, pp. 47–63
doi: 10.2478/rtuect-2019-0054
https://content.sciendo.com

Progress in Renewable Energy Technologies: Innovation Potential in Latvia

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Abstract **– The development of renewable energy technologies (RET) depends on a wide range of criteria and regulations. To evaluate which RET (solar photovoltaic (PV), wind power plants (WPP), hydroelectric power plants (HPP) or bio-energy plants) have the greatest potential in Latvia, the most suitable approach is a multiple criteria decision making (MCDM). The proposed MCDM methodology involves TOPSIS model based on information entropy, which contributes as a criteria weighting tool. The study investigates seven main criteria from technical, economic, environmental and social aspects. Firstly, each alternative country is analysed due to the chosen RET criteria. Secondly, the assessment is extended, comparing specific data with Latvia's MCDM of RET results. The research results show that, according to the best available examples of RET, hydro energy plants still play a substantial role for Latvia, the most promising RET development is based on bio-energy and wind renewable energies.**

Keywords **– Europe-2020; low/zero emission energy technology prioritization; *Matlab* programming; multi-criteria decision making (MCDM); TOPSIS**

1. INTRODUCTION

The appropriate use of renewable energy sources (RES) is a key element of convenient energy policy – decreased dependency on fuels imported from countries outside the European Union (EU) and reduced emissions from fossil fuel sources. RES is considered as a reliable energy source. However, many conditions, rules and limits need to be taken into account for RET to correspond to a convenient and resilient RET infrastructure [1], [2].

Appropriate RET development means that a vast variety of terms must be considered before making a final decision about the most suitable RET development in a specific area. It is important to remember that although RES is inexhaustible natural energy sources, some years can be less windy or sunny, meaning that RET cannot be relied upon to produce the same amount of electricity. A RES power system requires flexible and firm capacities to balance variable RES generation with existing hydropower, cogeneration or combined heat power plant (CHP) and biofuel energies. For this reason, far-sighted decisions can be made when RET development includes expansion of cross-border transmission and generation capacities, well-managed integration of demand-side technologies, implementation of energy efficiency measures, large-scale mobilisation of already existing resources and additional costs [3].

MCDM approach in this research helps to deal with various terms, indicators, conflicting objectives and criteria to find optimal results for complex RET planning and development.

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Due to the flexibility of the method, it provides the possibility to acknowledge the criteria and objectives simultaneously to consider future prospects of RET in Latvia [4].

EU's Directive 2009/28/EC on the promotion of the use of RES lays down accounting criteria for the 2020 renewable energy targets. One of the main targets for the EU is to achieve 20 % renewables by 2020. Moreover, to save global leader position in renewable energy by 2030, the EU must ensure that a goal of at least 27 % renewables in final energy consumption is reached [5].

Background Eurostat data analyses and collected data from other statistic data shows that RES had 17.5 % share of the EU's gross inland energy consumption in 2017. The considered RES were wind power, solar power (thermal, PV and concentrated), hydro power, tidal power, geothermal energy, biofuels and the renewable part of the waste.

The Eurostat data represents that in 2017 the highest share of renewable energy in the EU is still in Sweden (54.5 %) followed by Finland (41.01 %), Latvia (39.01 %) and Denmark (35.77 %). In the Baltic States Lithuania has 25.84 % and Estonia 29.21 % share of energy from renewable sources. Complete leaders are Iceland (71.6 %) and Norway (71.2 %), noting that both countries are not the EU Member States [6].

Detailed actual EU Member States renewable energy share progress and projections in gross final energy consumption in electricity, heating and cooling and transport from 2015 to 2017 are shown in Fig. 1.

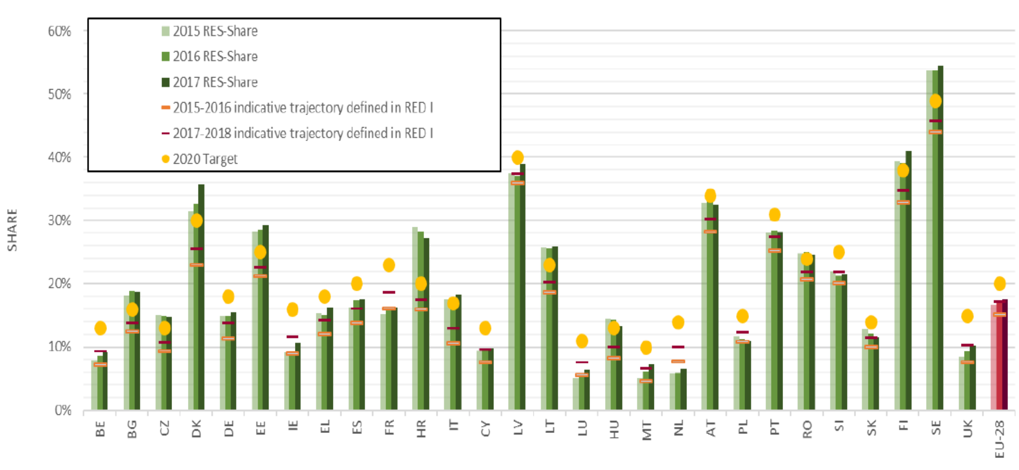

Fig. 1. EU and Member States renewable energy shares and trajectories set in gross final energy consumption [7].

Fig. 1 also shows the approximated RES shares for 2017 and the target share for 2020. The RES shares vary widely among the EU countries. Luxembourg (6.4 %) and the Netherlands (5.9 %) have the lowest shares in RES energy mix. Below indicative RES share targets for 2015/2016 is also France, although only by a limited margin. This overall target was calculated for the individual EU Member States to reflect their national circumstances, RES potentials and starting points [7].

One recent study observed that the EU Member States are on the road to their national targets. Generally, the EU Member States improves areas of research and development (R&D), environmental and educational policy. However, difficulties appear in social inclusion, poverty reduction and employment sectors [8].

All in all, this particular research focuses on overall final energy consumption from RET in the EU Member States, mainly focusing on electricity production. Heating technologies are also observed due to the CHP plants, which produce heat and electricity.

2. RET REVIEW IN NORTHERN EUROPE

2.1. RES and RET in Latvia

This section provides a brief summary of the actual situation in Latvia about renewables.

Latvia's gross energy consumption has not risen or decreased over the past five years, however natural gas has dropped and the proportion of renewable energy produced has grown. Moreover, the share of renewables has a growth of 5.5 % in 2017 (in comparison with 2016) [9].

Although Latvia is one of the leaders in EU in the share of renewables (37.2 %) in the final energy consumption (Fig. 1), the EU target until 2020 in the transport sector is 10 %, while in Latvia share of renewables in the transport is 2.8 % and the EU average is 7.1 %. One needs to take into account a considerable increase in the share of liquefied petroleum gas (LPG) during recent years. Since 2010 the use of LPG has grown 2.5 times, however compared to 2016 the consumption of LPG has decreased by 5.8 % [6].

According to the transmission system operator (JSC AST) in the Republic of Latvia released data, in 2017, net electricity consumption in Latvia was 7 282 170 MWh, average electricity exchange price decreased to 34.68 euros/MWh and local generation (7 346 336 MWh) covered Latvia's electricity consumption by 101 %, see Table 1 [10].

TABLE 1. ELECTRICITY PRODUCED IN LATVIA (MWH)

	HPP	**Thermal power plants**	**WPP connected to transmission**	**Renewable and assisted electricity generators**	**Total volume 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**

The large quantity of electricity generated in hydropower plants can be explained by the high precipitation amounts and high water inflow in river Daugava. It had an upward result on the amount of electricity produced. That leads to Latvian energy independence (an indicator that is calculated by subtracting the volume of exports from the volume of imports of energy resources and dividing this number by total energy consumption) and helps to get closer to strategic objective regarding to use of RES. The aim is to reach 40 % of the energy produced from renewable resources in the gross final energy consumption until 2020 [5].

As the most common RET in Latvia can be named HPP, biomass CHP plants, biogas CHP plants, including CHP plants using landfill or sewage gases and WPP. Each of the RET alternatives represents particular RES, respectively, hydro, bio or wind energies. Data provided by International Renewable Energy Agency presents that in Latvia generating capacities to produce electricity also provide solar PV installations (~1 MW) [9], [11].

2.2. RES and RET in Other EU Member States

In order to do a comprehensive evaluation, the context of the EU Member States must be defined. As mentioned above, Latvia is one of the leaders in renewable energy production, that is why for RET potential forecast Sweden, Finland, Denmark, Lithuania and Poland are chosen.

Northern European countries are considered leaders in renewable energy and Lithuania has already reached its 2020 target. To perform comprehensive research and comparison including all aspects, Poland is included in the evaluation considering it as a fossil fuel-friendly country.

2.2.1. Denmark

During the last decade the strategic Danish energy planning has gained increased attention as Denmark is already one of the leaders in the transition towards renewable energy systems, including development and implementation of RET.

The main question for such a country as Denmark is how the implementation of strategic energy planning can be successfully improved. Currently, strategic energy planning focuses on the technological aspects of energy systems and social aspects in the implementation of the RET is left behind [12].

According to Denmark's determined renewable energy targets for renewables, there are identified some major obstacles according to electricity production decentralisation – spatial constraints, social acceptance and economies of scale. It is very likely that without changes in energy policy, electricity production from renewables could become more centralised again, due to the large offshore and onshore wind farms and large electricity transmission infrastructure. However, centralised infrastructure is not sufficient, in order to achieve a fossil fuel-free energy system. The closest "competitors" are cross-sector solutions that can use excess electricity to replace fossil fuels in transport and heating [13].

One of Denmark's ambitious aims in its national Energy strategy is to replace oil boilers with RES technologies by 2035. This target leads to studies and researches about the preferred RET substitutes for fossil fuel technologies.

Research which was conducted in Northern Europe carried out that bio-energy (wood pellet boiler) remains the least favourable option to substitute oil boiler because it generates small particles and nitrous oxide etc., which pose a hazard for human health and for the environment. According to experts, the best substitute for oil boilers is a solar heating system, followed by heat pumps and wood pellet boilers. One of the reasons is that the price for installing a heat pump is for 50 % higher than installing the same power solar heating system. Also, by cause of marginal costs for heat pump technology (use of electricity to produce heat) and solar technologies (energy received directly from the sun), provides conditions where solar collectors seem more understandable for the end user. Moreover, one big drawback is the tendency to have lower efficiency than estimated [14].

That is why it is important to inform and educate potential heat pump system users about heat pumps as an alternative to the oil boiler. There is a lack of knowledge about how a heat pump works. The education about RET should be united with energy policy makers (the reduced electricity tariff for heat pumps owners), to integrate heat pumps in the green energy transition in Denmark [15].

All in all, to tackle the Danish challenges, more holistic theoretical framework for strategic energy planning is necessary. Only then it would be possible to develop strategic energy planning in Denmark and also form strategic energy planning concepts and practice [12].

2.2.2. Sweden

Sweden's experience as one of the leaders in renewables can contribute to the RET development in other countries of the EU.

Study case in Sweden proves that each adopter can have several different motives to maintain RET. That confirms that both environmental and economic motives have great general importance for RET adoption. Interest in renewable electricity technologies has grown much higher than in previous studies. Moreover, not only economic revenues and cost reductions are important motives, but also the access to the RES – piece of land for wind power production or a free roof for solar PV technologies.

The most notable finding in the study presents that wind, small-scale hydro power and solar power adopters differ significantly from each other. Each of renewable electricity technologies adopters emphasize either economic revenues (wind), renovations (hydro) or energy cost reductions (solar) as important motives for technologies adoption.

RET adopters are not only important market players, but also represents a new potential source of capital. Therefore, energy policy makers should consider the motives of these RET adopters to design policies to induce investments. Energy policies should appeal to different adopter categories. For example, household stimulation adoption can exclude important aspects which could be crucial to municipalities or diversified companies.

Energy policy makers need to consider which types of renewables they want to promote. Policy makers need to be cautious about particular policy instruments and rethink the significance of each RET before adjusting policy mix to the renewable energy sector [16].

Energy policy makers also play a big role in the promotion of Swedish RET applicability. To manage the current situation and promote RES technologies for heating, a survey was conducted. The aim of the survey was to figure out which innovative heating system (heat pumps, wood pellet boilers, district heating) is the best mitigation option for detached homes.

Applying an adopter-centric approach, lead to the evaluation of the influence of investment subsidies on resistance heater or oil boiler heating system conversion. The results from the questionnaire survey (1 500 homeowners), showed that 80 % of the respondents did not plan to invest in a new heating system.

The majority of respondents preferred heat pump as the best option over any other heating system (district heating, pellet system, wood boiler, solar, electric boiler, resistance heater). These results differ from the study in Denmark, where solar heating was considered as the best option for oil boiler alternative [17].

The government subsidies were influential for conversion from the resistance heating, still not from the oil boilers. The cause of it is that replacing resistance heater is considered as early adoption while replacing oil boilers is recognized as a laggard approach.

2.2.3. Finland

Similarly to Denmark, Finland also needs to deal with a set of new challenges related to the electricity system planning and supply-demand balance for renewable energy policies.

According to RES and RET, there are several hypotheses for cross-impact analyse about internal dynamics of the near future development of the electricity supply, electricity transmission system and electricity demand.

Electricity price is a major driver in the energy system. If electricity price increases, then electricity production also increases, with direct impact on solar and wind power production. Increasing electricity price also incentivizes an increase in electricity storage. Conversely, electricity price increase leads to a decline in energy consumption and the use of intermittent power sources in the electricity system. Altogether, in high electricity price scenario, subsidies for solar and wind power are less necessary.

Wind power capacities in Finland is relatively lower than in other EU Northern countries. This is the reason why wind power is considerate as RET which capacities could double by 2030. There is need for beneficial regulatory and subsidy policy conditions. Wind (and solar) power production can support increase in electricity storage, consequently increasing market-based elasticity of consumption. Experts claim that escalation.

Expansion of intermittent power sources will force investments and require advancements in storage technologies, which can lead to tolerance of consumers to exercise their consumption decisions, based on market elasticity.

Many things depend on consumer behaviour and expectations. There is a necessity to provide consumers information on the price changes through convenient communications technology. It could influence their electricity consumption based on the electricity price [18].

As to the study in Finland, the acceptance of RET is based on understandable technical solutions and installations, that need to satisfy the majority of building owners, real-estate developers, energy providers and key stakeholders. The most influencial factors were considered investment cost, payback time, reliability and national incentives. The study concluded that ground source heat pumps and solar technologies were selected as the most popular options, while wind and CHP technologies were estimated as the least favourable option as RET. In general, respondents point out that the most important factors to invest in RET are tax deductions and a reduction of carbon footprint. It means there is not one best alternative. On the contrary, respondents prefer a diversity of RET options.

The study concluded that RET should be subsidized in a balanced manner. It would allow people to decide, which RET is the most suitable for their local conditions, preferences and perceptions of reliability [19].

An advanced study about renewable policies carried out several scenarios on how to scale down the dependency and security of energy supply systems in Finland. A system dynamics approach was used in the research to evaluate renewable energy policies. Several energy policy schemes were proposed – support packages, feed-in tariff, investment grants, support schemes and offsets. The main conclusion was that the implementation of citizen-friendly renewable energy policy plans can lead to significant savings for natural gas imports [20].

To sum up, studies in Finland has shown that implementation of energy action plans when renewable energy capacities are installed could lead to 660-million-dollar savings for natural gas imports in 2020 [20].

2.2.4. Lithuania

As 2020 target Lithuania has committed to reach 23 % of RES shares in total final energy consumption. One of the analysis of the renewable energy promotion in Lithuania concluded that feed-in tariff system is necessary, the measures for power and heat generation and support schemes or findings are fundamental to RET promotion and also for the long-term sustainability and security of Lithuania's energy sector [21].

In Lithuania in 2018 a study was carried out to determine the most perspective micro-generation technology in heating production from electricity. As stated in the study, the analysed RET were solar thermal, solar panel, biomass boilers and micro wind installations. Twelve experts were asked to provide a valuation of four energy micro-generation technologies (17 indicators, a five-point system) suited for Lithuanian households and future energy potential. The wind micro-generation technologies were considered as the least alternative. It concluded that biomass boilers or solar-thermal installation appear to be the most favourable micro-generating technology in Lithuania. The solar technologies appeal to both the public (society) and private (consumers) sectors. Biomass boilers could be preferable when engaged as biomass residue technology. It is to be noted that biomass and solar thermal technologies were cited as close alternatives [22].

As Lithuania imports about 77 % of energy, it does not make Lithuania energetically safe state. Currently, the most used RES are wind and biofuel, besides wind produces 24 % of all electricity. To develop RET the formation of RES strategy for a long-term period is necessary. The strategy must be developed by scientists, who are not related to traditional (fossil) energy producing business. Involvement of small investors is necessary to achieve decentralisation in energy production from RES [23].

2.2.5. Poland

Another study in Poland was conducted in 2018. The focus on two unique synthesizing criteria methods proposed prioritization and evaluation hybrid model for low-emission energy technologies development. A fuzzy analytic hierarchy process (FAHTP) and FTOPSIS MCDM model were made. As a result, regardless of the MCDM method, the situation in Poland remain stable – the best alternative is solar energy, followed by biomass and biogas, wind and nuclear energy in 2018 [24].

According to another study in 2009, the Polish Government proposed Energy Policy of Poland (Target 2030), where plans were set is to put biomass, wind and hydro power at top priority according to renewable resource availability and technical development [25], [26].

In 2010, the Polish Government released its National Action Plan for Renewable Energy Sources (Target 2020). This plan proposes biomass, biogas and wind energy as best for development in Poland conditions, excluding hydro power energy. It is due to hydro power generation limitations (units below 1 MW) and Energy Policy to expanded existing dams, which can lead only to efficiency increase, due to that dams can produce as much power as water resources allow (not endless capacities). Moreover, the Action plan was modified, including support for PV technologies in 2012 [25], [27].

In 2018 research about geothermal energy potential in Poland was done. In brief, there are mainly sedimentary rocks (sandstone, limestone, dolomite, igneous rocks (crystalline, volcanic)) which are considered as the technology of Poland's future. Polish Lowlands are strategically important areas of underground reservoirs [28], [29].

It is rational that the majority of geothermal energy is used SPA centres (for therapy, bathing, recreation purposes). Lodz is considered to have one of the best geothermal conditions. It is necessary to point out, that contribution can be possible, if the heat of the rocks is utilized as petrogeothermal energy. The energy accumulated in sedimentary, volcanic and crystalline rocks, is one of the most abundant resources, which can be used in Polish Lowlands [28].

Depending on public and private sector needs, the geothermal energy resources can be used for heating, as well as for therapeutic and recreational purposes. This RES is well-recognized, however, the development of technologies is slow, due to a shortage in financial support. The situation is trying to be saved by a Central Fund for Water Management and Environment Protection. In 2016, the Fund launched a co-financing program for geothermal investments. In many regions of Poland are economic, fiscal barriers to develop utilization of geothermal energy technologies. Despite all of the above, geothermal as renewable energy is not a meaningful source for heating or electricity.

All mentioned above, shows that the analysed studies [24], [25], [28], [29] and compared results from the second study [28] lead to convincing and logic conclusions – investigated researches satisfy Polish Government document objectives, where the most perspective RET are solar, bio and wind energy.

To sum up all the analysed data and information about the EU Member States, it can be affirmed that the importance of renewable energy expansion is crucial for each of the EU Member States.

RET development causes economy focused on sustainability. RET is important for the economy because they help to achieve energy security and environmental protection goals. RET are a key factor to achieve also decarbonisation goals for the energy sector. The greenhouse gas emissions will decrease by one-tenth in comparison with 2005. Long-term RET development also allows a decrease in demand for fossil fuels.

To achieve positive environmental impacts – climate protection and resource efficiency – the major role plays the development of a bioenergy market based on bio-resources. As scientists claim, there is essential necessity for searching no-food biomass to balance the support of biofuels production. Another major aspect is EU innovation progress. At this moment, the EU is the owner of 30 % world patents related to energy sources. Renewable business model craves for innovations to adjust political incentives and revenue mechanisms to leverage sustainable solutions [31]. Overview about the EU Northern countries show that the government's energy policy framework, the concept of sustainable development and accessibility of RES are basic elements on which focuses the development of RET un the EU.

3. METHODOLOGY

Since the evaluation and planning of renewable energy systems have been recognized as a multi-criteria decision making problem, this research provides a developed algorithm of prioritizing the sequence of each RET alternative based on MCDM technique for order preference by similarity to the ideal solution (TOPSIS). The weight values of each criterion were calculated using information entropy methodology, followed by TOPSIS method to rank the alternatives.

The TOPSIS method as a multi-criteria decision making (MCDM) technique is widely approved by many kinds of researches and scientists. The literature review identifies that MCDM techniques are used in many studies where renewable energy systems/projects/sources are ranked.

Previously mentioned study in Denmark also used MCDM method. The MCDM methodology firstly performed survey for 18 experts, which provided judgment for oil boiler alternatives and criteria. Chosen criteria were technical (high performance (short heating time), few reparations, reliable, easy to use), economic (reduced energy bill, reduced operating expenses, low initial investment, short payback period, subsidies) and environmental (reduction of greenhouse gas emissions, use of renewables). There were several limitations due to the TOPSIS method combination with an intuitionistic fuzzy set, where subjective judgments are involved. What is more, primarily chosen criteria are not the only ones which can influence the choice of RET. Literature has shown that attitude towards the environment and peer communication also have a big impact on RET decision making [14], [32].

In the example of Lithuania mentioned study implements three of MCDM techniques into a framework for multi-criteria assessment – TOPSIS, the Evaluation Based on Distance from

Average Solution (EDAS) and the weighted aggregated sum product assessment (WASPAS). Firstly, weighting and averaging are applied to collect ratings. Secondly, the expert ratings are merged with the WTP (willingness-to-pay) measures. WTP stands for private sector's impacts, while the experts present the public sector's impacts. After that follows MCDM technique implementation. Finally, the test on the robustness of the results (sensitivity analyses) is done with the help of Monte Carlo simulation to investigate how the choice of the weights results on rankings. Overall, the basic feature of the MCDM model is that it incorporates private and public impacts, therefore the proposed approach combines multiple MCDM approaches [21].

A case study in Poland for MCDM analyses used FAHP-FTOPSIS MCDM hybrid model. This hybrid model requested to define the relative importance of criterions using the fuzzy AHP method, after what implementing of FTOPSIS helped to rank five technologies according to their relative closeness to ideal solution. To measure specific study among other studies, where hybrid methods of FAHP and TOPSIS are used, the results are compared with other research results [24], [30].

In the study, where support framework for renewable energy supply systems (RESS) in Turkey in 2015 was developed, authors used Fuzzy TOPSIS MCDM method to rank RESS alternatives. The potential of electricity production from RESS was analysed by determined criteria. Among 24 RES ranking criteria (technical, economic, environmental, social), only nine of them was suitable for Turkey's RESS's analyse. According to the Interval Shannon's Entropy methodology, preference was given to the amount of energy produced, land use, operation and maintenance cost, installed capacity, efficiency, payback period, investment cost, job creation and value of CO_2 emission. MCDM analysis showed the most suitable renewable energy supply systems and concluded that in order of priority the government of Turkey should evaluate projects that relate to these renewable energy resources and endorses the decisions already made by the government [33].

The general idea of TOPSIS is to compare alternatives to some reference solution. There are two reference solutions – a positive ideal solution (PIS) and negative ideal solution (NIS). With the help of TOPSIS, the best alternative has the nearest distance to PIS and the longest distance to NIS. As a result, the PIS covers positive criteria and the worst criteria sums up to the NIS [34].

As a decision support tool for the weighting of each criterion, the information entropy method is used. The entropy shows the uncertainty of criteria and displays how much each criterion reflects the information of the system. There are two types of criteria considered – positive (should be increased) and negative (should be decreased). There are approximately 30 typical evaluation criteria of energy supply [35].

At first, TOPSIS MCDM is made to find out which of analysed Northern Europe countries (alternatives) has the best RET development according to chosen criteria. After that, alternatives are compared to Latvia's TOPSIS MCDM results. In the end, conclusions are made for Latvia's RET development, according to comparison with alternative countries. The methodology of the research is shown in Fig. 2.

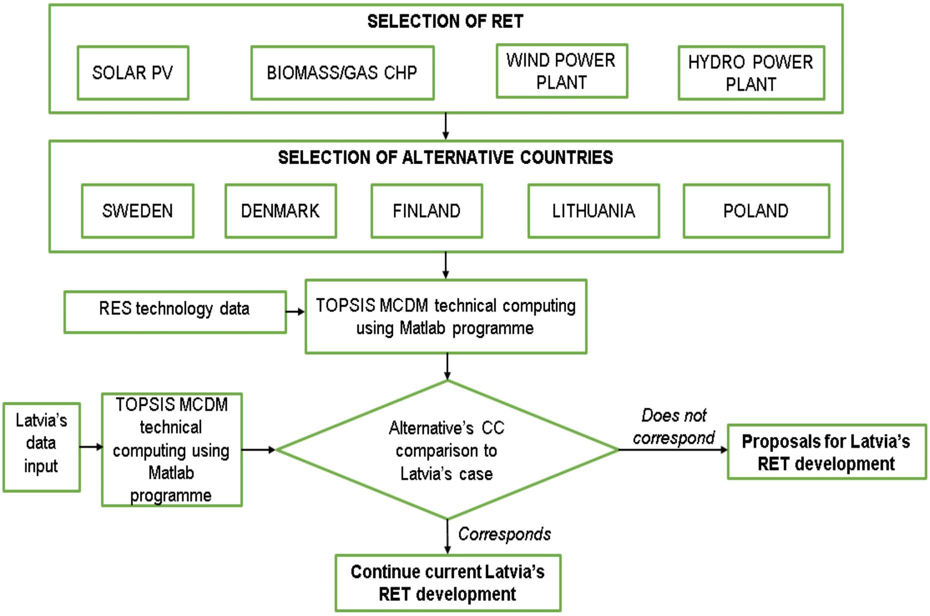

Fig. 2. Simplified scheme of research approach.

In the current case study of Latvia solar PV, on-shore WPP, HPP and bio-energy CHP (biomass and biogas) are considered as primary RET, see Table 2.

TABLE 2. ALTERNATIVES OF RET

Alternative of RET	Abbreviated name
Solar Photovoltaic (A_1)	Solar PV
Wind Power Plant (A_2)	WPP
Hydroelectric Power Plant (A_3)	HPP
Biomass and biogas CHP (A_4)	Bio-energy CHP

To conduct a correct evaluation of each RET, seven main criteria out of 30 typical evaluation criteria are determined – installed electrical capacity, investment cost (euros/kW), operation and maintenance cost, RES equipment (module, turbine, plant) prices by manufacturer, levelized cost of electricity (LCOE), RET life cycle CO_2 emissions, job creation. The criteria were chosen according to the actual information available about the EU Northern countries. The criteria are outlined in Table 3.

Despite the fact that in general RET have a positive impact, in this study the most part of the criteria in Table 1 have a negative impact on decision-making, except installed electrical capacity (C1) and job creation (C7). This is due to the reason that investment cost (C2), operation and maintenance cost (C3), RES equipment prices by the manufacturer (C4), LCOE (C5), life-cycle CO_2 emissions (C6) criteria values are related to costs.

TABLE 3. EVALUATION CRITERIA TAKEN INTO ACCOUNT TO SELECT THE BEST RET FOR LATVIA

Main criteria	Sub-criteria	Unit
Technical	Installed electrical capacity (C1)	MW
Environmental	Life-cycle CO_2 emissions (C6)	gCO_2eq/kWh
Economic	Investment cost (C2)	€/kW
	Operation and maintenance cost (C3)	€/kW
	RER equipment prices by manufacturer (C4)	€/kW
	Levelised cost of electricity (C5)	€/kWh
Socio-economic	Job creation (C7)	thousands

The data collection process was carried out in several ways – analyse of scientific papers about each country and RET, overall data collection from International renewable energy Agency (IRENA) reports and statistical data from the Eurostat database [11], [37].

For this paper, to rank and evaluate RET alternatives in the EU Northern countries, an environment of technical computing *Matlab* programme was used. All the calculations – formulas and steps according to the TOPSIS method were programmed as *Matlab* function code, including the weighting of criteria with information entropy method.

The TOPSIS method based on information entropy was implemented through the following steps:

1. Specification of alternatives and criteria for the indicators to which RES must be allocated. Alternates are called A = {A1, A2, A3, A4}, which are evaluated against criteria called C = {C1, C2, C3, C4, C5, C6, C7};
2. Assigning ratings for criteria and alternatives, using the matrix method as shown in Eq. (1), where the matrix $X_{\mathrm{A\cdot C}}$ is indicated by values of alternatives for criteria:

$$X_{\mathrm{A}(i)\cdot\mathrm{C}(j)} = \begin{bmatrix} x_{\mathrm{A1\cdot C1}} & x_{\mathrm{A}i\cdot\mathrm{C}j} & x_{\mathrm{A1\cdot C7}} \\ x_{\mathrm{A2\cdot C2}} & \cdots & x_{\mathrm{A2\cdot C7}} \\ x_{\mathrm{A4\cdot C1}} & x_{\mathrm{A}i\cdot\mathrm{C}j} & x_{\mathrm{A4\cdot C7}} \end{bmatrix}, \tag{1}$$

where

$x_{\mathrm{A}i\cdot\mathrm{C}j}$ Value of alternative A_i for criterion C_j.

3. Calculation of criteria weight by entropy technique to normalize the decision matrix $X_{\mathrm{A\cdot C}}$ as shown in Eq. (2):

$$q_{ij} = \frac{x_{ij}}{x_{\mathrm{A1\cdot C1}} + \ldots + x_{\mathrm{A6\cdot C7}}}; \forall_{\mathrm{C}} \in \{1, \ldots, 7\}, \tag{2}$$

where

q_{ij} Criteria weight.

4. Information entropy of criteria (Δ_g) is explained by the definition of information entropy presented as shown in Eq. (3):

$$\Delta_g = -k \sum_{i=1} q_{ij} \cdot \ln q_{ij} ; \forall_C \in \{1,\ldots,7\}, \tag{3}$$

where

Δ_g Information entropy of criteria;

k Coefficient for conversion to positive values of the information entropy.

The correct value of information entropy $0 \leq \Delta_g \leq 1$ can be ensured with the coefficient k, through $k = 1/\ln(m)$. The bigger information entropy Δ_g, the greater the variation of this index. That is why, deviation degree d_g weighting is computed as shown in Eq. (4):

$$d_g = 1 - \Delta_g ; (g = 1,\ldots,7), \tag{4}$$

where

d_g Deviation degree weight.

5. Using entropy technique, the weight of criteria is calculated by the formula as shown in Eq. (5):

$$w_g = \frac{w_g}{w_1 + \ldots + d_7}, \tag{5}$$

where

w_g Weight of criteria.

6. Finally, the aggregated weight (w'_g) is obtained as shown in Eq. (6), by use of formulas as shown in Eq. (4) and Eq. (5) to aggregate the weight vector (λ_g):

$$w'_g = \frac{\lambda_g \cdot w_g}{\lambda_1 \cdot w_1 + \ldots + \lambda_7 \cdot w_7}; \quad w' = \{w'_1, w'_2, \ldots, w'_7\}. \tag{6}$$

where

w'_g Aggregated weight of criteria.

7. After information entropy criteria weighting follows classical TOPSIS MCDM calculation [37], [38] implementation into *MATLAB* programming platform to rank the RET alternatives. As a result, the ranking reveals the best alternative, which has the highest value as a representation of greater importance and priority.

4. RESULTS

In this study, MCDM TOPSIS method was applied to several Europe countries – Sweden, Finland, Denmark, Lithuania and Poland, as well as Latvia.

The first results in Table 4 show the best alternative in the context of the most accepted RET applications. Each of the four the most accepted RET was evaluated against seven criteria – installed electrical capacity, investment cost, operation and maintenance cost, RES equipment (module, turbine, plant) prices by manufacturer, LCOE, RET life cycle CO_2 emissions and job creation.

TABLE 4. TOPSIS RESULTS OF CLOSENESS COEFFICIENT (IDEAL POINTS) WITH RESPECT TO THE RET ALTERNATIVES

	Solar PV	**WPP**	**HPP**	**Bio-energy CHP**
Latvia				
Closeness coefficient	0.3374	0.3916	0.7580	0.4697
Rank	**4**	**3**	**1**	**2**
Finland				
Closeness coefficient	0.2591	0.3562	0.8024	0.5966
Rank	**4**	**3**	**1**	**2**
Sweden				
Closeness coefficient	0.591	0.6389	0.8024	0.3244
Rank	**4**	**2**	**1**	**3**
Lithuania				
Closeness coefficient	0.2591	0.8308	0.6210	0.3244
Rank	**4**	**1**	**2**	**3**
Denmark				
Closeness coefficient	0.4196	0.8308	0.1200	0.5966
Rank	**3**	**1**	**4**	**2**
Poland				
Closeness coefficient	0.2591	0.8308	0.3370	0.5966
Rank	**4**	**1**	**3**	**2**

Each of alternative countries have a specific ranking of RET due to the contribution of each RET in electricity production, however, Latvia has the same tendency of most favourable RET as Finland.

The second results are described in Table 5.

TABLE 5. TOPSIS RESULTS OF CLOSENESS COEFFICIENT (IDEAL POINTS) WITH RESPECT TO THE RET ALTERNATIVES

	Finland	**Sweden**	**Latvia**	**Lithuania**	**Denmark**	**Poland**
Closeness coefficient	0.6977	0.6732	0.6487	0.5031	0.3059	0.2818
Rank	**1**	**2**	**3**	**4**	**5**	**6**

As the best alternative according to RET among comparative countries is Finland, followed by Sweden, Lithuania, Denmark and Poland.

As stated in the TOPSIS results for Latvia's situation, they correspond to Finland's TOPSIS results. A similar trend is in Sweden, where the best RET is considered HPP, and the worst alternative is solar PV – similar as in Latvia. As to Lithuania's and Denmark's results, there are differences due to the big impact of WPP and weak application level of HPP. Poland has the same trends as Lithuania, as a result, it differs from Latvia's conclusions about the most favourable RET.

Turning to the distribution of RET ranks according to literature review [14], Denmark remains as the leader in solar technologies due to its contribution to electricity production, however, the most popular RET, in general, is WPP. The results of TOPSIS evaluation confirms results the of the study [17] in Sweden, where bio-energy installations are less preferable in the context of heating systems.

Overall, the ranking of RET and European countries as the best alternatives shows that Latvia has the same trends as Finland and Sweden, where mainly HPP and bio-energy CHP are leading contributors to electricity production. Lithuania, Denmark and Poland have a high level of WPP development, however these countries stay behind when the best alternatives of RET is compared.

5. DISCUSSION AND CONCLUSIONS

A comprehensive RET evaluation implied four dimensions – technical, economic, environmental and social. The research was defined as MCDM problem, where the question was to decide which RET have the highest potential of development. The extensive literature review conducted shows that MCDM is one of the tools applied the most in sustainable development evaluation issues [22], [34].

As results show, the dominant countries in shares of renewable energy (Sweden, Finland) have the same RET development trends as Latvia [7]. The leading countries have large resources of hydro power, which represents a high share of HPP in electricity production (Finland – 43.4 %, Sweden – 58.5 %, Latvia – 87.0 %) [11].

Firstly, it means to follow the example of Sweden in electricity production and implement WPP installations. Denmark, Lithuania and Sweden also show high shares of WPP in electricity production – Denmark has 70.9 % share of WPP, Lithuania – 62.0 % and Poland – 71.5 %. Latvia is considered as one of the most efficient locations for scaling up wind deployment. Supporting wind-based electricity generation presents profitable markets for investors [39].

Secondly, bio-energy CHP installations should be considered as sufficiently developed RET. Every alternative country has a share of 13.3 % (Poland) to 17.4 % (Denmark) of bio-energy CHP as electricity production RET. Bio-energy is important for heating private houses which are attached to district heating. In the near future, as Latvia is widely known as forest rich land, bio-energy applications should be maintained without extra support from the government's side, because CHP technologies are efficient enough to operate self-sufficiently. Extra research on the development of low-quality biomass (for example, logging residues) usage is recommended [40].

Thirdly, solar PV technologies should be developed as in the case of Denmark and Lithuania, which have respectively 11.6 % and 10.0 % share of solar energy in electricity production.

The most important factors are functional reliability and economic aspects of specific RET. The major drawback is that each of the RET has various advantages, which lead to confusion about which is the most suitable for specific homes/buildings/regions. The development of RET should rely on understandable technical solutions and installations. This is the reason why the best support for practical information about RET is considered interpersonal and installer's communication sources, according to Sweden's example. As to other benefits from

Sweden's example of RET application development, government subsidies indicate to also have a large influence on conversion from fossil fuels to RES. The risk appears when there is a need to decide which of RET should be supported. The recommendation is to do it in a balanced manner and leave the main decision to each individual, according to his or her living conditions and perceptions of RET reliability.

The main conclusion for Latvia is that energy policy should be upgraded. There is a number of reasons why this is needed. Comprehensive energy policy enables the government to develop the most appropriate political incentives. Relevant government support encourages to take a step towards the implementation of RET. Also, the government itself should ensure the availability of financial resources for renewable energy production.

Government support should be clear for all involved sides and support should be flexible and resilient to sudden and unexpected circumstances. That is why the legal framework needs to be arranged in order to uphold legitimate expectations of RET promoters. The trusted legal framework helps foreign investors to make bigger investments in RET. Moreover, it also boosts up the progress in the renewable energy industry and national economy of Latvia.

Latvia's government uncertain foresight about which of RET should be supported has already shattered investors trust and stopped investor's cash flow to Latvia. Plus, currently, the normative regulation is not arranged and does not meet the requirements of the law. Investments in RET cannot be done without investors trust in government and national laws. Investors have legal rights to go to court and demand explanations to Latvia's government about a change of support for RET. All that do not place faith in Latvia as a reliable partner for RET progress.

RES and RET are not only political question – it connects industry, investors, enterprises, technology developers, householders and all that goes hand in hand with local social acceptance (as public negotiations often play a significant role in RET building acceptance).

When government support is stable and clear, local people and investors or businessman can make strategic future decisions to invest in RET. Permanent and balanced RET support also leads to faster industry expansion. RET developers and installers trust in stable, government supported, and that leads to renewable entrepreneurship stimulation. The progress of RET may have the potential to stimulate employment in Latvia and the EU when new "green" technology jobs can be created.

The confidence and trust to RET could lead to extra education and R&D. According to the Eurostat data [39], Denmark, Sweden, Norway, Finland, Austria, Switzerland, United Kingdom, France and Germany have high (up to 3 %) R&D intensity in their countries. Unfortunately, in the Baltic States, R&D intensity cannot reach 2 %. The situation is particularly poor in Latvia – 1 % of R&D intensity. It means that in Latvia there is a lack of big central R&D centres. This R&D indicator could be named as one of the biggest drawbacks of renewable energy expansion in the EU and Latvia. In R&D Latvia lags behind not only on a Europe scale, but also among the Baltic State countries. For example, Latvia's use of peat as an energy resource is one of the lowest, although The Energy Peat Europe Agency estimates that the energy value of peat reserves suitable for production in Latvia is 663 terawatt hours.

To summarize, it can be stated that Latvia has the same tendency of RET development as leading countries in renewables, however, need to consider WPP as the best potential of RET development in the future. However, unclear Latvia's government decisions about renewable energy support and political incentives lead to a pessimistic stance of RET industry in Latvia.

ACKNOWLEDGEMENT

This research is funded by the Ministry of Economics of the Republic of Latvia, project "Assessment of Latvia's renewable energy supply-demand economic potential and policy recommendations", project No. VPP-EM-2018/AER_1_0001.

REFERENCES

[1] Klavins M., Bisters V., Burlakovs J. Small scale gasification application and perspectives in circular economy. *Environmental and Climate Technologies* 2018:22:42–54. doi:10.2478/rtuect-2018-0003
[2] Kittipongvises S. Assessment of environmental impacts of limestone quarrying operations in Thailand. *Environmental and Climate Technologies* 2017:20:67–83. doi:10.1515/rtuect-2017-0011
[3] Zappa W., Junginger M., Broe M. Is a 100% renewable European power system feasible by 2050? *Applied energy* 2019:233–234:1027–1050. doi:10.1016/j.apenergy.2018.08.109
[4] Kumar A., et al. A review of multi criteria decision making (MCDM) towards sustainable renewable energy development. *Renewable and Sustainable Energy Reviews* 2017:69:596–609. doi:10.1016/j.rser.2016.11.191
[5] Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC. *Official Journal of the European Union* 2009:L140/16.
[6] Eurostat. Renewable energy statistics. Statistics Explained [Online]. Available: https://ec.europa.eu/eurostat/statistics-explained/index.php/Renewable_energy_statistics
[7] European Commission. Report from the commission to the European parliament, the Council, the European economic and social committee and the Committee of the regions. Brussels: European Commission, 2019.
[8] Rogge N. EU countries' progress towards 'Europe 2020 strategy targets'. *Journal of Policy Modeling* 2019:41(2):255–272. doi:10.1016/j.jpolmod.2019.03.003
[9] Central Statistical Bureau of Latvia. Catalogue of Statistical Publications 2019.
[10] Electricity Market Review by JSC Augstsprieguma tikls [Online]. Available: http://ast.lv/lv/electricity-market-review
[11] IRENA. Renewable capacity statistics 2018. Abu Dhabi: International Renewable Energy Agency (IRENA), 2018.
[12] Krog L., Sperling K. A. comprehensive framework for strategic energy planning based on Danish and international insights. *Energy Strategy Reviews* 2019:24:83–93. doi:10.1016/j.esr.2019.02.005
[13] Zinck Thellufsen J., Lund H. Cross-border versus cross-sector interconnectivity in renewable energy system. *Energy* 2017:124:492–501. doi:10.1016/j.energy.2017.02.112
[14] Yang Y., et al. Using multi-criteria analysis to prioritize renewable energy home heating technologies. *Sustainable Energy Technologies and Assessments* 2018:29:36–43. doi:10.1016/j.seta.2018.06.005
[15] Dansk Arkitektur Center. Green growth in Denmark towards 2050. Four future scenarios. DK 2050.
[16] Bergek A., Mignon I. Motives to adopt renewable electricity technologies: Evidence from Sweden. *Energy Policy* 2017:106:547–559. doi:10.1016/j.enpol.2017.04.016
[17] Mahapatra K., Gustavsson L. An adopter-centric approach to analyze the diffusion patterns of innovative residential heating systems in Sweden. *Energy Policy* 2008:36(2):577–590. doi:10.1016/j.enpol.2007.10.006
[18] Panula-Ontto J., et al. Cross-impact analysis of Finnish electricity system with increased renewables: Long-run energy policy challenges in balancing supply and consumption. *Energy Policy* 2018:118:504–513. doi:10.1016/j.enpol.2018.04.009
[19] Jung N., et al. Social acceptance of renewable energy technologies for buildings in the Helsinki Metropolitan Area of Finland. *Renewable Energy* 2016:99:813–824. doi:10.1016/j.renene.2016.07.006
[20] Aslani A., Helo O., Naaranoja M. Role of renewable energy policies in energy dependency in Finland: System dynamics approach. *Applied Energy* 2014:113:758–765. doi:10.1016/j.apenergy.2013.08.015
[21] Gaigalis V., Markevicius A., Katinas V., Skema R. Analysis of the renewable energy promotion in Lithuania in compliance with the European Union strategy and policy. *Renewable and Sustainable Energy Reviews* 2014:35:422–435. doi:10.1016/j.rser.2014.04.013
[22] Zhang C., et al. Probabilistic multi-criteria assessment of renewable micro-generation technologies in households. *Journal of Cleaner Production* 2019:212:582–592. doi:10.1016/j.jclepro.2018.12.051
[23] Valodka I., Valodkienė G. The Impact of Renewable Energy on the Economy of Lithuania. *Procedia - Social and Behavioral Sciences* 2015:213:123–128. doi:10.1016/j.sbspro.2015.11.414
[24] Ligus M., Peternek P. Determination of most suitable low-emission energy technologies development in Poland using integrated fuzzy AHP-TOPSIS method. *Energy Procedia* 2018:153:101–106. doi:10.1016/j.egypro.2018.10.046
[25] Paska J., Surma T. Electricity generation from renewable energy sources in Poland. *Renewable Energy* 2014:71:286–294. doi:10.1016/j.renene.2014.05.011
[26] Polityka energetyczna Polski do roku 2030 (Energy policy of Poland until 2030). Appendix to Resolution no. 202/2009 of the Council of Ministers of 10 November 2009. (in Polish)

[27] Krajowy plan działania w zakresie energii ze zrode ł odnawialnych (National Action Plan for Renewable Energy Sources). Warszawa: Ministerstwo Gospodarki, 2010. (in Polish)
[28] Sowizdza A. Geothermal energy resources in Poland – Overview of the current state of knowledge. *Renewable and Sustainable Energy Reviews* 2018:82(3):4020–4027. doi:10.1016/j.rser.2017.10.070
[29] Kępińska B. Geothermal energy use – country update for Poland, 2013–2015. Proceeding European geothermal congress 2016, Strasbourg, France, 2016.
[30] Ligus M. Evaluation of economic, social and environmental effects of low-emission energy technologies development in Poland: a multi-criteria analysis with application of a fuzzy analytic hierarchy process (FAHP). *Energies* 2017:10(10):1550. doi:10.3390/en10101550
[31] Bórawski P., et al. Development of renewable energy sources market and biofuels in the European union. Accepted manuscript. *Journal of Cleaner Production* 2019:228:467–484. doi:10.1016/j.jclepro.2019.04.242
[32] Karatasou S, Laskari M, Santamouris M. Models of behavior change and residential energy use: a review of research directions and findings for behavior-based energy efficiency. *Advances in Building Energy Research* 2014:8(2):137–147. doi:10.1080/17512549.2013.809275
[33] Sengül U., et al. Fuzzy TOPSIS method for ranking renewable energy supply systems in Turkey. *Renewable energy* 2015:75:617–625. doi:10.1016/j.renene.2014.10.045
[34] Hwang C. L., Yoon K. P. Multiple attribute decision making: Methods and applications. Springer, 1981.
[35] Wang J., Jing Y., Zhang C., Zhao J. Review on multi-criteria decision analysis aid in sustainable energy decision-making. *Renewable and Sustainable Energy Reviews* 2009:13(9):2263–2278. doi:10.1016/j.rser.2009.06.021
[36] IRENA, Renewable Power generation Costs in 2017. AbuDhabi: International Renewable Energy Agency (IRENA), 2018.
[37] Lauka D. Sustainability analysis of renewable energy sources. Riga: RTU Press, 2018.
[38] Sianaki O. A. Intelligent Decision Support System for Energy Management in Demand Response Programs and Residential and Industrial Sectors of the Smart Grid. School of Information Systems. Curtin: Curtin Business School, 2015.
[39] Mezősi A., Szabó L., Szabó S. Cost-efficiency benchmarking of European renewable electricity support schemes. *Renewable and Sustainable Energy reviews* 2018:98:217–226. doi:10.1016/j.rser.2018.09.001
[40] Lauka D., Barisa A., Blumberga D. Assessment of the availability and utilization potential of low-quality biomass in Latvia. *Energy Procedia* 2018:147:518–524. doi:10.1016/j.egypro.2018.07.065
[41] European Commission. First estimates of Research & Development expenditure "R&D expenditure in the EU increased slightly to 2.07% of GDP in 2017. Brussels: European Commission, 2019.