Modelling of Electricity Accumulation from Irregular Renewable Energy Resources

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Abstract:

The role of irregular electricity production has increased within the last decade since the options of available technologies to accumulate electricity from irregular sources have followed the same trend. In the light of that, the paper focusses on five electricity accumulation and management methods suitable for use in the Baltic countries:

1. Electrical load management, focused on the compensation of the periodical nature of solar, wind energy and hydro plants.
2. Additional use of loads through connection of users to irregular resources to produce electricity in periods when a surplus of electricity is produced.
3. Development of renewable energy distributed hybrid systems through the instalment of small scale electricity production hybrid technologies, hydro-wind.
4. Other electricity accumulation systems using solar and wind electricity surplus:
   - production and accumulation of compressed air;
   - generation and use of methane to replace fossil natural gas.

All the above mentioned alternatives have specific benefits and disadvantages related to level of innovation, costs and environmental impacts. Possibilities to integrate these technologies in the Baltic countries are analysed. Factors significant for increase of national share of electricity production from renewables and consumption are defined. The weight and significance for each indicator is assigned. The TOPSIS method based model is used for multicriteria analysis.

Keywords:

Wind, Energy storage, Energy management

1.Introduction

According to European Union directive [1] a target of 20% share of renewable energy resources by 2020 is set. Such renewable resources as wind and solar energy are stochastic in their nature, therefore an energy management system is necessary to maintain the quality of the electricity grid.

Within the large number of scientific research addressed to the energy accumulation systems Kousksou et al. [2] propose a review of the state of technology for the most common energy storage systems including the storage properties, the current state in industry and maturity. According to Kousksou et al. [2] study, all these technologies are analysed from a perspective to use them together with renewable energy technologies. The main characteristics are identified for the following technologies:

- Pumped Hydro Storage (PHS);
- Compressed air energy storage system (CAES);
- Flywheel energy storage (FES);
- Battery energy storage;
- Hydrogen-based energy storage system (HESS);

- Flow battery energy storage (FBES);
- Capacitor and supercapacitor energy storage;
- Superconducting magnetic energy storage (SMES).

The study provides an overview of the characteristics of these technologies, however it does not include a comparison of the different systems. Moreover, syngas production technology, where electricity together with CO_2 is used to generate synthetic methane, is not analyzed. More details about the production of synthetic methane are provided in Chapter 2.4.

Ibrahim et al. [3] highlight the need to store energy in order to strengthen power networks and maintain load levels. Lead batteries are described as a most popular energy storage solution however they cannot withstand high cycling rates or store large amounts of energy in small volumes, therefore other technologies (hydrogen energy storage systems, compressed air energy storage, flywheel energy storage, pumped hydro storage) are becoming more popular [3,4]. Five main characteristics are used to compare technologies [3]:

- Power comparison as a function of field of application;
- Comparison of the energy efficiency (per cycle) of the storage systems;
- Comparison of the investment cost;
- Comparison of the investment cost per charge–discharge cycle;
- Comparison based on mass or volume density.

2. Grid energy management

Grid energy management systems that could be applied in the Baltic States are analyzed in the next chapters. These include load management systems with pumped hydro storage technologies, demand response systems where demand is shifted in time or consumer appliances are switched on when surplus energy is available, compressed air energy storage systems and synthetic methane production.

2.1. Pumped hydro storage

Pumped Hydro storage is the most popular and mature electric energy storage technology. It accounts for an installed power of 120 GW globally and represents approximately 99% of all storage systems. Pumped water is used as a power source to compensate faults in the prediction of wind power. The maturity of the PHS can be proven by the fact that the first station in operation was finalized in the year 1904 and it is still running [5]. Pumped storage electricity is a method of storing and producing electricity to supply high peak demands by pumping water from a lower reservoir to an upper reservoir [2]. The pump elevates water from the lower reservoir, sea or river or an artificial pool, to the upper reservoir using excess solar and wind energy during periods of surplus. Pumps are activated during periods when the electricity price is lower. When the power demand is high, water flows from the upper reservoir to the lower reservoir, activating the turbines to generate electricity [6].

According to [7] there are two solutions of PHS systems, double – penstock system is popularly used because it is easier to stabilize the power and frequency since charging and discharging can occur simultaneously. The single – penstock system employs reversible pump – turbine set and simultaneous charging and discharging is not possible. Deane et al. [8] proposes the following classification: pure PHES (also known as ‘closed-loop’ or ‘off-stream’) and pump-back PHS. Pure PHES plants rely entirely on water that has been pumped to an upper reservoir from a lower reservoir. Pump-back PHES use a combination of pumped water and natural inflow to produce power/energy.

A system that can be adjusted for the Baltic States involves the use of already installed hydro power stations. Basically there could be two solutions depending on the size of the planned investments.

Taking into account small investments, balancing can be done by stopping the largest hydro power stations from keeping wind power stations on maximum power available and release the power when there is deficiency, therefore increasing capacity factor of wind power station. It must be noted that in this case the hydro power station must be designed to run under such conditions, since some could be designed to run under constant speed. In Latvia, the largest hydro power stations are built on the river Daugava and, according to their technical specifications they are designed to provide peak power and therefore they could be used for balancing. The drawback of such a system is that it is passive. One solution would be to use the same reservoirs but install additional pumps to provide more demand when there is a surplus of energy in the grid.

Another solution includes the usage of available pumped hydro storage abroad. The solution is analyzed in SINTEF research [9] where two scenarios are simulated: 209 MW wind park and six wind parks with total power of 2 GW were disconnected from the grid. Load balancing in this case was provided by interconnections between countries. Hydro power stations in Norway were used. Input data for the simulation were used from wind parks located in Denmark, and available power of high voltage direct current (HVDC) cables between the countries – 1.9 GW. Research showed that in both scenarios it is possible to stabilize the grid.

Duque et al. [10] analysed actual data and MATLAB simulation from a wind park coupled with PHS. Results showed that at any time there is an increase of total energy produced if both systems are working together. The increase in produced electricity is from 9% to 133%, depending on the season and weather conditions.

2.2. Demand response

Smart grid is a concept that allows electricity delivery in a controlled, smart way [11]. Demand-response (DR) offers to customers a broad range of potential benefits on system operation and expansion and on market efficiency [11]. DR can reduce the system peak load, and thus, the system risk of being exposed to forced outages and electricity interruption [12]. DR refers to "*changes in electric usage by end-use customers from their normal consumption patterns in response to changes in the price of electricity over time, or to incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized*" [13]. In the first scenario, demand reacts to market price and accordingly switches on or off electric devices. Another concept provides a solution in which the electricity provider has a contract with the consumer which allows the latter to switch off utilities under the conditions agreed upon with the former. In general terms, environmental emissions and energy efficiency are two main benefits of the smart grid [14]. Apart from stabilizing the electricity grid, demand response programs can bring financial benefit to electricity consumers. Successful programs show that the combined use of smart grid technologies with DR programs allows utilities to reach significant economic savings [13]. Flexibility of conventional generators is restricted by technical constraints, such as ramp rates, power system reliability using only generation side flexibility becomes technically too constrained and this potentially compromises efficiency [15].

Smart grids and demand-response can become more significant when vast amounts of electric vehicles will be introduced in the electric grid. Uncontrolled or unscheduled vehicle charging may increase the residential peak and the risk of electric distribution network failure [16]. To reduce this impact, consumers with high consuming electric devices are encouraged to become involved in demand response programs in order to avoid power peaks and distributing utility usage over time. Fig. 1 illustrates load shifting, where green area represents power consumption without demand response, and orange represents shifted power curve. It can be seen that in such an operation mode, peak power is also reduced. In a practical power system with DR, the generation resource can be replaced with the demand resource [12].

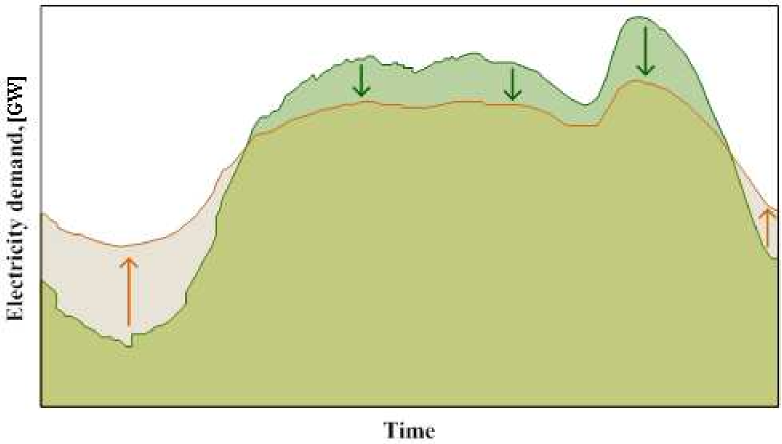

Fig.1. – Electricity demand shifting [14]

Mitigating the intermittency of renewable energy resources can be achieved by implementing (1) demand response, (2) predictive wind power model, and (3) the use of physically implementable dynamic model-predictive dispatch of responsive demand, wind power, and conventional power plants [18]. A case study [19] showed that the look-ahead dispatch of the proposed method is physically implementable and when used with the elastic demand, wind power generation up to 50% can be accommodated. Broeer et al. [20] simulated a system with 35 MW of wind power and 10000 households with HVAC as the main consumers. The results show that demand response can smooth grid operation, however the balancing effect disappears if constantly high or low power production rates are observed for a longer period. Compared with PHS and CAES there is uncertainty and unexpectedness of demand resources which can cause significant reliability problems in the power system when customers with unstable and unpredictable behaviors participate in the DR market [12]. Therefore the main conclusion is to integrate different appliances, which have different power and conditions at which they operate.

2.3. Compressed air energy storage

The surplus of energy can also be used for power compressors, therefore free energy is stored in compressed air which can be used later when production does not meet the demand. Compressed air energy storage (CAES) is one of the most promising storage technologies due to the large amount of energy that can be stored at an economical cost [21]. CAES systems store the compressed air in large reservoirs, typically making use of existing geological formations and structures, such as salt caverns, aquifers, and abandoned mines [22]. CAES plants currently being in service use mined underground salt caverns to store compressed air. Lined rock caverns are currently subject to investigation [23]. Compared with other systems, the fact that these structures already exist reduces the capital costs. There are two types of compressed air ES plants [24]. In adiabatic process the heat from compressed air is stored and used in discharge mode, this allows to supply the heat needed for an expansion process from otherwise rejected compression heat [25].

In diabatic process natural gas has to be co-fired while discharging to prevent the turbine from freezing during expansion of the air [26]. For the heating of the compressed air conventional CAES plants require the use of additional energy sources like natural gas [23]. Adiabatic CAES are more complex and more efficient than diabatic CAES [26]. According to these are the advantages of CAES systems: high power capacity (50–300 MW), large energy storage capacity (2–50+ h), a quick start-up (9 min emergency start, 12 min normal operation), a long storage period (over a year), and relatively high efficiency (60–80%) [27].

As an alternative to pumped hydro storage, CAES is a promising method for energy storage, with high reliability and economic feasibility and its low environmental impact [28]. It shows a greater siting flexibility compared to PHS together with relative low specific investment cost [28]. Compressed air energy storage (CAES) is located slightly below pumped hydro systems, in terms of power, but it also has drawbacks: finding a suitable site, the rather extended construction time, and the relatively high initial cost [29].

CAES is a modification of the basic gas turbine (GT) technology, in which off-peak electricity is used for storing compressed air in an underground cavern. This air is then heated and expanded in a gas turbine to produce electricity during peak demand hours [30]. Two plants have been constructed in the world so far, both of them are diabatic type; one in Germany and one in the USA at turbine capacities of 390 MW and 110 MW, respectively [30]. In terms of energy storage size and maturity, CAES can be considered as a very close competitor for pumped hydro storage.

2.4. Synthetic natural gas

One of the most recent technologies that have been developed is synthetic methane production. Hydrogen is produced by using extra electricity and then mixed with CO_2. H_2 reacts with CO_2 in Sabatier reaction (1) and forms methane [31].

$$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O \quad (1)$$

Generation of syngas can be divided in three steps: carbon and electricity production, dissociation of oxides and fuel synthesis (Fig.2) [32]. Synthetic methane can be distributed among already existing gas infrastructure.

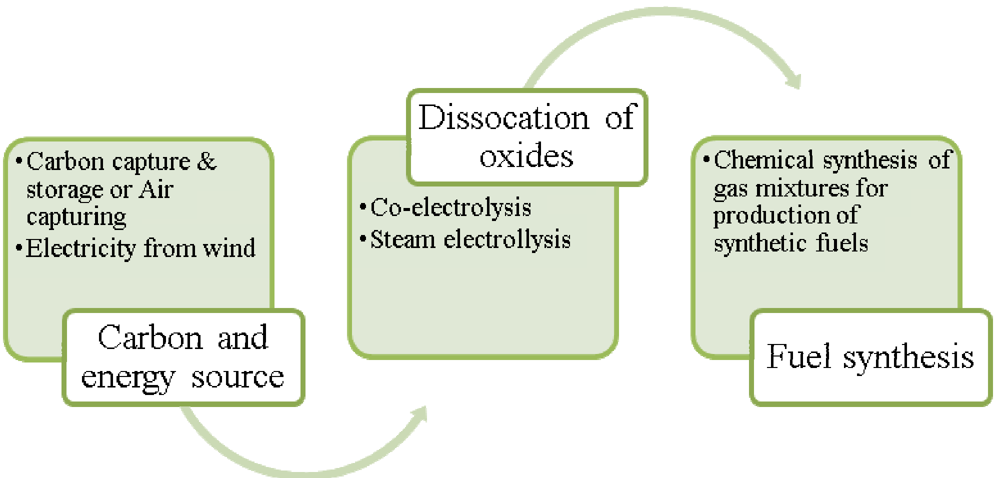

Fig.2. – Synthetic fuel production [32]

An additional benefit of this system is that the end product, compared with other grid energy storage systems, can be used not only for electricity production, but also for other means. Syngas can be a power source for vehicles, boiler houses or CHP. The reconversion to electricity can be done by conventional natural gas fired power plants (e.g. GT or CCGT plants) [26]. This grid energy storage system links together power infrastructure with gas infrastructure as can be seen in Fig. 3. Since methane is used as a storage medium, existing natural gas storage and distribution capacity can be used, this could alleviate some major problems associated with intermittent renewable electricity supply [26].

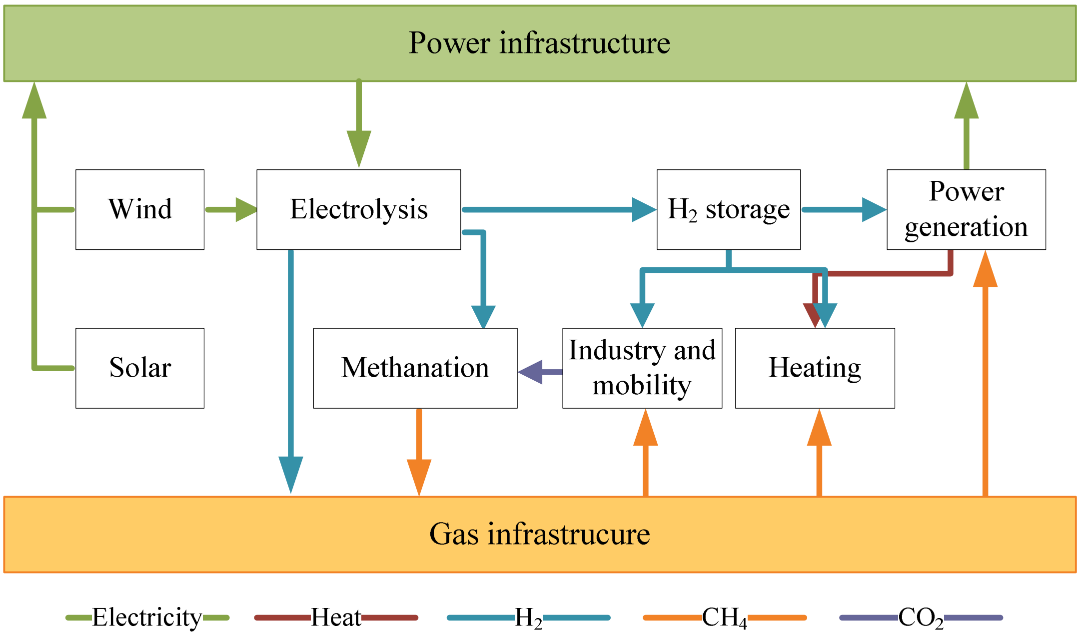

Fig.3. – Power to gas infrastructure [33]

It must be pointed out that the transportation sector consumes 19% of energy resources and accounts for 23% of CO_2 emissions [32]. Since CO_2 is one of the main components in production of synthetic methane, it can be assumed that CO_2 neutral fuel is created. Therefore, the use of SNG technologies reduces emissions at two stages – allows storing of surplus electricity coming from renewables, uses CO_2 emissions that otherwise would not have been used.

3. Analysis of the necessity for an accumulation system in the Baltic States

Knowing the main characteristics of grid energy management and accumulation systems, it is important to characterize necessities (size, availability, nature of electricity production) of accumulation systems in the Baltic States. In order to do that, data from the Latvian Transmission system operator has been gathered. A target is set in order to replace all electricity import and electricity generated in Latvia in large (>10MW) cogeneration plants (CHPs) with wind energy. A scenario with 100% wind energy has been selected due to the data availability. Solar power is not included in the study due to lack of the data. With information on the actual electricity demand, power from small power (<10MW) stations and hydro power at every hour during 2013, it is possible to calculate the energy amount that has to be replaced by wind energy. This is represented in Fig. 4, where green line shows how much power it would be necessary to generate from wind plants. Maximum power deficiency (difference between demand and actual power generation) according to data from 2013 is 1020 MW. It can also be seen that, during the spring period, power coming from HPP and small stations completely covers demand. This is due to the fact that water flow to hydro power stations increases due to melting snow and ice, so water storage behind water dams is not possible.

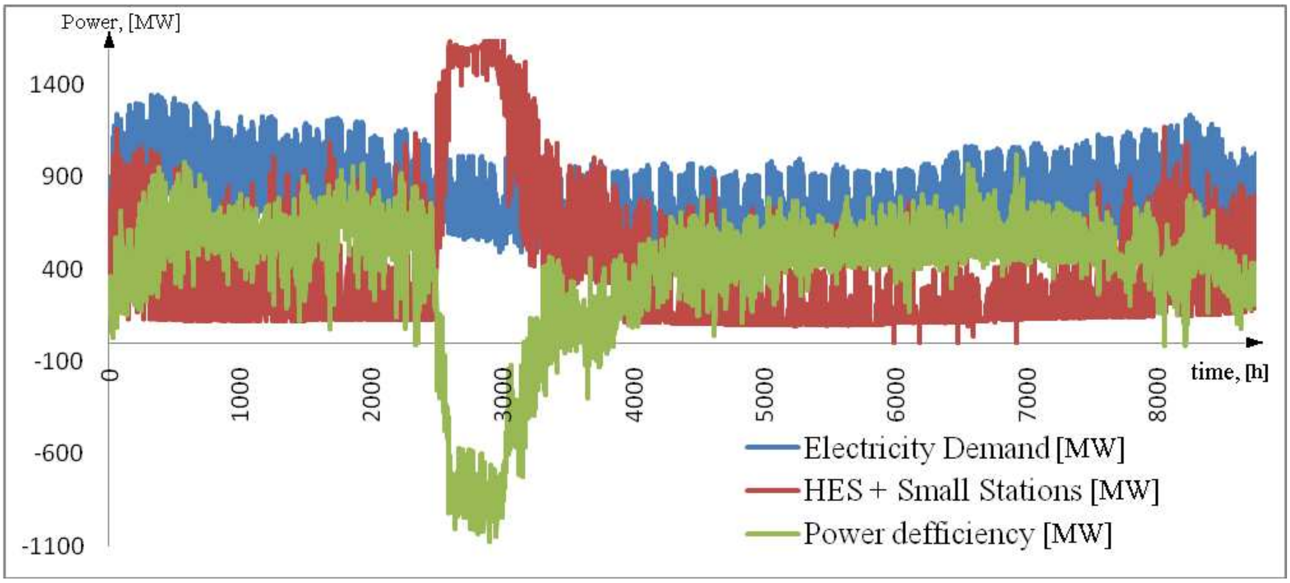

Fig.4. Electricity demand, production and deficiency in 2013 in Latvia

The total energy deficiency according to this data would be 3432 GWh, which is calculated by adding together deficiency of every hour throughout the year. Taking in account the total deficiency and capacity factor, it is possible to calculate nominal power that would cover demand, which is ~2.3 GW. The wind park with nominal power 2.3 GW would generate surplus energy, which can be calculated by multiplying nominal power with capacity factor and subtracting demand. By summing surplus energy data at every hour it is possible to represent the usage of energy storage (2).

$y = \sum_{i=0}^{n} f(x_i)$, where (2)

y – sum of surplus energy

$f(x_i)$ – surplus energy at a given point in time

n – total number of points, $0 < n < 8760$

Ascending energy storage trend line represents the level of filling of storage. The results can be seen in Fig. 5. Storage is filled with energy when surplus energy is available, in times of energy deficiency, energy from storage is used (descending energy storage size trend line).

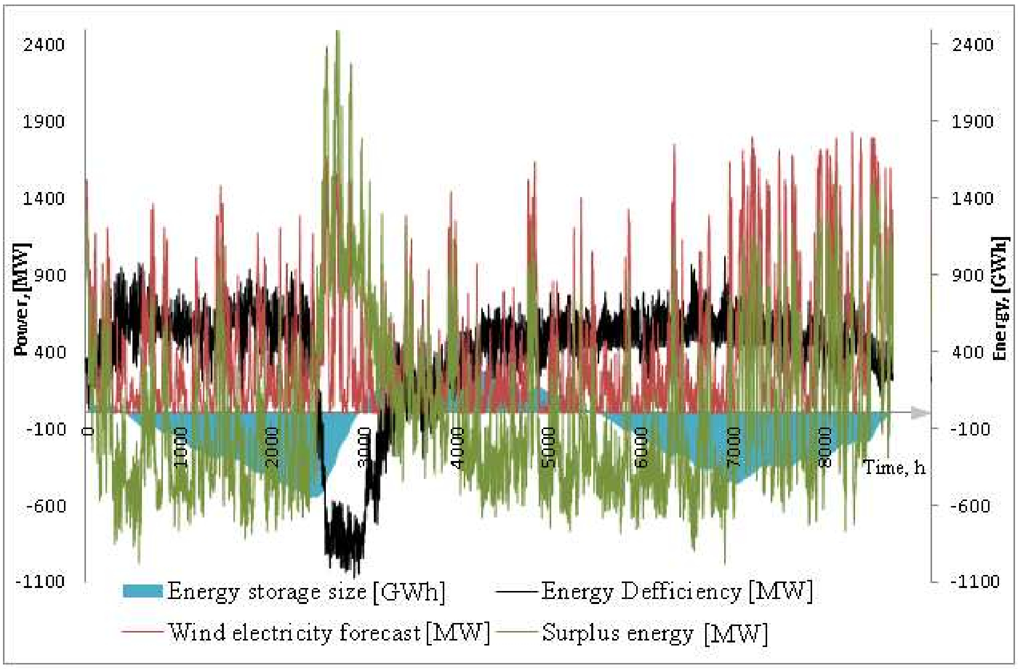

Fig. 5. Grid energy storage, calculated size

Maximum necessary storage size at given conditions can be calculated by subtracting the minimum value from maximum value, that gives 889 GWh.

Based on literature overview and necessary storage capacity, four energy accumulation methods were promoted for multicriteria analysis as the most promising in the region:

1. Pumped hydro storage
2. Compressed air energy storage
3. Synthetic natural gas
4. Hydrogen based Energy Storage System

PHS and CAES are the most price competitive technologies. PHS can be installed by using already built structures for the largest HES in the Baltic States on the river Daugava. There is a potential to build CAES in Estonia – using old oil shale mining caves and in Latvia by using caverns in the Kurzeme region or near the town of Dobele. Latvia and Lithuania heavily depend on imported natural gas from Russia and there is a large infrastructure to distribute it: the same network can be used to distribute synthetic methane. Hydrogen is used in comparison since it is a well-developed technology and the transportation sector is investing in H_2 powered vehicles that could become more and more used. Clearly PHS, CAES, H2 and SNG are the only storage technologies available for high power ranges and energy capacities [34].

3.1. Costs

According to [34] capital costs for PHS vary from 443 – 1477 EUR/kW, 295 – 1477 EUR/kW for CAES, and 370 – 1107 EUR/kW for HESS. Maintenance and operating costs according to the same document vary from 3.7 to 74 EUR/kWh, 1.6 to 74 EUR/kWh and 7.4 to 15 EUR/kWh for PHS, CAES and HESS accordingly. Source [35] gives the following indicators, PHS - 10 to 70 EUR/kWh, CAES - 3 to 170 EUR/kWh and HESS 2 to 15 EUR/kWh see Table 1.

Since the average value would not be representative because for some systems the range from minimum to maximum value is very large, but for others it is small, the decision is made to use the average of minimum values available in literature sources. Currency exchange course 0.7352 for $

to EUR is used. SNG from all compared technologies is the most recent and information about costs of technology is poor, therefore an assumption is made that costs are proportionally larger than costs of HESS technology by a coefficient that is maintained from a ratio of efficiency for both technologies, which is 0.883.

Table 1. Capital and maintenance costs of grid energy storage systems

Technology	Capital costs, EUR/kW	Maintenance and operating costs [34], EUR/kWh	Maintenance and operating costs [35], EUR/kWh
PHS	443 – 1477	3.7 – 74	10 – 70
CAES	295 – 1477	1.6 – 74	3 – 170
HESS	370 – 1107	7.4 – 15	2 – 15

3.2. Maturity

Maturity is assigned according to the scale provided by Kousksou et al. [2], see Table 2. Maturity represents whether technology is in its early stage of research and developing or it is already well developed and commercially used.

Table 2. Grid energy storage system state of art coefficients

State of art	Points
Developing	1
Demonstration	2
Developed	3
Commercial	4
Mature	5

3.3. Efficiency

According to [34] efficiency of PHS is around 70-80%, CAES 41 – 75%, HESS 34 – 44% and SNG 30 – 38%. Source [2] gives 75 – 85% for PHS, 50-89% for CAES and 75-85% for HESS. And there is slightly different information from [35], PHS 65 - 80%, CAES 70 – 73%, HESS 35% - 42%. A similar approach as for average cost is used to calculate average efficiency, only maximum values are used therefore creating a scenario of the best available technologies with the lowest costs.

3.4. Lifetime

According to the sources [35], [2] and [34] lifetime of PHS is 30 – 60, for CAES 30 – 40 years, HESS 5 – 15 years. The average value is calculated for each technology by adding both limits together and dividing by two. Lifetime of syngas technologies is assumed to be equal to HESS since both technologies include production of Hydrogen.

3.5. Storage capacity

According to sources [35], [2] and [34] storage capacity for PHS is 500 MWh – 10 GWh, CAES 580 to 2860 MWh, HESS and SNG technologies have very similar boundaries: from 1 MWh to more than 100 GWh. Since variation is from few hundreds of MWh to more than 100 GWh, this would leave huge and disproportionate impact on multi - criteria analysis, therefore a scale is made and coefficient is used in analysis (see Table 3).

Table 3. Coefficients for storage capacity size.

Storage size	Storage capacity range	Points
Small	<100 MWh	1
Medium	100 MWh – 10 GWh	2
Large	10 GWh – 100 GWh	3
Extra large	>100 GWh	4

4. Methodology

As stated before, the multi-criteria analysis method TOPSIS is selected for evaluation of the research topic. The Technique of Order Preference by Similarity to the Ideal Solution (TOPSIS) is a classical multi criterion decision making (MCDM) method. Since it was developed by Hwang and Yoon [36], TOPSIS method has been used for numerous applications in various fields from construction and development [37] to spacecraft [38].

Data analysis is based on decision making matrix (Fig. 6.), with n evaluation criterions (x_j) and m alternatives (A_i). In this case four alternatives: PHS, CAES, SNG, HESS and six evaluation criterions are used: capital cost EUR/Kw, maintenance cost EUR/kWh, maturity (scale 1-5), efficiency (%), lifetime (Years) and storage capacity (scale 1-4).

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

Fig. 6. TOPSIS decision making matrix

A_1, A_2,…, A_i, ..,A_n } represents alternatives. Criterions by which there alternatives are evaluated are represented as {x_1, x_2, …, x_i, …, x_n}. Decision making matrix with data for this study is displayed in table 4.

Table 4. Decision making matrix

	Capital cost Euro/kW	Maintenance cost Euro/kWh	Maturity 1-5	Efficiency %	Lifetime Years	Storage capacity 1-4
PHS	441	6.84	5	80	45	2
CAES	294	2.23	3	74	35	2
SNG	415	5.29	3	38	10	4
HESS	367	4.68	4	43	10	3
Weight	0.3	0.2	0.1	0.15	0.05	0.2

Criterions have different dimensions; therefore, criterion value normalization is necessary in order to be able to use these data for analyses.

In this case normalized values (b_{ij}) were obtained using Jüttler's -Körth's (1969) linear normalization method (3), (4).

$$b_{ij} = \frac{\max x_{ij} - x_{ij}}{\max x_{ij} - \min x_{ij}}, \qquad (3)$$

if max x_{ij} is preferable;

$$b_{ij} = \frac{x_{ij} - \min x_{ij}}{\max x_{ij} - \min x_{ij}}, \qquad (4)$$

if min x_{ij} is preferable.

Normalized data are also arranged in a matrix and then weighted multiplying them with criterion weights (w_j) (See Fig. 7.)

$$\begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_i \\ \vdots \\ A_n \end{array} \begin{array}{c} \begin{matrix} w_1 b_1 & w_2 b_2 & \cdots & w_j b_j & \cdots & w_n b_n \end{matrix} \\ \begin{bmatrix} w_1 b_{11}^k & w_2 b_{12}^k & \cdots & w_j b_{1j}^k & \cdots & w_n b_{1n}^k \\ w_1 b_{21}^k & w_2 b_{22}^k & \cdots & w_j b_{2j}^k & \cdots & w_n b_{2n}^k \\ \vdots & \vdots & \cdots & \vdots & \cdots & \vdots \\ w_1 b_{i1}^k & w_2 b_{i2}^k & \cdots & w_j b_{ij}^k & \cdots & w_n b_{im}^k \\ \vdots & \vdots & \cdots & \vdots & \cdots & \vdots \\ w_1 b_{n1}^k & w_2 b_{n2}^k & \cdots & w_j b_{nj}^k & \cdots & w_n b_{nm}^k \end{bmatrix} \end{array}$$

Fig. 7. Normalized and weighted data matrix

The next step of TOPSIS analysis is determination of Positive and Negative Ideal solution.

Positive Ideal solution (5)

$$A^+ = \mathbf{Max}_j\, w_j b_{ij} \qquad (5)$$

Negative Ideal solution (6)

$$A^- = \mathbf{min}_j\, w_j b_{ij} \qquad (6)$$

Separation from Positive Ideal solution (S+) is calculated by following formula (7).

$$S^+ = \sqrt{\sum_{j=1}^{n} \left(v_{ij} - v_j^+\right)^2}, \text{ i =1, 2,.., m} \qquad (7)$$

Separation from Negative Ideal solution (8):

$$S^- = \sqrt{\sum_{j=1}^{n} \left(v_{ij} - v_j^-\right)^2}, \text{ i =1, 2,.., m} \qquad (8)$$

Last step is calculation of alternatives Relative Closeness to the Ideal Solution (9).

$$C_i^* = \frac{S_i^+}{(S_i^+ - S_i^-)}, \text{ i= 1,2,..,m} \qquad (9)$$

Relative Closeness to the Ideal Solution is a number in range from 0 to 1. Where 1 means that the alternative is the Positive Ideal solution and 0 is the least desirable outcome. Higher number equates better alternative [39]. The mentioned calculations are applied and results are described in the next chapter.

5. Results

Results show (Fig. 8.) that the best alternative is CAES with rating 0.66, possibly due to it having the cheapest relative capital and maintenance costs. The second is HESS with 0.56, SNG and PHS follows very closely with 0.54 and 0.52.

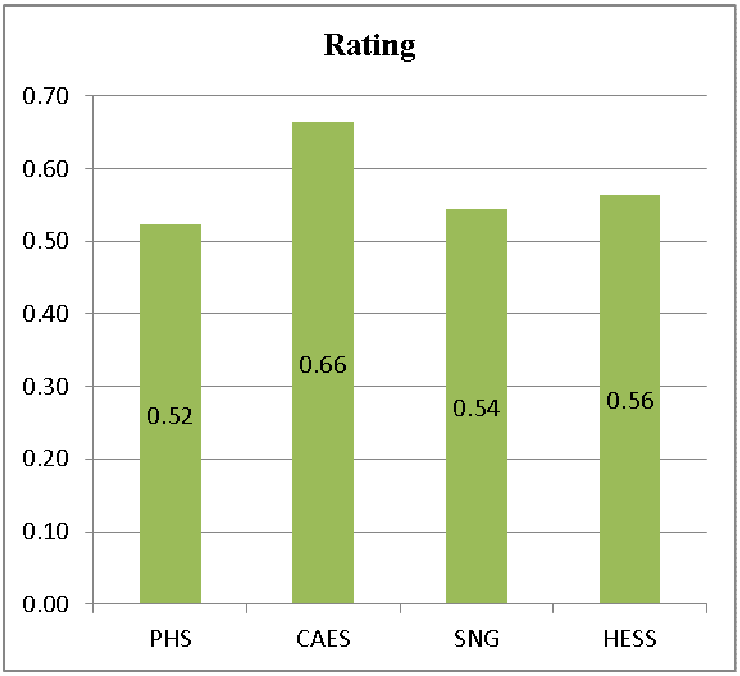

Fig. 8. TOPSIS analysis results

Choosing of weight coefficient is a crucial part in multi-criteria analysis. In this specific case, more weight was put on economic indicators, capital cost – 0.3. The maintenance cost together with storage capacity had an assigned weight of 0.2. Storage size is an important part since large storage is necessary to integrate big wind or solar parks in electricity grid. If more storage capacity is available more stochastic renewable resources can be connected to the electric grid with more efficiency. Efficiency has weight of 0.15, then follows maturity with 0.1 and system lifetime with 0.05 which has the smallest weight, because with continuous development it could even be good that technology has a shorter lifetime and it can be more often replaced with a more efficient technology.

It is important to note that in this analysis, the average indicators from numerous publications has been used [2], [3], [34], [35] and for some indicators, like energy storage capacity and system costs, the range of indicator value for one technology was very wide. This of course leaves an impact on results. There is big difference if maximum, minimum or average indicators are used, for example for maintenance costs, different sources indicate values from 1.47 – 73.83 EUR/kWh. Since economic indicators usually have more impact than other indicators, an additional research has to be made to specify what would be costs for such storage systems located in the Baltic States, taking in account geographic constraints and the already available technologies.

One of the reasons why HESS and SNG technologies are further from Ideal Solution is because of very low system efficiency. Here it must be mentioned that round trip efficiency assumes that all energy is converted back to electricity. End product from HESS and SNG can be used in transportation sector. Synthetic methane can also be used as a fuel for boiler houses and CHP, these are system side effects that has not been expressed in any indicators at the moment. Another aspect in favor of SNG and HESS is the fact that energy matter can be transported, in case of mechanical or electrical problems in one power station, the energy can be produced in other power station, which brings additional security and reliability to power system.

PHS according to the results is the worst scenario, because of the highest capital and maintenance costs compared to other technologies. Positions where PHS is better than other technologies are maturity, efficiency and lifetime (see Table. 3), but these indicators have less weight. Baltic States in general are with flat relief, but there is a potential to use hydro power stations as PHS. As can be seen from Fig. 4. hydro power stations in Latvia are usually running with an overall average ~500 MW power and during spring season average power comes up to ~1400 MW, this indicates that there is a potential of energy storage. More analysis has to be done to calculate what is actual potential of energy storing in already existing hydro power stations in Baltic states, taking in account two scenarios: regulation of production (without adding pumps to existing structures), installing pumps and creating PHS of existing hydro power stations.

6. Conclusions

Within the proposed study, a multi-criteria analysis on different electricity accumulation technologies of irregular renewable energy sources has been proposed.

The scientific research was addressed to understand the role of wind energy in Latvia within the ambitious target set in order to replace all electricity import and electricity generated in large (>10MW) cogeneration plants.

The topicality of the study was addressed to the comparison of four different types of technologies with highest power and capacity ranges that have been identified in the context of the Baltic States, more specifically:

- Pumped hydro storage (PHS),
- Compressed air energy storage (CAES),
- Synthetic natural gas (SNG),
- Hydrogen based Energy Storage System (HESS).

Five principle criteria (i.e. costs, maturity, efficiency, lifetime, storage capacity) have been selected within the implementation of a multi-criteria analysis (MCA) through the use of TOPSIS methodology with a more important attention focused on the economical dimensions (i.e. weighting factor equal to 30%).

The results from the MCA show that the CAES scenario represents the best option from the set of the proposed criteria mainly due to the cheapest relative capital and maintenance costs. It must be underlined that the implementation of the only CAES scenario cannot provide all the storage capacity necessary meaning that must be considered a combination of storage technologies, demand response system and power grid interconnection to other energy systems used to fully integrate large penetrating energy resources in electricity grid.

Important numerical and analytical outcomes from the study are connected with the scenario where the PHS technology is implemented, in fact have been evaluated that when the electricity demand in Latvia is covered by the PHS and small power stations (<10 MW) the energy storage demand is accounted for a value of 889 GWh.

This study represents an important milestone within the evaluation of the reliability and feasibility for the strengthening of electricity production from local irregular renewable sources. The overall results show that wind energy has a feasible and reliable key role within the increasing of hybrid electrical systems involving irregular energy sources.

Even though more research must be devoted to the analysis of specific regional indicators (e.g. total storage capacity available locally) and to a more extended version of the criteria selected for the MCA. Moreover a more exhaustive sensitively analysis should be taken into account within further research.

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EIROPAS SOCIĀLAIS FONDS

EIROPAS SAVIENĪBA

IEGULDĪJUMS TAVĀ NĀKOTNĒ

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