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Carbon driven energy equilibrium at the municipal scale –

Energy Equilibrium

GoA 2.4 - Roadmap for renewable energy transition in BSR municipalities

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1 Introduction and Instruction of the roadmap

1.1 About Energy Equilibrium

The project Energy Equilibrium aims to help public authorities and energy suppliers to secure uninterrupted energy supply by developing solutions for renewable energy storage. For this goal, the project has developed the Energy Equilibrium platform: an innovative tool designed to provide municipalities and local energy suppliers with interactive energy modelling, accessible online to everyone.

- The platform aims to support local public authorities in making informed decisions, helping the development of efficient action plans to accelerate local renewable energy sources utilization and energy storage integration in the Baltic region.
- The project has furthermore produced reports about energy storage in Sweden, Finland, Latvia, Lithuania, Poland, and Germany, through collaboration with municipalities, universities, and energy clusters.
- As a next step, this roadmap has been developed to outline how local authorities on a local level in the Baltic Sea Region can implement actions and strategies to support renewable energy solutions and energy planning, and how the platform can be used in this process.

1.2 How to use the Energy Equilibrium Roadmap

The purpose of the roadmap is to assist local and regional decisionmakers to create a positive and responsive policy environment for the increased deployment of renewable energy technologies and renewable energy storage solutions in regions around the Baltic Sea Region.

The roadmap outlines practical recommendations for how energy agencies, energy supply companies, regional and local public authorities, and interest groups can overcome barriers and develop and implement more efficient energy planning and action plans at a municipal level, with a particular focus on how these actors can more effectively support renewable solutions and advance towards climate neutrality.

This is the content of the Energy Equilibrium roadmap:

1. The roadmap initially outlines the EU objectives and programs for energy transition, which are the basis for the goals of the Energy Equilibrium project and the recommendations here outlined.
2. It continues to describe the Energy Equilibrium Platform for energy modelling, why it is useful and how it was developed.
3. The next section presents a summary of participating countries' energy system, challenges in the EU and each country to achieve the project's objectives of efficient energy planning, deployment of renewable energy and storage deployment and finally the expectations of how each participating country can apply the tools developed in Energy Equilibrium.
4. This is followed by an outline of recommendations by The Joint Research Centre (JRC) at the European Commission (SECAP, P Bertoldi, 2018) on how energy planning on a local level is successfully developed, and how the Energy Equilbrium platform can be used by local authorities in the steps of a successful energy action plan.
5. As a next step, the roadmap outlines recommended legal, regulatory, fiscal, technological, infrastructural, and social and cultural incentives for the Baltic Sea countries.
6. Finally, the roadmap presents recommended analyses and actions that can be implemented by local authorities to support more efficient energy planning and a carbon neutral energy transition.

2 EU – Energy transition

For the EU, the energy transition from fossil fuels to RES and mitigation of greenhouse gases is essential. To achieve the objectives set, energy transition programs have been developed by the European Commission. The EU objectives and programs are the basis for the goals and recommendations in the Energy Equilibrium Roadmap.

2.1 The EU Green Deal

Climate change and environmental degradation are an existential threat to Europe and the world. To overcome these challenges, the European Green Deal will transform the EU into a modern, resource-efficient and competitive economy, ensuring:

- no net emissions of greenhouse gases by 2050.
- economic growth decoupled from resource use.
- no person and no place left behind.

One third of the €1.8 trillion investments from the NextGenerationEU Recovery Plan, and the EU's seven-year budget will finance the European Green Deal.

2.2 EU Fit for 55

The European climate law makes reaching the EU's climate goal of reducing EU emissions by at least 55% by 2030 a legal obligation. EU countries are working on new legislation to achieve this goal and make the EU climate-neutral by 2050. The Fit for 55 package is a set of proposals to revise and update EU legislation and to put in place new initiatives with the aim of ensuring that EU policies are into line with the climate goals agreed by the Council and the European Parliament.

The package of proposals aims at providing a coherent and balanced framework for reaching the EU's climate objectives, which:

- ensures a just and socially fair transition
- maintains and strengthens innovation and competitiveness of EU industry while ensuring a level playing field vis-à-vis third country economic operators
- underpins the EU's position as leading the way in the global fight against climate change

Fit for 55 refers to the EU's target of reducing net greenhouse gas emissions by at least 55% by 2030. The proposed package aims to bring EU legislation in line with the 2030 goal.

3 Why an Energy Equilibrium Platform

The Energy Equilibrium Platform is an interactive and easy-to-use online tool that enables energy simulations for modelling local energy systems and their transition to a low-carbon energy infrastructure. The aim of the Energy Equilibrium Platform is to support municipalities and energy suppliers in decision-making related to the development of efficient action plans to accelerate local RES utilisation in the region, including development of sufficient energy storage infrastructure.

The Energy Equilibrium Platform offers several functions, including modelling the energy sector for the development of long-term energy policies, identifying optimal renewable energy strategies, identifying the expansion of local renewable energy potential through storage solutions and simulating energy development scenarios for low-carbon systems.

The key target groups of the Energy Equilibrium platform are municipalities, local energy suppliers, regional public authorities, energy clusters and consulting companies, renewable energy and energy storage association, energy infrastructure technology companies, energy developers, and others.

The Energy Equilibrium Platform is intended for modelling energy policy in both energy production and main consumption sectors of the municipal energy system up to 2050. With the help of the model, it is possible to search for solutions to achieve the long-term local energy decarbonisation and efficiency targets and each of its users can find their own way to achieve the targets.

The platform can be used in day-to-day decision-making related to the development of energy infrastructure, the improvement of energy efficiency and the general optimisation of the sustainability of the energy system. It is intended that the results of the platform can significantly contribute to the development of feasible and reliable energy action plans in municipalities and regional authorities.

By using local energy data for input in the model and assumptions on the development of the energy system as well as for storage techniques, the model can calculate and predict the development of the energy system on a local level including cost calculations. The following areas can be supported using the energy equilibrium model:

- **Scenario building** – The energy equilibrium tool will, when having access to quality data, in an accurate way model the energy system with predictions of the development forward. These scenarios can be used in different ways further on.
- **Evaluation of storage techniques** – In using the model it is possible to add different storage techniques to the system and evaluate what the effect will be by implementing them, both on a technological level and an economic level.
- **Indication of cost for investments** – When using the model, it will give an estimation of cost included for implementation of different energy storage techniques. Cost varies over time and when storage techniques develop into production of larger scale and innovations lower the price, the data for costs of storage techniques need to be updated.
- **Visualisation of energy system development** – When running the model with quality input data the development of the energy system will be visualised and can be used in various occasions when visualisation will improve understanding and result of stakeholder dialogues.
- **Basis for decision making** – By running the model and visualising the result of energy system development, the tool gives a robust foundation for decision makers to build their opinion on both relevant and customized data, to make it possible and supporting a more fact-driven approach for decision making regarding the development of the energy system.

- **Development of policies** – The tool and its usage can be an essential supporting instrument for evaluation and development of policies within the energy and climate area on a local and regional level.
- **Education and involvement of stakeholders** – The tool can be used for education of politicians, civil servants, business, academia and other stakeholders in the energy system on a local level. The tool is also an excellent facilitator in involving stakeholders in the energy transition development on a local level.
- **Support local energy planning** – The tool is an essential supporting device in the energy planning work on a local level, assisting the development of a municipal energy plan and an important tool in facilitating implementation of actions in the area of RES deployment and energy storage on a local level.

4 Development of the energy equilibrium platform

Within the Energy Equilibrium project a thorough tool for modelling the energy system on a local level and the effect of implementing energy storage techniques has been developed. The tool will support the EU energy transition on a local level. To carry out the development of the tool in an organised and structured way, the Energy Equilibrium Platform pilot activities were differentiated by two main approaches – platform pilots for project partners and general pilot activities for stakeholders outside the partnership. Project partner pilots were carried out in two rounds. The first round of pilots for the project partners included individual meetings with each partner municipality to discuss the characteristics of each municipality's energy sector based on the energy data provided by the municipality. Platform pilots took place in the following municipalities: Gulbene municipality (Latvia), Tukums municipality, Mikolajki Pomorskie municipality (Poland), Wejherowo municipality (Poland), Taurage municipality (Lithuania) and Tomelilla municipality (Sweden).

There were seven main steps of the first pilot round that were carried out for each municipality before the pilot meeting to determine the key positions to be discussed and clarified.

1. Adaptation of the formatting of the municipal energy data to the model template. For the data import of the system dynamics model, the data had to be converted into CSV files.
2. Once the data had been entered into the model templates, outliers and missing data items were identified. On this basis, RTU defined the questions to be discussed with the municipalities in the first pilot round.
3. The data for each municipality case was then imported into the model separately.
4. Model optimisation and data adjustment. During model calibration, the items were optimised for a better fit of the model.

5. Model validation based on historical data. Modelling is only carried out for the items for which data is available. In the segments with missing data, modelling can be performed based on assumptions.
6. Identification of items that cannot be validated. Three main reasons for validation errors were identified: an error in the model; an error in the data; an unpredictable event (e.g. a reform) where the dynamics cannot be adequately assessed.
7. An individual meeting is held with the municipal representatives to discuss the results and any inconsistencies in the energy data.

After each individual meeting with the municipalities the model was improved and adjusted based on the responses provided by the municipalities during the first round of pilots. Moreover, municipalities were asked to provide additional data on their energy sector and municipal sociodemographics to be included in the model. The second round of pilots included a webinar organised for all partner municipalities. The webinar gathered 34 participants, including project partners, their stakeholders and internal working groups. During the webinar, the latest version of the Energy Equilibrium platform was explored, demonstrating its improved features and functionalities. Municipalities had the opportunity to delve into hands-on exercises, simulating various development scenarios tailored to the specifics of each municipality. Energy Equilibrium platform general pilots were carried out in three main events and activities where participants engaged in the events, which included hands on local energy system modelling, used and further developed the Energy Equilibrium platform.

5 Summary of energy systems in participating countries

A short summary of each participating country´s electricity and energy system is presented, setting the prerequisites for working with energy storage and energy transition on a local level. A more detailed description of each country´s energy systems, is presented in Annexes.

5.1 Finland

Finland's electricity system consists of power plants, the transmission grid, high-voltage distribution networks, distribution networks, and electricity consumers. In 2023, 38 % of the electricity originated from nuclear, 20 % from wind power,17 % from hydropower, 15 % other and 10 % biopower. Finland is part of the Nordic synchro-nous area along with Sweden, Norway, and eastern Denmark. Finland is also linked to Estonia by direct current connections. The distribution network is an electricity network with a nominal voltage below 110 kV. The high-voltage distribution network has a nominal voltage of 110 kV. The core network is a nationwide integrated electricity transmission network consisting of power lines, substations and other installations with a nominal voltage of 110 kV or more.

The design and implementation of energy storage systems will have a major impact on the benefits that can be achieved, how well the use can be optimised and how real-time monitoring can be achieved. In Finland, the active stakeholders in energy storage in the electricity grid include several parties that influence energy production, distribution and consumption. The main stakeholders for energy storage are power plants, energy storage companies, grid operators, consumers, legislators and regulators, research and development organisations and non-governmental organisations and environmental groups.

5.2 Latvia

Latvia's energy system is made up of various forms of energy production, distribution, and consumption, with a major focus on hydropower and other renewable resources. Latvia produces a large amount of its electricity from renewable energy sources. In 2023, electricity was produced by hydropower 60%, natural gas 23 %, bioenergy 12 % and wind 5 %. The three main hydropower facilities on the Daugava River—Plavinas, Kegums, and Riga—account for a substantial amount of the nation's electric-ity production. The country is renowned for its considerable hydropower capacity. With plans to in-crease the share of wind and solar energy in the future, Latvia also uses biomass, wind, and solar energy to a lesser extent. Natural gas, which is mostly imported from nearby nations, helps bridge energy shortages, especially when hydropower output is low.

Local authorities in Latvia are increasingly involved in energy storage, especially in promoting decentralized renewable energy production and integrating storage solutions. Municipalities take charge of the planning and permitting processes for renewable energy and storage initiatives. They collaborate with private companies to set up small-scale energy storage systems within communities, which boosts local energy resilience and efficiency. The strategic documents of the Latvian Association of Local Governments do not set a common target for the construction of electricity storage facilities, but the municipalities are interested in greater energy independence and economic development.

5.3 Lithuania

Lithuania has set ambitious targets under the National Energy Independence Strategy to contribute to the Energy Union and the EU's 2030 energy and climate policy goals, with a target of 45% of final energy consumption to be from renewable energy sources.

The largest share of renewable energy comes from solid biofuels, such as firewood and wood and agricultural residues for fuel. In 2022, biofuels accounted for 51.8% of electricity and district heating consumption, and 34.1% of household consumption. Energy producers produced 67.2% of all heat produced in power plants and boiler houses and 17.1% of all electricity produced in power plants from biofuels. In the first half of the year 2024. solar and wind power plants generated almost 70% more electricity than in the same period in 2023 and twice as much as in 2022.

Municipalities have an important role to play in the implementation process by increasing the use of renewable energy sources. It's not just wind and solar power plants that are speeding up progress in municipal sustainable energy development. The contribution of each municipality is crucial to achieving the goals set out in the National Energy Independence Strategy and the National Energy and Climate Action Plan of Lithuania - to reduce greenhouse gas emissions, increase energy efficiency and promote the wider use of renewable energy sources. Municipalities elaborate municipal Energy and Climate Action Plans and are responsible for their implementation.

5.4 Sweden

In Sweden the main production of electricity origins from hydropower 40 %, nuclear 30 %, wind power 20 % and biopower 10 % year 2023. Use of renewable energy of all energy use was 66 % year 2022 (www.energimyndigheten.se).The authority Svenska kraftnät is responsible for the transmission of electricity from production facilities to end consumers. The grid consists of three levels. The first level is the transmission grid, where large amounts of electricity is transferred from large production facilities to regional grids around Sweden. The voltage in the transmission grid is 220 or 400 kV to lessen the power losses. The transmission grid is built through the whole country, from north to south and is in total about 17 500 km. Svenska kraftnät is the owner and developer of the transmission grid. The second level is the regional distribution grid. The regional distribution grids connect to the national transmission grid and transports the electricity further to the local distribution grids. The regional grids are owned by large energy companies and the voltage is 130 kV. Vattenfall, Ellevio and E.ON owns the majority of the regional grids and are in total about 31 500 km. The third level is the local grids which transfers the electricity to consumers, industries and households. The voltage is 40 kV or lower and before the electricity is delivered to the customer, the voltage is lowered to 400 V. The local grids are owned by many different energy companies, which can be both public and private. The total length of the local grids are about 534 500 km.

Energy storage is a growing field in Sweden, especially smaller batteries in single family houses. Larger scale storage solutions using techniques as batteries or hydrogen production have not yet been implemented to any larger extent. This is due to the large share of hydropower in Sweden, in itself a natural energy storage solution. In coming years, medium to larger scale energy storage solutions are projected to increase. Local authorities have a role to work with energy storage when working with local energy planning. There is a law in Sweden stating that each local authority needs to have an updated energy plan for production, distribution and use of energy. When developing this plan dialogue with stakeholders in the energy field is important and it is possible to investigate how energy storage could be located in the energy system. As an owner of buildings, both for housing and premises, there are possibilities to work with medium scaled energy storage in own building stock. Some local authorities own both or either energy company or electricity distribution grid. In that case there is a possibility to more directly work with energy storage on a more general level in the energy system with implementation of energy storage solutions.

5.5 Poland

In 2023, Poland generated nearly three-quarters (73%) of its electricity from fossil fuels, falling from 79% in 2022, with 61% of its electricity generated by coal. Wind and solar produced 21% of the Polish electricity mix in 2023. The electricity transmission network in Poland is managed by Polskie Sieci Elektroenergetyczne SA (PSE), which is the sole transmission system operator (TSO) in the country. The entire power system in Poland and throughout Europe (excluding the frequency of railway electric traction in Germany and four other countries) operates at a frequency of 50 Hz. Transmission lines transport electricity over long distances from power plants to substations. They operate at high voltages to reduce energy loss during transmission (750 kV, 400 kV, 220 kV). High-voltage distribution network (110 kV) is part of the distribution network, however, due to the way it works, it is largely identical to the transmission network. Its work is mostly coordinated by the TSO. These facilities step down the high voltage electricity to lower voltages suitable for distribution to homes and businesses (especially the main power supply points, Główne Punkty Zasilania (GPZ) in Polish). RES installations are also connected to GPZ, such as the Jasna wind farm of Stadtwerke München in the municipality of Mikołajki is connected to GPZ Gdańsk-Błonia by an underground 110 kV high-voltage cable network. These substations also play a crucial role in managing the flow of electricity and maintaining grid stability.

The process of getting energy storage facilities recognized as fully integrated with the network involves multiple decisions and can be lengthy, with some applications still under review. The 2023 amendment to the energy law restricts system operators from owning, building, or managing energy storage facilities unless specific conditions are met and approved by URE, which can limit the development and deployment of these systems. These challenges highlight the need for continued regulatory adjustments and technological advancements to fully leverage the potential of energy storage in Poland.

5.6 Germany

In recent years, electricity generation from renewable energies has risen continuously. While 46% of electricity in Germany was generated from renewable sources in 2022, this figure rose to 52% in 2023. This trend continued significantly in the first half of 2024. In the first six months of the year, 58% of electricity in Germany was already generated from renewable energy sources. Germany aims to generate 100% of its electricity requirements from renewable energies by 2035. By 2030, the target is 80% of production from renewable energies.

Most of the renewable energy generation comes from photovoltaics, which are located throughout the country with a focus on the southern Federal States, as well as wind power, with a focus on the northern and eastern Federal States, and offshore in the North Sea and the Baltic Sea. One challenge is therefore to ensure the transport of wind power from the North Sea, the Baltic Sea and the northern Federal States to the industrial centres in the west and south of the country.

The next step is the development of regional storage infrastructures. There are several large storage facilities in northern Germany. These are primarily pumped storage power plants and battery storage systems. The expansion of further pumped storage plants is limited due to the geographical conditions and the necessary interventions in the landscape. The capacities of the battery storage plants have been further expanded in recent years, so that in 2024 they will exceed the capacities of the pumped storage plants in Germany and the capacities used by Germany in Austria and Switzerland for the first time. Storing energy in the form of hydrogen has also become increasingly popular in recent years. Storage facilities are to be built in the coming years, especially in eastern Lower Saxony, where the potential is particularly high due to storage in salt caverns that were previously used commercially and the good connection to seaports. In Krummhörn, the company Uniper is planning a hydrogen storage facility with a capacity of 200,000 m³ in an underground salt cavern. Such a storage facility is also planned in Stade. Storengy Deutschland is planning two storage facilities, the first of which is to be connected to the grid in 2030 and the second in 2034.

6 EU and country specific challenges

The countries around the Baltic sea are all part of EU except for Norway. The countries are bound to the binding objectives set by the European Commission on increase for renewable energy sources (RES) and reduction of greenhouse gas emissions. One important factor in achieving the set objectives is the energy transition and the reformation of the energy system. This includes movement from centralised energy production with distribution to end users to decentralised energy production and for end users to become prosumers. A prosumer will both use energy and produce different means of energy. Many energy systems will include both centralised and decentralised energy production. In addition to that, additional renewable energy sources are needed to be installed on a decentralised level for achieving RES objectives on a country level.

To be able maintain a stable energy and electricity system, energy storage is needed to supplement the energy production system both from a technical point of view and economical point of view. Energy storage will be a key element in enabling the development of the revised energy system needed for the clean energy transition in EU. Each country has its own challenges but a couple of common areas have been identified in the Energy Equilibrium project for enabling the energy transition with starting point in preconditions for using the Energy Equilibrium model and toolkit:

- **Political and legislative alignment** - Political and legislative bodies do need to create more precise, long-term plans that align with national and EU energy policies.
- **Available data** - The access of available quality data on a regional and local level for energy is of decisive importance for being able to plan and model the energy system and the development needed for achieving EU objectives.
- **Involving additional forces** – Local authorities are needed to involve a broad range of stakeholders in the energy transition process, recognizing that it's not solely a municipal issue.

- **Funding support and financial incentives** – Local authorities often lack both human and financial resources for implementing energy transition actions. This is especially true for medium-sized and smaller municipalities.
- **Coherent municipal energy transformation strategies** – Municipalities prepare low-emission economy plans (SEAP, SECAP, MPA). These documents serve one purpose, i.e. planning projects aimed at energy transformation, but they are often inconsistent which makes it difficult to implement the municipality's development policy.
- **Implementing real solutions** – Local authorities carry out a lot of planning and strategy work that is of importance for identification of optimal solutions in the energy transition. When it comes to implementing significant solutions on a larger scale the result is often more limited.
- **Local energy planning** – Several countries, like Poland, Sweden and Lithuania, have laws regulating establishment of local energy plans in municipalities. Other countries perform similar local energy planning. There is no standard set for developing and executing these plans. A standard would support a coherent, effective and robust result from the implementation of the plans.
- **Energy security** – Local governments are responsible for energy security. One way to ensure energy security on a local scale is to create energy clusters operating within county or several municipalities (which may include individuals, legal entities, scientific units, research institutes or local government units).

7 Successful implementation on a local level

7.1 Successful implementation of tools

Many previous projects have used various tools to successfully implement energy planning on a local level. Below, two examples are outlined.

CO2MMUNITY: This Interreg project helped municipalities, regional energy planning agencies and citizens' associations across the Baltic Sea region to implement community energy projects and ultimately move towards renewable energy sources. Co2mmunity provided a knowledge base for clean energy stakeholders across the Baltic Sea. The project enhanced the institutional capacities of municipalities, institutions responsible for regional energy planning, political decision-makers, and energy and citizen's associations for facilitating community energy projects.

PLAN4CET: The main objective of this project is to support European regions and cities in the design, development and implementation of clean energy transition plans adapted to their needs and possibilities. Following this purpose, the project is developing tools, methodologies, capability building initiatives and technical assistance frameworks to support EU regions and cities in their clean energy transition planning, implementation and monitoring processes and activities.

7.2 Key phases in local energy planning

The Joint Research Centre (JRC) at the European Commission has released a guidebook on the development of an energy plan on a local level (How to develop a Sustainable Energy and Climate Action Plan (SECAP), P Bertoldi, 2018) where it is described how to successfully develop a SECAP in connection with the Covenant of Mayors initiative.

The main steps in the process to develop a Sustainable Energy and Climate Action Plan (SECAP) is outlined below based on the European Commission report. The Energy Equilibrium platform provides support in the full planning process, but especially in the **planning phase** when establishing the vision and the elaboration of the plan with concrete actions. The tool is also a valuable supplement in the **initiation phase**, to build support from stakeholders and to get political commitment as well as mobilising departments in the municipality.

1. **Initiation phase**

   a. Political commitment

   i. Provide key political leaders with information about the benefits and resources needed. Make sure documents presented are short, comprehensive and understandable to the political authorities.

   ii. Provide clear roles and responsibilities for the personnel from each involved department, with allocated resources to work with energy planning. Allocate a coordinator who has resources and political support to lead the work.

   b. Build support from stakeholders

   i. Host meetings or discussion sessions with key figures in the energy system to gather input and gain understanding throughout the process.

2. **Planning phase**

   a. Assessment of the current framework: Where are we?

   i. Analysis of relevant regulations: What are the current legal frameworks or policies that may help or block clear access to key data and its analysis?

   ii. Baseline review: Do an inventory of current emissions and do a climate change risk and vulnerability assessment, to understand current conditions and risks in relation to the energy system and climate change.

   b. Establishment of the vision: Where do we want to go?

   i. Establish a realistic and still ambitious vision that is understandable for citizens and stakeholders.

ii. While the main commitment concerns GHG emission reduction, it is advisable to also define energy savings and/or energy production targets, and to state sector-specific targets. This will clarify prioritized areas of intervention and allow for better monitoring of results.

c. Elaboration of the plan: How do we get there?

i. Make a prospective of good practices and technologies that have delivered effective results in similar contexts. What energy interventions and policy changes could be done for households, industrial buildings, public properties, etc?

ii. Prioritize what should be implemented by considering costs, risks, and benefits according to a list of criteria, and select key actions.

d. Plan approval and submission

i. Draft a well-planned action plan with an associated budget, and formally approve it in the municipality with an allocated budget.

3. Implementation phase

a. Implementation

i. Implement small-scale pilots and demonstrations to test and gather knowledge regarding the desired energy system changes. Scale up successful solutions and spread information about them to inspire others.

ii. Offer training to the internal team and have follow-up meetings with stakeholders to invite ideas.

4. Monitoring and reporting phase

a. Monitoring

i. Define indicators related to the energy transition and follow its change over time.

b. Reporting and submission of the implementation report

i. Make quarterly or annual reports that provide the current situation and progress in the energy transition on a municipal level. Make sure that the reporting is accessible to anyone.

c. Review

i. Annual or quarterly adjusted plans should be done based on the current progress, challenges, and risks.

The European Commission report furthermore summarizes key elements to address for a successful SECAP. In many of the steps below, the use of the Energy Equilibrium platform can assist in working with key elements addressed like supporting stakeholder communication and collaboration, educating decisionmakers, developing political vision and understanding, and modelling long-term energy needs and pave the way for a fruitful and successful implementation of energy transition actions on a local level.

1. Build support from stakeholders and citizen participation: if they support the SECAP, nothing should stop it.
2. Secure a long-term political commitment.
3. Ensure adequate financial resources.
4. Do a proper GHG emissions inventory as this is vital.
5. Make a Climate Change RVA, based on an analysis of the local/regional trends of various climate variables and city socioeconomic and biophysical specificities.
6. Integrate the SECAP into everyday management processes of the municipality: it should not be just another nice document, but part of the corporate culture.
7. Ensure proper management during implementation.
8. Make sure that staff have adequate skills, and if necessary, offer training.
9. Learn to devise and implement projects over the long term.

8 Expectations and possible applications on a country level of the energy equilibrium platform

In the Energy Equilibrium project the platform tool has been thoroughly piloted and tested in partner local authorities. Below is a summary of expectations and possibilities for areas of use for the tool, gathered from participating municipalities and partners on a country level, when supporting local energy transition in local authorities.

8.1 Finland

- The tool helps find cost-saving and emission-reducing solutions.
- Municipal energy companies develop their own business for the needs of future energy systems, where energy storage plays a greater role. An interactive and easy-to-use tool to support decision-making for municipalities and energy suppliers.
- The tool supports municipal energy companies in the development of local renewable

energy action plans and decision-making, focusing on promoting energy storage infrastructure.

- Increasing electricity and thermal energy storage can smooth out cost peaks caused by price fluctuations, and the tool can model the operation of the energy system.
- A better understanding of the municipal energy system can be achieved through simulation.

8.2 Latvia

- The tool is functional and is working with the existing data available providing input to the tool.
- The function to analyse heating equipment is included and the tool support which heating device to choose.
- The tool supports analysis of justifications to install acclimation equipment.
- The tool includes a database of components with specifications, datasheets, and usage examples.
- The tool eases the work of energy specialists by reducing the time spent on data processing.
- By including dynamic reports and customizable dashboards, the tool will enable users to swiftly obtain the required data in various formats, such as graphs, tables, and charts.
- By modelling scenarios, it is easier to understand the potential energy gain from the implementation of a project.

8.3 Lithuania

- The tool is functional with the input data from Municipality.
- The tool indicates how to improve the performance of the heating and the transport sector.
- The tool assesses the effect of the thermal storages for the new generators in district heating systems.
- The tool assesses the effect of battery use in municipal electricity sector due to introduction of new PV capacities.
- The tool assesses the effect of battery use in the transport sector.
- The tool should also be acceptable for the assessment of storage facilities in already existing energy generation systems with clear technical, economic, and ecologic factors.

8.4 Sweden

- It is important to use the platform within the context of a local authority, with challenges that municipalities in Europe face today, e.g. new EU-directives or lack of capacity or energy production in the region.
- The explanations of parameters to fill in are clear and obvious, as well as explanations of how different values affect the end result. If not included in the platform it should be available in a manual or in the introduction of the platform.
- The tool is easy to use for local authorities.
- The tool provides better understanding of the energy system in the local authority.
- The tool is useful also for part of a local authority or area in the local authority.
- The tool can be used to explore options for new investments in windmills and replacing the current turbines.
- It can be used to explore how the platform could help a local authority to simulate different scenarios to reach self-sufficiency objectives.
- It can include information on distributed pV systems, battery and hydrogen storage.

8.5 Poland

- The tool provides reliable information for local authorities, supporting local authorities in their work of providing necessary energy needed for the proper, reliable and continuous operation of the water and sewage infrastructure and buildings belonging to the municipality.
- The proposed solution should be acceptable: financially sound, ecological, reliable and stable.
- Solutions include biogas plants which should be built in local authorities, taking into account ecological, practical and economic reasons.
- The tool is supporting the municipality in making decisions and developing action plans aimed at accelerating the local use of renewable energy sources in the region and conducting a low-emission economy while maintaining the reliability of heat and electricity supplies to consumers.
- The tool provides possibilities to test various alternative variants of the commune's energy development, taking into account economic criteria.
- Determining the possibilities of implementing modern heat and electricity production technologies in the municipality, taking into account the requirements of Poland's energy policy and the requirements of European directives.

- Possibility to verify the municipality's heat and electricity supply scenarios developed every 4 years in local documents required by the Polish Energy Law ("Heat, electricity and gas fuel supply plans for the municipality.
- Checking the impact of various external factors on the possibility of reducing energy demand on the part of consumers (thermal renovation of housing stock and public utility facilities).

8.6 Germany

- Easy-to-use model for simulating the electricity system in municipalities and storage requirements
- Practical uses of model for municipalities
- Reasonable effort in obtaining data
- Consideration of the limited availability of data
- Focusing on relevant data
- Focusing on a limited number of criteria, questions and scenarios > the tool rather simulates general climate protection activities and less scenarios for the expansion of storage facilities
- Will network extension plans be considered?
- Simulation of mobility behaviour is complex and does not only include the share of electromobility
- The municipal vehicle fleet, which can be largely influenced, has only a small influence on the scenarios
- Ability to use simplified platform? One complex model with lots of variables, one model with less therefore being more simplistic
- Costs for network extension (in specific scenarios)
- Energy communities as financing model plus improvement on social acceptance (in specific scenarios)
- More variability in fuel property indicators (possibility of diversifying the amount of electricity into renewable and non-renewable energy sources) (in specific scenarios)

9 Policies to implement on a national level in BSR countries

Within the Energy Equilbrium project, the consortium has identified a number of policies of importance for increasing successful implementation of RES deployment and energy storage on a local level. These include legal and regulatory incentives, fiscal incentives, technology incentives, infrastructure incentives, and social and cultural incentives.

9.1 Development of legal and regulatory incentives

- **Legislating energy communities.**

Governments could pass legislation to formally recognize and support energy communities, allowing local groups of residents, businesses, and municipalities to collectively produce, store, and manage their energy.

- **Legal and regulatory initiatives**

Regulations often do not keep up with the rapid development of technology and market needs (the processes of obtaining permits for the construction of new energy installations are often lengthy and complicated). A more harmonized regulation for planning purposes could increase implantation level. Local planning that selects areas for development and location of energy storage could further enable a controlled and safe implementation of larger-scale storage solutions in towns and cities.

- **Improving access to data**

Policies and regulations that enable access to local or regional energy and building data could further empower local authorities to improve their modelling of energy systems. Often there is a lack of availability of quality data for local energy planning and modelling. By a more harmonized regulation regarding the availability of data, the quality of energy modelling and planning will increase.

9.2 Development of fiscal incentives

- **Renewable energy initiatives (feed-in tariff).**

Introducing or expanding feed-in tariffs could incentivize the generation of renewable energy by guaranteeing stable prices for energy producers who feed excess electricity into the grid.

- **Financial initiatives**

Investments in new energy technologies, such as renewable energy sources, require large financial outlays. The lack of appropriate financing mechanisms often limits the possibilities of their development, and supportive financial frameworks can speed up investments to enable a faster transition.

9.3 Development of technology incentives

- **Energy storage initiatives.**

Implementing policies that support the development and deployment of energy storage solutions, such as subsidies or tax incentives for battery storage systems, would be essential for enhancing energy security and stability.

- **Grid modernization and flexibility.**

Policies should focus on modernizing the grid infrastructure to accommodate a growing share of renewable energy and energy storage systems. A flexible grid would allow for better integration of distributed energy resources, such as rooftop solar panels and local wind turbines.

9.4 Development of infrastructure incentives

- **Infrastructure initiatives**

Modernization and expansion of energy networks are necessary to integrate new energy sources (there is a need to expand transmission networks).

9.5 Development of social and cultural incentives

- **Social and educational initiatives**

There is a lack of social awareness and education on the benefits of energy transformation. Education and information campaigns are key to increasing social acceptance for new energy technologies and what beneficial impacts they can have locally.

- **Political initiatives**

Energy and climate policy cannot be the subject of political disputes, because it makes it difficult to implement coherent and long-term transformation strategies on the local level.

10 Roadmap for analysis and implementation on a regional and local level

The consortium has identified a number of actions to implement on a local level from the described work of the development of the Energy Equilibrium tool. The actions below need to be adapted and developed to existing local and national conditions but are in general terms relevant for all EU countries around the Baltic Sea. The section also includes a list of recommended areas of analysis, which are important to better guide decisionmakers in the right direction for appropriate decisions in the energy systems and for its actors.

10.1 Recommended areas of analysis

Further understanding and basis for decision-making can be developed through following suggestions for analysis of stakeholders and system components. With a more thorough analysis, the possibilities to choose the relevant actions in 10.2 increases significantly.

- **Energy system analysis**

An initial analysis of the existing energy system and its energy-mix as well as the producers and consumers forms the basis for understanding the options for action, for further steps to involve the actors and for drafting a basic mission statement. Different spatial planning categories (urban centers, outskirts, rural areas) and different economic structures (industry, agriculture) offer fundamentally different conditions for further development.

- **Analysis of potential producers and solutions**

An initial potential analysis defines the future building blocks and potential producers of the energy system that are relevant for the respective location. Here, too, there are differences between the localities (coastal region, mountainous regions), the spatial planning categories and the economic structures.

- **Stakeholder mapping**

A mapping of stakeholders is used to identify the relevant interest groups in the energy system and categorize them according to their influence and interest. This method helps to understand the needs and expectations of the various stakeholders and to develop suitable communication strategies. Through targeted analysis, risks can be minimized and cooperation with the stakeholders can be managed effectively. In addition, knowledge of the interest groups forms the basis for requesting the necessary data.

10.2 Recommended actions for implementation

- **Investment costs calculations**

There is a cost connected to the energy transition for investments in deployment of RES and energy storage in local authorities and regions.

Action: By using the energy equilibrium tool, an indication of the cost for the energy transition regarding energy storage on a local and regional level is possible to estimate. The calculations could be a starting point for further discussions regarding measures to take in relation to the energy transition.

- **Sustainable energy planning in local authorities**

In some countries there are laws regulating local authorities to work with energy planning on a local level and in other local authorities often work with non-mandatory documents like sustainable energy action plans or similar.

Action: By using the energy equilibrium tool in the energy planning process or similar planning process, the possibilities increase to gather stakeholders around a common view on the energy system and what actions are needed to be taken. The tool can function as an assisting facilitator for the dialogue between municipal planners and stakeholders needed for implementation of actions.

- **Education of politicians and civil servants**

The knowledge of facts needed for the energy transition on a local level is of great importance for the successful implementation of actions.

Action: By educating civil servants on how to operate the energy equilibrium tool the possibilities increase for civil servants being successful in increasing the knowledge needed for the energy transition on a local level. Result from the tool can be used to educate politicians on different energy scenarios in the local authorities and actions needed for the successful implementation of the energy transition on a local level.

- **Development of financial solutions**

The shortage of available capital and the magnitude needed for impact installations regarding renewable energy sources and energy storage on a financial level, makes it crucial that regional and local authorities find possibilities to enable investments for the energy transition.

Action: Regional and local authorities could develop programs for enabling solutions of available funding schemes, where stakeholders looking for funding possibilities are put in contact with available funding programs and learn more about them. This could include national funding programs, eventual regional funding programs, public private partnerships, green loans, EIB, Elena and other EU initiatives. The tool underlines the importance of funding.

- **Policy development**

Local authorities develop a lot of plans and programs within the area of environment and energy. Part of the objectives in these documents are often not consistent and not well underbuilt. The decision making might be difficult to perform.

Action: By using the energy equilibrium platform, politicians and municipal civil servants will get a great tool to develop well underbuilt objectives in the area of renewable energy and energy storage, leading to policy development and unification of objectives within the environmental and energy area. Policy development could also mean clarification of municipal opinions within the area. The decision-making process is supported by the tool.

- **Development of businesses**

The secure supply of energy as well as an affordable price on energy is of significant importance for regional and local authorities in attracting competitive businesses to be established and to grow in the local and regional area.

Action: By working with and applying the energy equilibrium tool on the local and regional energy system, the basic foundations for important priorities within the energy area are in place. By building an energy system built on stable supply of energy, deployment of proper energy sources and optimal use of energy including storage, the preconditions for a reasonable energy price leading to well developed businesses are present.

- **Development of a resilient society**

Factors that local and regional authorities do not decide over themselves will have an impact on the society on a local and regional level. Larger incidents like climate driven events or conflicts in the nearby area could challenge existing infrastructure and societal functions.

Action: By implementing renewable energy sources and energy storage installations, the resilience of society increases. The possibilities to endure a larger happening improves. There is also the possibility to improve local and regional economy over time in implementing new techniques in upcoming technical solutions, for example use of hydrogen. The tool supports the development of a resilient energy system.

- **Development of objectives with stakeholders and residents**

Through early exchange with the relevant stakeholders, a common perspective and a mission statement can be discussed and agreed upon. This can include a locally adapted definition of the goal of climate neutrality and basic perspectives, for example for the expansion of wind energy and open-space photovoltaics. Informing local residents about planned energy projects also opens the possibility of taking account of their ideas for the area, allows for educating the population about the need and impact of RES and sustainable energy infrastructure, and creates bigger acceptance for energy projects in the landscape.

Action: By gathering relevant stakeholders in dialogue, local and regional authorities can gain understanding of the conditions and needs to develop the energy infrastructure in a sustainable direction, and how its challenges best can be met by the public sector. Dialogue with private stakeholders, such as housing companies, industries and energy companies, can further help the energy market move along in a more sustainable direction through collaboration. Early and continuous conversation and education with locals about the need and impact of planned energy infrastructure can reduce potential local resistance, open up for local ideas, and make energy planning more participatory.

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Carbon driven energy equilibrium at the municipal scale – Energy Equilibrium

Summary report on energy system and energy storage in Sweden 2024

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Co-funded by the European Union
ENERGY TRANSITION
Energy Equilibrium

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1 The energy system and electricity system in Sweden

In Sweden the main production of electricity origins from hydropower 40 %, nuclear 30 %, wind power 20 % and biopower 10 % year 2023. Use of renewable energy of all energy use was 66 % year 2022 (www.energimyndigheten.se).

1.1 Organisation of electricity grid

In Sweden the authority Svenska kraftnät is responsible for the transmission of electricity from production facilities to end consumers. The grid consists of three levels. The first level is the transmission grid, where large amounts of electricity is transferred from large production facilities to regional grids around Sweden. The voltage in the transmission grid is 220 or 400 kV to lessen the power losses. The transmission grid is built through the whole country, from north to south and is in total about 17 500 km. Svenska kraftnät is the owner and developer of the transmission grid. The second level is the regional distribution grid. The regional distribution grids connect to the national transmission grid and transports the electricity further to the local distribution grids. The regional grids are owned by large energy companies and the voltage is 130 kV. Vattenfall, Ellevio and E.ON owns the majority of the regional grids and are in total about 31 500 km. The third level is the local grids which transfers the electricity to consumers, industries and households. The voltage is 40 kV or lower and before the electricity is delivered to the customer, the voltage is lowered to 400 V. The local grids are owned by many different energy companies, which can be both public and private. The total length of the local grids are about 534 500 km. In addition, the Swedish electricity grid is connected to several countries electricity grid and the transfer of electricity between countries depends on the market price.

Source:www.svk.se

1.2 Distribution system operators in electricity grid

For the transmission grid it is the authority Svenska kraftnät that is the distribution operator. To adapt the Swedish electricity system to the green transmission and be able to receive and distribute electricity from wind power and solar electricity, the transmission is under development and a lot of investments are done. The current net is old and a lot of investments are needed. The net consists of 17 500 km cable and around 175 transformator and connection points. Development projects for increasing capacity and strengthening the grid are ongoing in the whole country. In the region of Skåne currently four larger projects are ongoing. Larger wind power parks and pV parks could be directly connectet to the transmission grid.

The regional distriubution grids are owned by five regional net grid owners but two are vey small. E.ON is the largest regional grid owner followed by Ellevio and Vattenfall. They own about a third each of the distribution grid. Wind power plants and pV parks are quite often connected to the regional grid.

The local grids are owned by 172 local grid owners and have the longest length of cable in the three level of grids. Out of the 172 local grid, 129 are publicly owned. Smaller solar energy installation are connected to the local grid but also large solar parks could be connected to the local grid.

Source: www.svk.se and www.iva.se

1.3 Stakeholders active of energy storage in electricity

- Vattenfall – Power as a service - Battery energy storage, Power Supply (batteries, hydrogen)
- Atlas Copco – Hybrid energy plant, battery storage combined with power supply from vind power or solar energy
- Energiengagemang – battery energy storage medium to large
- OX2 – large battery energy storage
- E.ON – battery energy storage medium to large (30 kWh to 30 MWh)
- Forum – battery energy storage
- Axpo – large battery energy storage
- Checkwatt – virtual large scale battery storage, connecting several smaller batteries in a virtual power plant

Source: Sustainable Business Hub

1.4 Role of local authorities for energy storage in connection to electricity

Local energy planning – There is a law in Sweden stating that each local authority needs to have an updated energy plan for production, distribution and use of energy. When develop this plan dialogue with stakeholders in the energy field is important and it is possible to investigate how energy storage could be located in the energy system.

As an owner of buildings, both for housing and premises, there are possibilities to work with medium scaled energy storage in own building stock.

Some local authorities own both or either energy company or electricity distribution grid. In that case there is a possibility to more directly work with energy storage on a more general level in the energy system with implementation of energy storage solutions.

Source: Sustainable Business Hub

1.5 Role of hydrogen and power to x in todays energy (electricity) system

There are a lot of possible Power to X and production of hydrogen from renewable energy production in Sweden but it is actually hard to implement and start to construct the facilities. One example is Flaghsip one in Örnsköldsvik, developed by company Liquid Wind, where 55 000 tons of e-methanol should be produced as fuel for the shipping industry. The project was bought by Örested in 2022, the facility should be constructed 2023 and running 2025. Örsted informed in August 2024 that they will not proceed with the project since it is impossible to run it with profit. Örsted states that the interest for green fuels in the shipping industry is lower than expected and that is difficult to develop long term agreements with realistic pricing and adapted to commercialization. This together has resulted in Örested leaving the project since it is impossible to gain the profit needed in the project.

Liquid Wind are planning for the second project Flagship two in Sundsvall where 130 000 ton e-methanol will be produced 2027.

Source: www.liquidwind.com and www.orsted.se

1.6 Business models for energy (electricity) storage

There are serveral possibilities to use electricity storage as a business case.

1 Electrical arbitrage

The first is to be able to use the locally produced renewable electricity when there is no wind or no sun and the market price for electricity is expensive. The battery can be loaded with electricity from renewable energy sources when the electricity price is low. When the price for electricity has increased the battery can be unloaded and cheap electricity from the battery can be used. With a larger battery there is also the possibility to sell electricity to the grid when the prices has increased.

2 Peak shaving

It is more common that the electrical grid owner and DSO price the subscription for electricity in reference to the used load, meaning the used maximum peak of capacity by the customer. By using electricity from the battery to lower total load and minimise used peak capacity the cost for the electrical subscription can be lowered. Peak shaving also leads to a more stable electricity grid.

3 Back up power supply

If the business relies on continuous power supply, a battery can support the facility with electricity if the electricity grid is not working. If the facility has a solar electricity installation, there is a possibility that the pV installation can continue to operate in island mode.

4 Support services in the grid

There is a possibility to use energy storage for electricity, normally batteries, for support services to the grid. The national operator of the transmission grid, Svenska Kraftnät, needs to have different services available to balance electricity production and electricity consumption in the grid. One service is frequency management, where batteries play the role of stabilisers to the grid. The owner of the battery get paid for either store electricity in the battery from the grid or produce electricity in the battery to the grid. The reason why frequency management is needed is that the frequency in the grid needs to be 50 Hz, which there is when there is a balance between electricity production and consumption.

The owner of the resource

By constantly analyzing the market and making sure to use the resources for what gives the highest return, the profitability of the person who owns the resource is maximized.

The electricity market operator

By making resources available to electricity grid operators and offering increased flexibility regarding both production and consumption, costs for electricity grids and operation of the electricity system are reduced.

Society

By using the existing resources in a more efficient way, the electricity system becomes more cost-effective, operationally reliable and creates better conditions to greatly expand renewable electricity production.

Swedish power grids must have access to various services and measures to balance and manage disturbances in the power system. We do this primarily by purchasing various types of reserves from electricity market players.

As far as possible, Svenska kraftnät uses various reserves that are procured using bidding on the so-called balance markets. Svenska kraftnät also buys certain reserves on longer contracts.

Fast frequency reserve (FFR), Upward Frequency Containment Reserve (FCR-D,N), Automatic Frequency Restoration Reserve (aFFR), Manual Frequency Restoration Reserve (mFFR).

5 Local flexibility markets

A challenge in the energy transition is sufficient network capacity. The increase in electricity use, the establishment of new electricity-intensive facilities and distributed production puts pressure on the electricity grid. This applies today at all voltage levels because it is challenging to expand the electricity grid at the same rate as demand increases.

In order to deal with local grid capacity problems, so-called local flexibility markets have emerged where regional and local grids buy flexibility by calling for either increased or decreased withdrawal or input to the grid by connected electricity customers in order to manage overloading in the electricity grid within an electricity area.

In recent years, Svenska kraftnät has tested local flexibility markets as one of several ways to deal with this. The work has taken place in collaboration with the regional network owners concerned.

Source: www.svk.se, www.eon.se; and www.checkwatt.se

1.7 Organisation of other storage (biomethane, heat)

Vattenfall is in the process of establishing a pumped storage power station in the north of Sweden, namned Juktan. The power station could produce 315 MW over four days, equivalent to 300 000 EV. The facility is planned to be running in 2032. (www.vattenfall.se)

Picture:www.vattenfall.se

GoA 2.4 –Roadmap for renewable energy transition in BSR municipalities (Version 24.09.2024)

24 September 2024

1 Organization of the Electricity Grid (Transmission Grid) in Finland

Finland's electricity system consists of power plants, the transmission grid, high-voltage distribution networks, distribution networks, and electricity consumers. Finland is part of the Nordic synchronous area along with Sweden, Norway, and eastern Denmark. Finland is also linked to Estonia by direct current connections./1/

Fingrid is responsible for the operation and maintenance of Finnish transmission grid. The transmission grid refers to a high voltage looped main grid connected to large power plants, factories, and distribution networks. Finland's transmission grid includes about 14,500 kilometers of power lines and over 120 substations (as of 2023).

The Nordic system is also linked to the Central European system through direct current connections. The grid serves electricity producers and consumers by enabling trade between them at the national and cross-border level. The vast majority of electricity consumed in Finland is transmitted through the grid.

Fingrid's responsibilities include grid monitoring, operational planning, balancing services, network maintenance, construction, development, and promoting the functioning of electricity markets.

In accordance with the Electricity Market Act, the development plan for the grid is published every two years. The investments in the development plan reflect a sample of Fingrid's investment plan at the time of publication of the development plan. The investment plan is maintained and continuously updated according to the needs of the operating environment. The development plan also presents changes in the operating environment, the principles of grid development, and other factors influencing planning. The transmission grid development plan is based on network plans drawn up according to customer needs, electricity markets, grid condition, and transmission needs. It also takes into account the development plan for the Baltic Sea region and the Europe-wide Ten-Year Network Development Plan (TYNDP).

2 Electricity Distribution Network in Finland

The distribution network is an electricity network with a nominal voltage below 110 kV. The high-voltage distribution network has a nominal voltage of 110 kV. The core network is a nationwide integrated electricity transmission network consisting of power lines, substations and other installations with a nominal voltage of 110 kV or more. The core network includes the interconnectors with a nominal voltage of at least 110 kV under the control of the core network operator. Electricity grids and parts of grids with a nominal voltage of more than 110 kV are defined as the core grid if they are not access lines under the Electricity Market Act.

In 2013, Finland adopted legislation setting target levels for security of electricity supply. According to the law, the electricity distribution network must be designed, built and maintained so that, for example, a storm or snow load does not cause a power outage of more than 6 hours in a zoning area and more than 36 hours in other areas. Exceptions can be made in special circumstances, such as difficult conditions in archipelagos. Distribution companies have until 2036 to develop their networks to meet these requirements.

Distribution network operators must prepare development plans outlining the measures they will take to meet these quality requirements. The plans must be submitted to the Regulatory Information System by the end of June every even-numbered year.

Electricity distribution reliability can be improved in several ways. Overhead lines are vulnerable to natural phenomena and by burying the lines underground, i.e. by cabling, the security of electricity supply can be significantly improved. In addition, the so-called "conductor corridors", i.e. the bare area around the wires, can be widened. Electricity lines can also be moved to places where they can be repaired more quickly, such as along roadsides away from forests.

In urban areas, an effective improvement is to build back-up and ring connections, so that in the event of a fault, an area that would otherwise be without electricity can be supplied via another route. Intelligent components and functionality can also be added to networks, for example to provide the network company with information about a power outage and the exact location of the fault more quickly.

While there are many ways to influence the number and extent of blackouts, it is practically impossible to achieve a completely tame-free electricity supply. Good maintenance and effective fault repair are therefore key to the security of electricity supply. /2/

2.1 Electricity Distribution Network Operators

Finland's largest distribution companies are Caruna Oy, Elenia Verkko Oyj, and Helen Sähköverkko Oy. Together, the fifteen largest electricity distribution network companies in Finland account for about 70% of the distribution networks, electricity users and turnover of the companies. The smallest electricity distribution companies in Finland operate in the territory of a single municipality and serve a few thousand customers. Indeed, most of the almost 80 distribution network companies in Finland are owned by a municipality or a limited liability company with a majority stake in a municipality.

The map below shows the geographic responsibility areas of distribution network operators and closed distribution system operators. These areas are associated with the operators' rights, obligations, and responsibilities. In the electricity network licence, the Energy Agency assigns a responsibility area to the network operator for the distribution network. The network operators' areas of responsibility shall together cover the whole of Finland, excluding the Åland Islands, and shall not overlap. The Energy Agency will also monitor that the changes in the area of responsibility comply with the above requirements. The responsibility area map reflects the latest responsibility area information approved by the Energy Agency./3/

Figure 1: Geographical areas of responsibility of distribution system operators and closed distribution system operators in Finland.

3 Active Stakeholders in Energy Storage Systems

Energy storage stakeholders include people, groups, organisations, companies and communities that are directly or indirectly affected by energy storage activities. In Finland, the active stakeholders in energy storage in the electricity grid include several parties that influence energy production, distribution and consumption. The main stakeholders are:

- Power plants: various electricity generators, such as hydro, wind, solar and fossil fuel, which produce electricity and can benefit from storage.

- Energy storage companies: companies that develop and manage energy storage, such as battery capacity or other storage technologies.

- Grid operators: Operators of the electricity grid, such as Fingrid, who are responsible for balancing the grid and ensuring that generation and consumption are in balance.

- Consumers: industrial and residential consumers who can participate in demand response and storage, for example through smart appliances.

- Legislators and regulators: the role of government and other regulators is to set energy policies that affect energy storage and use.

- Research and development organisations: universities and research institutes that develop new technologies and innovations in energy storage.

- Non-governmental organisations and environmental groups: these actors can influence energy policy and practice, particularly from a sustainability perspective.

The changes caused by energy storage can be estimated. The assessments describe views on the measurable impacts of energy storage on the functioning of the energy system, and the benefits are the value that stakeholders derive from the impacts. The design and implementation of energy storage systems will have a major impact on the benefits that can be achieved, how well the use can be optimised and how real-time monitoring can be achieved.

The indirect benefits and consequences of energy storage activities are generally more difficult to define and measure than the direct benefits. These include environmental benefits such as reduced greenhouse gas emissions and other pollutants, improved energy independence and protection against energy price volatility. The construction and operation of an energy storage facility will also create new job opportunities in the region where it is located./4/

4 Role of Local Authorities in Connecting Energy Storage to the Grid

An electricity producer in Finland is entitled to connect its production facility to the electricity grid when the facility meets the technical requirements for it. The producer is entitled to transfer electricity to the grid when the connection and metering meet the relevant requirements and there is a buyer for the electricity. There is a primary the installation does not cause any disturbance to the network or damage to other network users. (Connection of an electricity generating installation to the distribution network 2016.)

When connecting energy storage and related systems to the grid, the consent of the local distribution system operator, the grid company, is always required.
The network company should be contacted in good time so that any necessary measures can be taken in good time.

The supplier must provide the distribution network company with the necessary information. The Energy Industry Association requires power plants with a capacity of up to 100 kVA to notify at least:
- type, rated power and rated current
- the type of inverter
- protection setting values and operating times
- the implementation of the islanding protection (method and operating time).
(Guide for small electricity producers. 2012.)
When connecting generation to the grid, a generation connection agreement is usually concluded, which applies to the Energy Industry Association's Generation Connection Conditions./5/

5 The Role of Hydrogen and Power-to-X in the Current Energy System

The role of hydrogen in the future energy system has steadily grown in Finland, and hydrogen has become a widely accepted assumption in energy sector scenarios.

The growth potential of the hydrogen industry is based on the fact that hydrogen produced from renewable electricity enables the phasing out of fossil raw materials and fuels in many industrial and transport sectors. This is also the basis for the European Commission's May 2022 REPowerEU plan1 , which aims to reduce imports of Russian fossil energy, significantly increase renewable energy production and accelerate the uptake of renewable hydrogen in the EU. The basic assumption in all scenarios is that Finland will meet its carbon neutrality target and that there will be a strong increase in the production of clean hydrogen in Finland.

In addition to the growth in demand for electricity for hydrogen production and P2X products, demand for other sources of electricity is projected to increase. Demand will increase in transport, heating and existing industry as fossil fuels are replaced by electricity. Moreover, new electricity-intensive industries, such as battery manufacturing and data centers, are anticipated to emerge in Finland. These sectors' electricity use is expected to develop similarly in all scenarios.
/6/

6 Business Models for Energy Storage

Business models for energy storage are evolving rapidly as the use of renewable energy increases and the reliability and flexibility of energy grids is improved. Storage technologies such as batteries, thermal and hydrogen storage offer new business opportunities. Energy storage systems can provide valuable services to balance the power grid and increase flexibility.

6.1 Energy Storage Owned by Energy Companies

Energy companies can own and operate large energy storage systems as part of their energy infrastructure. Energy storage is used to improve grid stability, especially in areas where electricity production is based on variable renewable energy (e.g., solar and wind).

Business model: Energy companies invest in storage systems and benefit from lower operating costs, better grid management, and efficient use of stored energy.

6.2 Energy Storage Integrated into Renewable Energy Projects

Storage systems are integrated directly into renewable energy production facilities such as solar or wind farms. Fluctuations in renewable energy production can be smoothed out by storing energy during high production periods and using it when production decreases. Energy storage systems can store electricity when market prices are low and sell it when prices are higher.

Business model: renewable energy producers invest in storage systems to maximise generation utilisation and revenue optimisation in a volatile market.

6.3 Consumer-Oriented Energy Storage Systems

Households and businesses can install energy storage systems, such as batteries, to ensure energy supply and control costs. Households and businesses can store self-produced renewable energy (e.g., from solar panels) and use it when grid electricity is more expensive. Excess energy can be stored and sold back to the grid, generating additional income. Consumers can use battery storage for backup power during outages, reducing their reliance on the grid.

Business model: consumers invest in their own storage systems and savings are generated by managing their energy consumption and selling surplus electricity back to the grid.

6.4 Hydrogen Storage Business Models

Hydrogen can be used for long-term storage of large amounts of energy, especially for utilizing excess renewable energy. Hydrogen can be used as an energy source in industries, replacing fossil fuels. Excess electricity can be used to produce hydrogen via electrolysis, which can be stored and later used for electricity generation or sold to other markets, such as transport or industry.

Business model: Hydrogen producers can sell stored hydrogen for industrial, transport or energy production. The business model is based on the growth in demand for hydrogen and the development of new uses for hydrogen.

7 Organizing Other Storage (Biomethane, Heat)

7.1 Biomethane

Biomethane (processed biogas) is a renewable gas that can be used similarly to natural gas, for example, for heating, electricity generation, or as a fuel in transportation. Small-scale production at farms and biowaste processing plants: Biomethane is often produced from organic waste or agricultural by-products and can be stored locally in pressure tanks or compressors. This can allow for direct use, for instance, as fuel for agricultural machinery or for electricity and heat production.

Business model: Producers can sell biomethane directly to local users (such as industrial facilities or as fuel for transport) or inject it into the grid.

7.2 Heat Storage

Heat storage is a key component in optimizing energy systems, especially in district heating systems and large industrial processes. Heat storage helps balance energy production and consumption and utilize cheaper or renewable energy.

7.2.1 District Heat Storage

The most common heat storage solutions are large hot water tanks where heat can be stored for district heating networks. Heat is produced when demand is low and stored for later use, for example, heat generated at night can be used during the day.

Seasonal heat storage can be used to store excess heat produced in summer for winter consumption peaks. This can be achieved through underground water storage or geothermal systems.

Business model: District heating companies can optimize their production by utilizing stored heat and saving on fuel costs. This also reduces the need for expensive energy production investments in winter.

7.2.2 Utilizing Industrial Waste Heat

Industrial heat storage systems: Large industrial facilities can store excess heat generated during processes and use it later for their needs or inject it into the local district heating network. For example, the metal and chemical industries produce significant amounts of waste heat.

Business model: Industrial facilities can save on energy costs by utilizing their waste heat. Additionally, selling waste heat to the district heating network can generate extra income.

7.2.3 Heat Storage in Single-family Houses

Individual households can use heat storage systems, such as water heaters or thermal batteries, to store heat produced by solar panels or heat pumps. This allows for optimizing energy use in single-family homes and properties.

Business model: Households save on energy bills by storing cheap or self-produced energy. Excess heat can also be fed into local networks if such infrastructure is available.

7.3 Summary

Business models for biomethane and heat storage focus on optimizing energy production, cost-effectiveness, and integrating renewable energy into energy systems. Infrastructure such as natural gas grid utilization for biomethane or district heating networks for heat storage is crucial, and local solutions can yield significant savings and additional income. As these technologies develop, business opportunities will diversify, particularly from the perspectives of local communities and industry.

References

/1/ Fingrid
/2/ Energiateollisuus
/3/ Energiavirasto
/4/ Oulun ammattikorkeakoulu
/5/ Lauri Holopainen, Principles for Connecting Energy Storage to the Grid
/6/ Fingrid

31.12.2024

Carbon driven energy equilibrium at the municipal scale – Energy Equilibrium

Framework conditions for energy infrastructure in (Northern) Germany

ZEBAU GmbH

Interreg Baltic Sea Region
Co-funded by the European Union
ENERGY TRANSITION
Energy Equilibrium

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1 Expansion path of renewable energies

1.1 Development to date

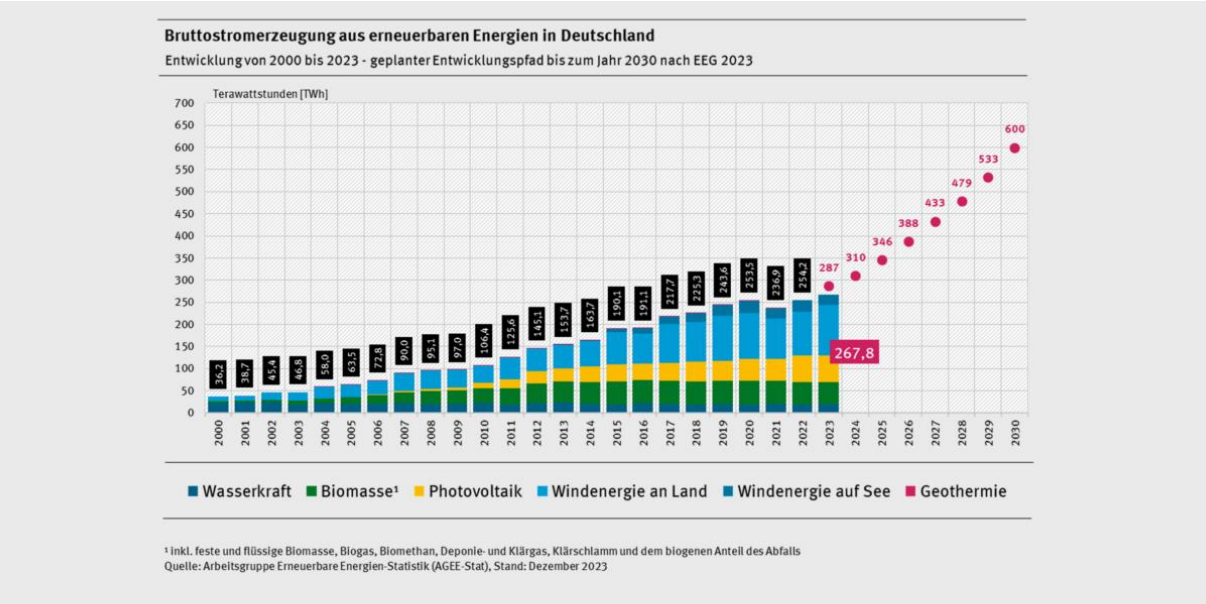

Figure 1: Gross electricity generation from renewable energies in Germany (Source: Umweltbundesamt; published: https://www.erneuerbareenergien.de/energiemarkt/energiemaerkte-weltweit/mehr-als-die-haelfte-des-2023-verbrauchten-stroms-aus-erneuerbaren)

In recent years, electricity generation from renewable energies has risen continuously. While 46% of electricity in Germany was generated from renewable sources in 2022, this figure rose to 52% in 2023. This trend continued significantly in 2024 with 59 % of electricity produced by renewable energy sources (ENERGIEN 2023; „SMARD | Der Strommarkt im Jahr 2024“ 2025).

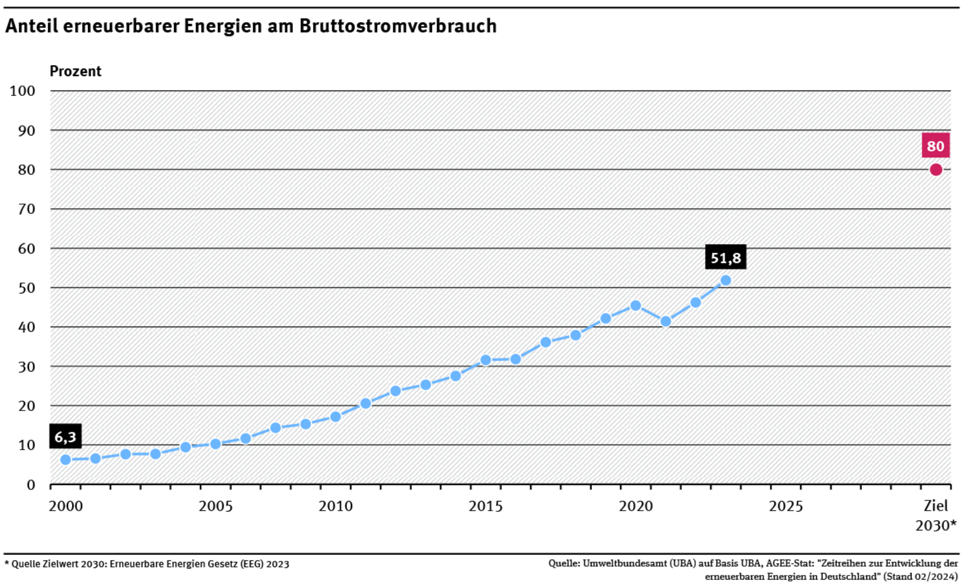

Figure 2: Development of the share of renewable energies in gross electricity generation in Germany (Source: Umweltbundesamt; published: https://www.umweltbundesamt.de/indikator-anteil-erneuerbare-am)

1.2 Expansion plans

Germany aims to generate 100% of its electricity requirements from renewable energies by 2035. By 2030, the target is 80% of production from renewable energies. By 2030, 115 GW of renewable electricity is to be generated from onshore wind power plants, 30 GW from offshore wind power plants and 215 GW from photovoltaic systems. At the end of 2023, 61 GW was produced from on-shore wind, 8.5 GW from off-shore wind and 81.8 GW from photovoltaic systems (Bücker 2024). According to an extrapolation with the expansion rate from 2022 and 2023, only the target for photovoltaic systems looks achievable. If the rate of expansion remains the same, 219 GW of electricity will be produced from photovoltaic systems in 2030. Wind onshore will only reach 78 GW and wind off-shore only 10.8 GW (own calculations).

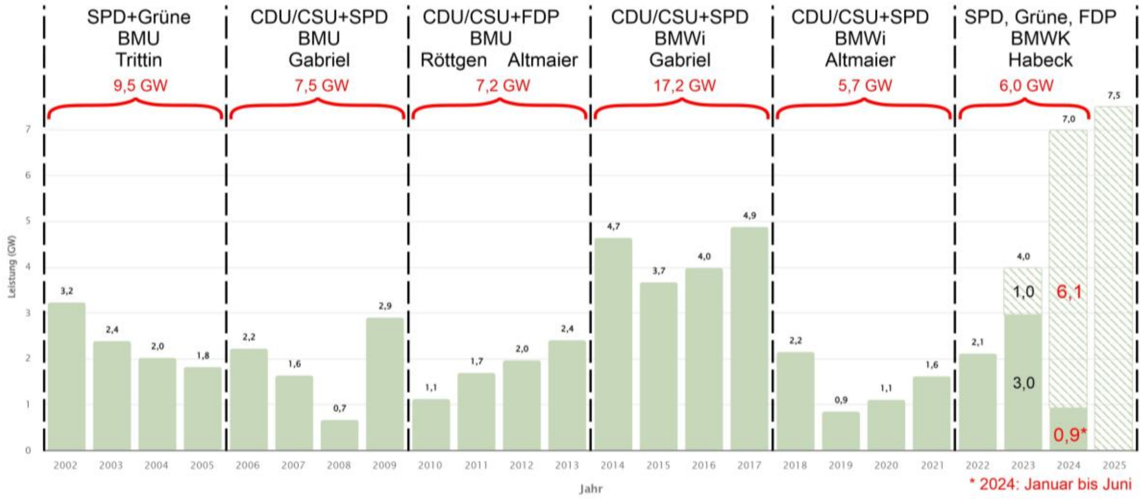

Figure 4: Annual expansion of wind onshore capacity in Germany (Source: Energy-Charts.info; published: https://x.com/energy_charts_d/status/1813835091405144098/photo/1)

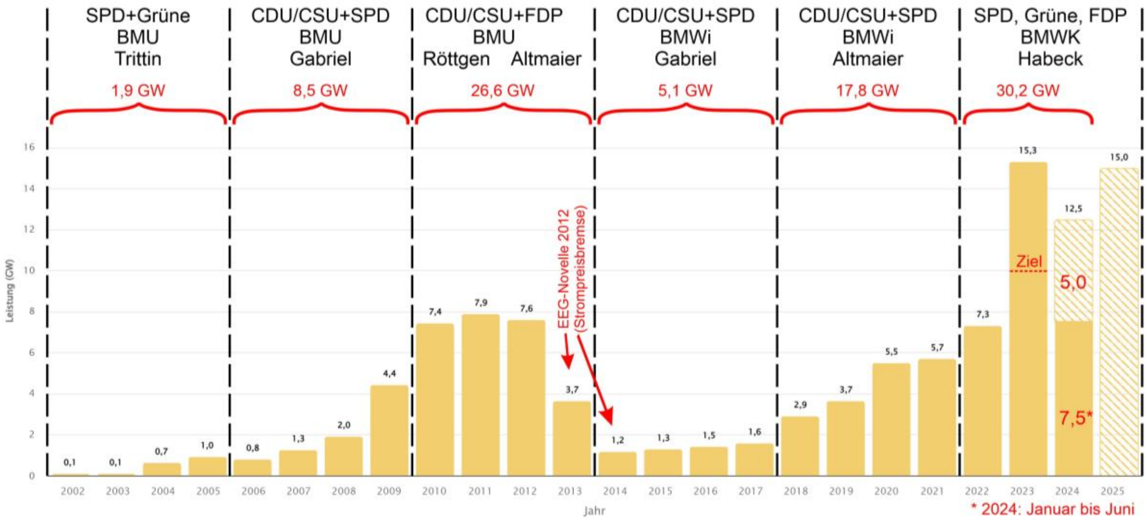

Figure 3: Annual expansion of photovoltaic capacity in Germany (Source: Energy-Charts.info; published: https://x.com/energy_charts_d/status/1813831484651999558/photo/1)

1.3 Challenges

1.3.1 Volatility and storage requirements

Renewable energies and their volatility pose one of the greatest challenges for the transformation of electricity production. In order to bridge days when neither the wind is blowing nor the sun is shining, options must be created to store the previously produced energy and release it again when required. It is important to ensure that enough energy can be stored to cover the energy requirements of several days. According to the German government's power plant strategy, gas-fired power plants, which will be able to run on hydrogen in the future, will play a major role. They are foreseen to provide 12,5 GW of balancing energy in the future (Action 2024). (Link)

If too much energy is produced due to high levels of wind and solar power in addition to the energy generated by conventional power plants, renewable energy sources would have to be switched off to avoid overloading the electricity grid (see 1.3.2 Lockdown and redispatch). This is unpleasant, as this potential energy is lost and can result in a negative electricity price on the electricity market because supply significantly exceeds demand. In the first three hours of the negative electricity price, renewable energy plants are still entitled to their feed-in tariff, which means that switching off these plants makes little sense for the operators („§ 51 EEG" 2023; „§ 51a EEG" 2023). However, the opportunity this presents is particularly interesting for operators of storage systems. In phases of negative electricity prices, storage systems can store the electricity. They do not have to pay for the electricity but receive money for storing it. When the electricity price moves back into positive territory, the electricity can be fed out and a profit generated. This makes storage systems an interesting investment. Consumers who are adapted to the supply can also benefit from negative electricity prices. (see 3.3.3)

In future, more storage facilities are to be built, conventional power plants are to be shut down more and more, and the flexibility of electricity use is to be increased, which in theory should reduce the negative electricity price and make it less frequent („Was sind negative Strompreise und wie entstehen sie?", o. J.).

1.3.1 Previous lockdown and redispatch

Until now, wind power and photovoltaic systems have sometimes been switched off at times of high production so as not to overload the electricity grid and cause it to crash. This means that energy that could be stored is lost, and at times of higher energy demand but lower production, fossil power plants are needed to cover the demand. However, if there is sufficient capacity, the curtailed energy could be stored and released when required. This would reduce the need for fossil-fuelled balancing energy and significantly increase the share of renewable energies in the electricity mix („Was sind negative Strompreise und wie entstehen sie?", o. J.).

In addition to curtailment, redispatch measures are also an important building block in the energy supply system. Redispatch refers to the regulation of feed-in from energy-producing power plants. Power plants report the planned energy production schedule for the following day at 15-minute intervals. If the load on the electricity grid changes due to spontaneous and unexpectedly high or low production or demand, the power plants must change their feed-in. In Germany, most wind turbines are located in the north, but the majority of energy is required in the west and south-west. If, for example, a strong wind blows in the north while the sun is shining at the same time, too much energy is produced there, and the electricity system is overloaded. Due to a lack of infrastructure, the energy cannot yet be fully transported to the south in line with demand. An imbalance arises behind the grid bottleneck, i.e. in the west/south of Germany, which has to be compensated for by adding power plants. There are three possibilities for redispatching: redispatching within a control area, i.e. within the system of a transmission system operator, redispatching across control areas, i.e. between two or more TSOs, and cross-border redispatching, i.e. balancing by buying or selling foreign energy. The redispatch process is divided into three phases. In the first phase, the grid operator must use instruments such as countertrading, balancing energy or load shedding. In the second phase, the grid operator may regulate conventional power plants to a minimum. Only in the third and final phase may the grid operator switch off renewable energy plants (Henning 2021).

A natural fluctuation can be seen in recent years with a constant increase in costs, redistributed energy and feed-in management. In the first half of 2024, the amount of energy that was redispatched was 20,813 GWh. In comparison: in 2023, this figure was 34,297 GWh („QuartalszahlenQ4_2023.pdf", o. J.; „Erneuerbare Energien in Zahlen" 2024). The fluctuations are mainly due to different weather conditions, but also to the expansion of renewable energies.

Withholding energy comes at a price. According to the Federal Network Agency's grid congestion reports, redispatch caused costs of €3.086 billion in 2023 („QuartalszahlenQ4_2023.pdf", o. J.).

2 Energy Infrastructure

2.1 Transmission network

Figure 5: Control areas of the four transmission system operators (TSOs) in Germany; as of 2019. (Source: Francis McLloyd; published: https://de.wikipedia.org/wiki/Datei:Regelzonen_mit_%C3%9Cbertragungsnetzbetreiber_in_Deutschland.png)

The German transmission grid is divided into four zones. This results from the historical distribution of the grid operators. Since 2010 only, there have been interconnection stations between the transmission grids. The task of the transmission system operators is to ensure the secure transmission of demand and guarantee security of supply.

The 4 areas are divided as following:

- The federal state of Baden-Württemberg is completely supplied by Transnet BW.
- The middle west and south-western parts of Bavaria are supplied by Amprion.
- 50 Hertz supplies eastern Germany including Berlin and in addition the city of Hamburg.
- Tennet takes care of the remaining areas, connecting the north of Germany with the south without interruption.

The electricity is transmitted through the supra-regional transmission grids with a voltage of 220 kV or more. There are a total of 38,500 kilometres of high-voltage lines in Germany that transport the electricity („Netztransparenz > Über uns > Aufgaben", o. J.).

Renewable energy plants with a capacity of less than 100 kW must supply their electricity directly to the TSOs, while plants with a capacity of more than 100 kW must hit the market and sell their electricity themselves on the electricity market („Übertragungsnetzbetreiber (ÜNB)“, o. J.).

The four transmission system operators have four specific tasks. Operational management and grid congestion management, i.e. ensuring grid stability and EU-wide trading at coupling points in the Europe-wide transmission grid. Frequency maintenance, which means consistently maintaining the frequency at 50 Hertz. This is important as otherwise the electricity system would collapse. To achieve this, loads may have to be switched on or off or the balancing energy changed. The third task is voltage maintenance. Like the frequency, the voltage must also be kept stable. Loads are also switched on and off for this purpose (see also 3.3.4). This also includes the so-called reactive consumption. The final task of the transmission system operators is to restore the supply. This means that the TSOs must ensure that the grid can be rebuilt as quickly as possible in the event of a collapse and that secure transmission is guaranteed in line with demand („Netztransparenz > Über uns > Aufgaben“, o. J.).

To adapt the transmission grid to the current challenges, several measures will be necessary over the next few years. These include the expansion of high-voltage direct current transmission lines, the expansion of renewable energy production as well as the storage of these volatile energy sources and better control of electricity demand to feed out electricity as required and not have to switch on unnecessary loads in order to prevent the grid from collapsing.

These measures are also based on the grid expansion plan. The grid expansion plan is created based on the scenario framework. The scenario framework, in turn, is calculated from the previous and forecast demand of recent and future years. The grid expansion plan thus establishes the demand for power lines and checks this against the currently existing lines. In cases of doubt regarding expansion measures, the Federal Network Agency takes over the project management („Netzentwicklungsplan Strom | Netzentwicklungsplan“, o. J.).

2.2 Distribution system operators / municipal utilities in Northern Germany

Figure 6: Distribution network operator (Source: VNBdigital, the joint internet platform of the electricity distribution system operators (DNB); published: https://www.bdew.de/energie/vnbdigital-gemeinsame-internetplattform-gestartet/)

In Germany, distribution grid operators are subordinate to the transmission grid operators. They transport the electricity from the high-voltage lines to the households. The voltage level is 230 V. Energy from smaller power plants is also fed directly into the distribution grid, for example from photovoltaic or wind power plants.
In northern Germany, Hamburg is supplied by one distribution grid.

Schleswig-Holstein's rural areas are also supplied by one distribution grid, while small towns have their own distribution grids, most of which are maintained by the respective municipal utilities.

The picture in Mecklenburg-Vorpommern is similar to that in Schleswig-Holstein. The rural areas are supplied by two large distribution networks, while the towns are also largely supplied by their own municipal utilities.

2.3 Centres of electricity demand

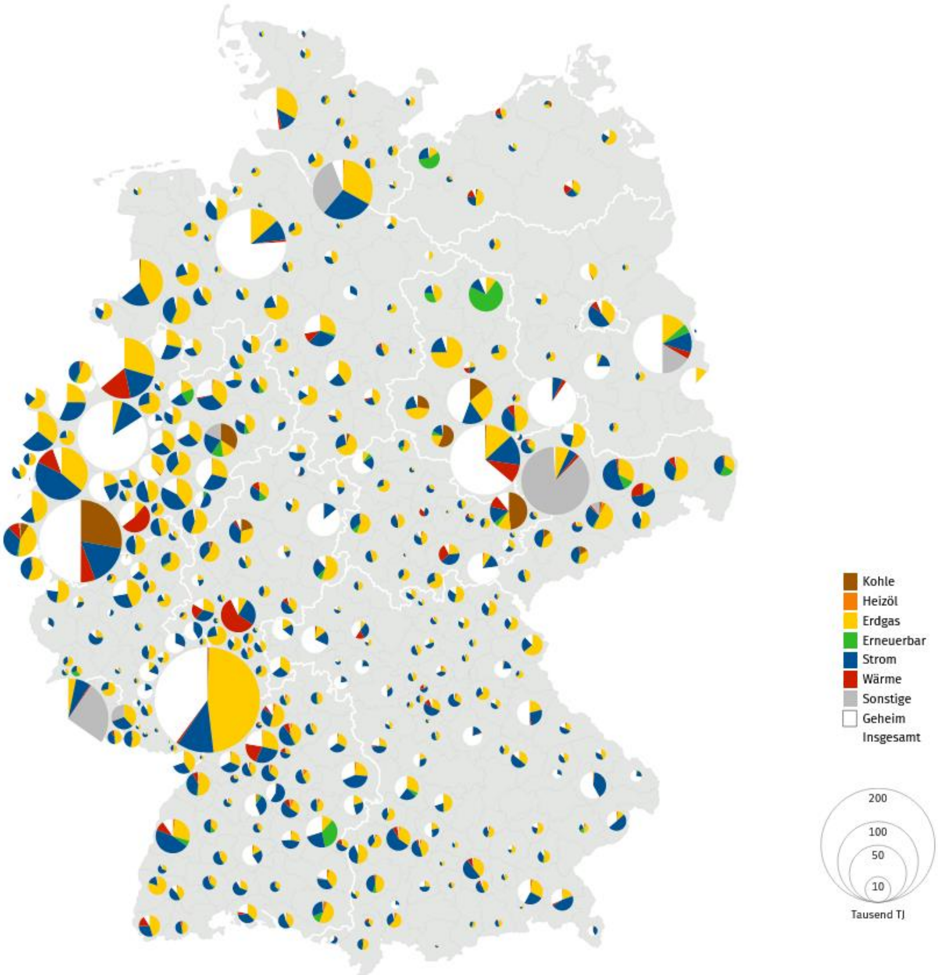

Figure 7: Energy consumption in industry 2022 by energy source (Source: Federal Office of Statistics; published: https://service.destatis.de/DE/karten/EnergieverbrauchIndustrie2022.html)

In Germany, the industrial sector consumed 667 TWh of final energy in 2022 (Wilke 2024). There are regional differences. For example, comparatively little energy is consumed in the north-east and south-east, while the west of Germany has a particularly high demand.

At the same time, with only 22% of final energy from renewable energy sources, there is still a high proportion of fossil energy sources in overall energy production (Wilke 2024).

The production of renewable energy in the north and the utilisation and provision of this energy in central and southern Germany also poses a major challenge. North Rhine-Westphalia and the region around Leipzig and Halle (Saale) in particular have high energy requirements. Little energy is required in central Germany, the north-east and south-east of Germany („Karte Energieverbrauch in der Industrie“, o. J.).

2.4 Power plant locations and the largest areas of onshore and offshore wind energy and PV systems

Figure 8: Coal-fired power plants in Germany; source: https://energiewinde.orsted.de/energiepolitik/kohlekraftwerke-karte-aus-stieg-datum)

The previous power plant locations of lignite and hard coal-fired power plants show a similar picture to the electricity demand centres. On a western axis that stretches from Hamburg in the north of Germany via the west to the south. Most of the power plants are located in North Rhine-Westphalia. In the east, there are some sites in the region around Leipzig and west of Dresden. The power plants still connected to the electricity grid are operated with an output of about 76,7 GW („Bundesnetzagentur - Kraftwerksliste" 2024).

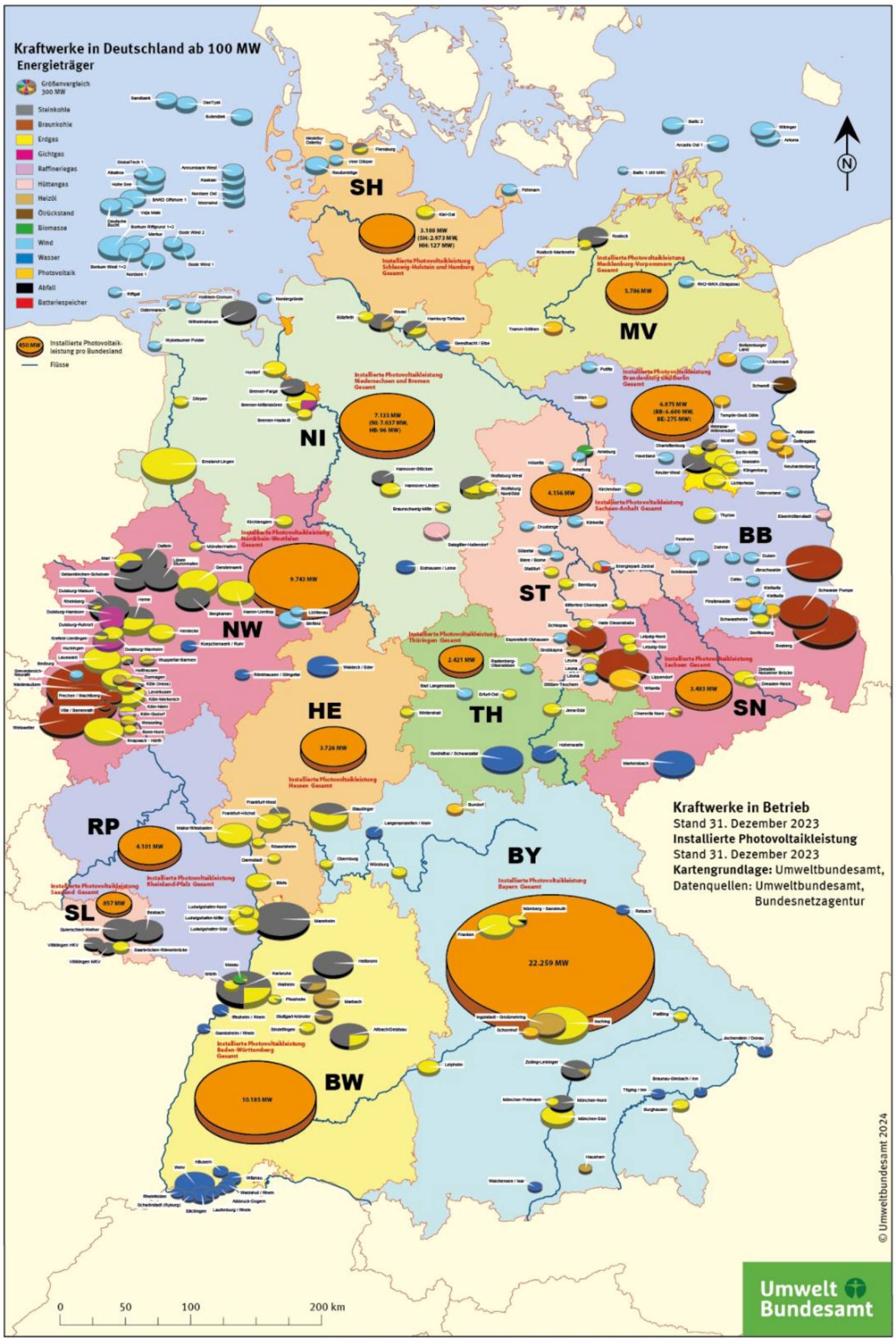

Figure 9: power plants and photovoltaic power in Germany; source: Umweltbundesamt; published: https://www.umweltbundesamt.de/bild/kraftwerke-photovoltaikleistung-in-deutschland)

In Germany, 97,3 GW are currently installed photovoltaic power plants and 72,4 GW wind turbines, 9,2 from off-shore production and 63,2 from on-shore (Hermann 2024). Further expansion of onshore and offshore wind energy plants is planned for the coming years. Electricity provider RWE, for example, plans to expand a wind farm with a total capacity of 1.6 GW over the next few years (RWE 2024). According to the German government's targets, a total output of 30 GW is to be installed by 2030 and 70 GW by 2045 from offshore plants alone (Bücker 2024).

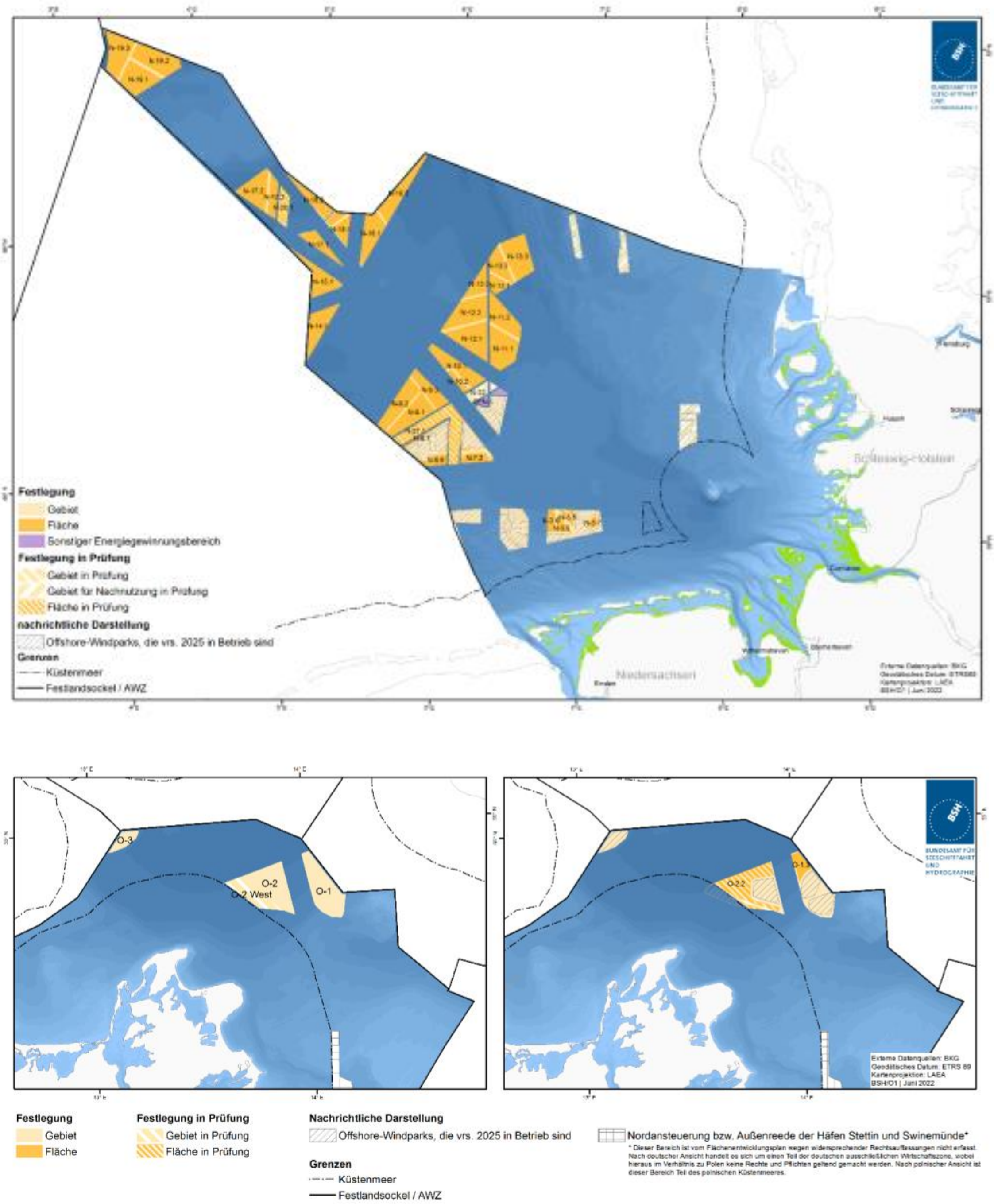

Figure 10: Determinations of areas and spaces in the EEZ of the North Sea and the Baltic Sea; source: Draft area development plan, 1.7.2022; Federal Office of Shipping and Hydrology)

Most off-shore areas are located in the North Sea, with isolated off-shore parks in the Baltic Sea. Most onshore areas can also be found on the North Sea coast, with large wind farms in Schleswig-Holstein and Lower Saxony. Most photovoltaic systems, on the other hand, are located in southern Germany.

2.5 "Electricity motorways"

Figure 11: Map of pipeline projects in Germany according to the Federal Requirements Plan Act (BBPlG 2013); source: Alexrk2; published: https://de.wikipedia.org/wiki/Suedlink#/media/Datei:Karte_BBPlG-Vorhaben.png)

In order to compensate for the challenge of the imbalance in electricity production and demand, as explained in the previous sections, large electricity lines, so-called electricity motorways, are needed across Germany. To this end, existing power lines are to be expanded and their capacity increased, and completely new electricity motorways are to be built (Lewicki 2023).

The largest project is the Südlink electricity motorway. Consisting of 2 direct current lines, it will bridge a distance of 700 kilometres and connect 10 million households. A maximum of 4 GW of electrical power will be transported at a voltage level of 525 kV („SuedLink“, o. J.).

The project is divided into 15 sections to make planning and authorisation easier. This will also make construction easier. Some of the planned sections are already under construction. Some of the planning approval projects are still pending, but the project has already been approved in accordance with the Grid Expansion Acceleration Act („SuedLink", o. J.).

Another important power line will be the NordLink connection. Over a length of 623 kilometres, two direct current lines will run from the south of Norway to Wilster in the north of Germany. The aim is to connect northern German wind power plants with Norwegian pumped storage power plants in order to simplify the storage of volatile renewable energy production („NordLink", o. J.).

By combining the NordLink and SüdLink lines, electricity stored in Norway can be easily transported to Bavaria to supply the country with electricity even at times of low energy production.

The "Gregy - Greek Egypt Interconnections" project is also planned. The aim is to build a power line from Egypt via Greece to the EU. This will primarily transport electricity from photovoltaic systems in North Africa to the EU and southern Germany. Lines to Italy are also already being planned. The aim is to utilise solar power from North Africa in Europe, but also to produce green hydrogen in Egypt in order to export it to the EU („‚GREGY' Interconnector", o. J.).

Another project is the hydrogen transmission line from major off-shore wind farms in the northern Sea. (See 2.7. AquaVentus)

2.6 Large-scale storage infrastructure

There are several large storage facilities in northern Germany. These are primarily pumped storage power plants and battery storage systems.

Figure 12: Installed net capacity of pumped storage and battery storage in Germany 2024 (Source: Energy-Charts.info; published: https://x.com/energy_charts_d/status/1809475949311783285/photo/1)

The expansion of further pumped storage plants is limited due to the geographical conditions and the necessary interventions in the landscape.

The capacities of the battery storage plants have been further expanded in recent years, so that in 2024 they will exceed the capacities of the pumped storage plants in Germany and the capacities used by Germany in Austria and Switzerland for the first time („Installierte Leistung | Energy-Charts", o. J.).

2.6.1 Pumped Storages

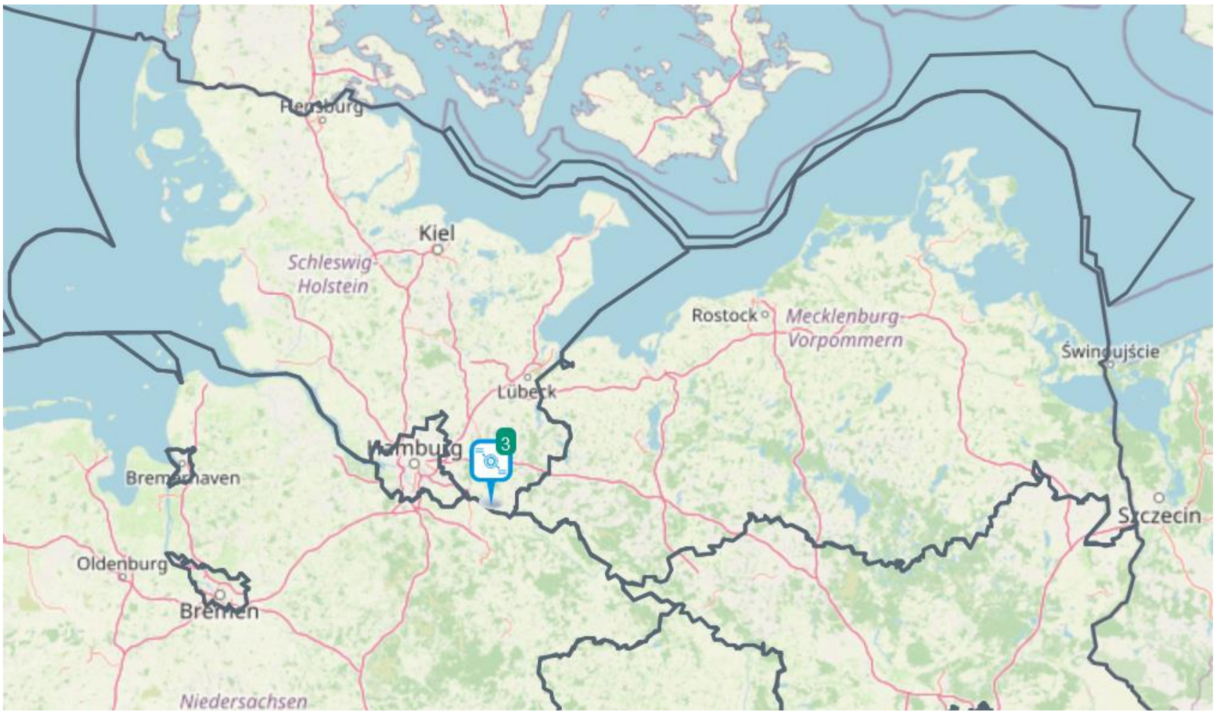

Figure 13: Locations of pumped storage power plants; source: Energy-Charts.info; published: https://energy-charts.info/map/map.htm?l=de&c=DE&country=DE&pp-source=bnetza&pp-bitmap=000000100&zoom=6&lat=55.597&lng=14.679

One pumped storage power plant can be found south-east of Hamburg in Geesthacht (see figure above). Operated by Vattenfall, the storage facility has been in operation since 1958. With an output of 119,1 MWe, it is the only storage power plant in northern Germany. 3 million m³ of water are pumped into the upper reservoir with a height difference of 80 metres or discharged into the river Elbe, which acts as the lower reservoir. When the upper basin is full and the turbines are operating at full capacity, the power supply can be guaranteed for 4.5 hours („Power plants: Geesthacht - Vattenfall", o. J.).

Another pumped storage power plant was planned in Lägerdorf in Schleswig-Holstein. The operator of the former gravel pits, HOLCIM, and the energy supplier E.ON commissioned a feasibility study. The results of which confirmed the technical feasibility but questioned the economic viability of the plant. As a result of this study, the project was cancelled by mutual agreement. A 70 MW plant with an output of 3.5 GWh was planned. Both the small difference in altitude and the poor geological conditions were problematic. The chalk soil does not allow comparisons with other projects and individual solutions would have had to be found, which would probably have driven the price up to threefold. Even with a low electricity price of less than 1 ct/kWh, the operation of this plant would not have been economically feasible. The plan was to produce renewable electricity from a nearby wind farm. This will probably not be built either. Further discussions took place between the parties involved to find other solutions so far without success („Holcim (Deutschland) AG und E.ON AG stellen Machbarkeitsstudie für Pumpspeicherwerk Lägerdorf vor" 2013).

2.6.2 Battery Storages

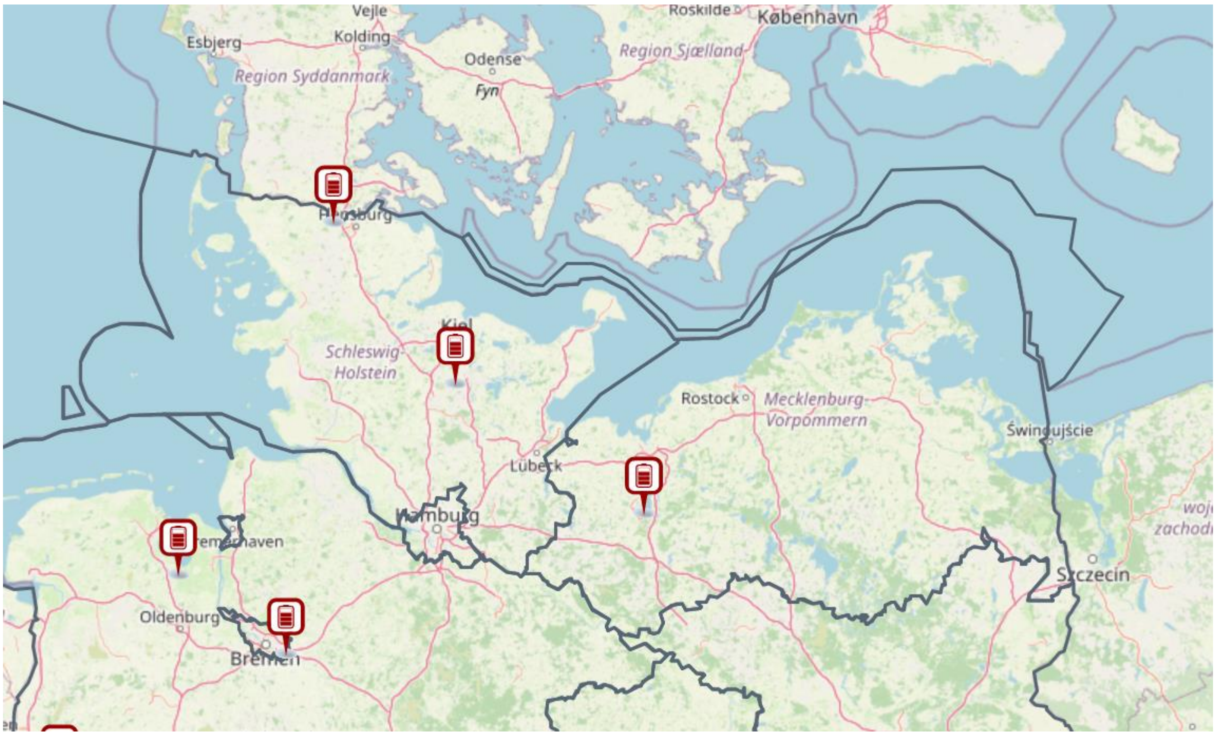

Figure 14: Locations of battery storage facilities; source: Energy-Charts.info; published: https://energy-charts.info/map/map.htm?l=de&c=DE&country=DE&pp-source=bnetza&pp-bitmap=000000100&zoom=6&lat=55.597&lng=14.679

The situation is different for battery storage systems. There are currently three large storage facilities in northern Germany.

A storage facility with an output of 15 MW and a capacity of 15 MWh in Bordesholm near Kiel, which is operated by Versorgungsbetriebe Bordesholm GmbH, made history at the end of 2019. In a pilot test, it was possible to supply the region self-sufficiently for one hour thanks to the regional production of renewable electricity in conjunction with the storage facility (Doppler-Roth 2019).

There is another battery storage facility in Jardelund near Flensburg. The storage facility operated by the ABE Group has an output of 48 MW and a capacity of 50 MWh („Batteriespeicher in Jardelund | ABE-Gruppe", o. J.).

WEMAG, a municipal energy supplier in the Schwerin area, has been operating a battery storage facility with an output of 5 MW since 2014; a second storage facility with an output of 10 MW and a capacity of 15 MWh is planned („Zweites WEMAG-Batteriespeicherkraftwerk geht in Schwerin ans Netz | www.wemag.com" 2017).

Further systems are planned. The largest battery storage facility under construction is located in Bollingstedt in the north of Schleswig-Holstein with a capacity of 239 MWh, operated by EcoStor. The ground-breaking ceremony was held in Bollingstedt-Gammelund on 19 April 2024. The battery storage facility is scheduled to be connected to the grid in 2026. The company is planning another battery storage facility of the same size with a capacity of 238 MWh in Schuby, not far from Bollingstedt („Projektseite Bollingstedt | ECO STOR", o. J.; „Projektseite Schuby | ECO STOR", o. J.).

Purple Energy is planning four further large-scale storage facilities in northern Germany with a total capacity of 48 MWh (ENERGIEN 2024).

Aquila Clean Energy EMEA is starting to build the first of 14 planned battery storages in Germany with a total capacity of 900 MW. In Strübbel, Schleswig-Holstein the company will build this 50 MW / 100 MWh storage unit close to the northern sea, providing ideal framework conditions for storing renewable energy („Aquila Clean Energy" 2024).

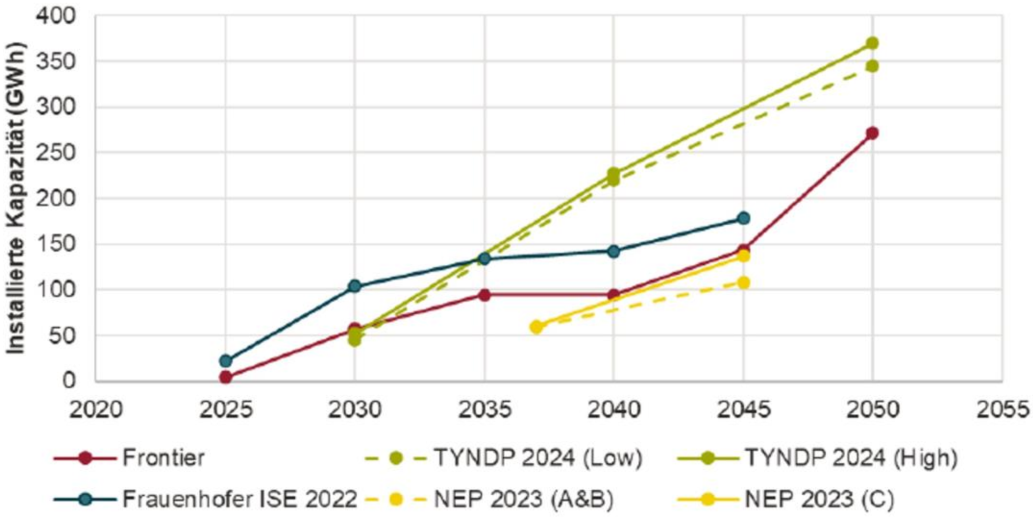

Figure 15: Expected expansion of battery storage in Germany (Source: Frontier Economics; published: https://www.kyon-energy.de/blog/wie-der-ausbau-von-batteriegrossspeicher-die-energiekosten-in-deutschland-um-12-milliarden-euro-senken-wird)

Overall, there is a clear ramp-up in the expansion of battery storage systems. This is shown by various studies on the expected expansion of large-scale battery storage systems in Germany.

The car manufacturer Volkswagen also wants to enter the market. Battery storage systems made from old car batteries are planned for the next few years, initially with a capacity of 350 MWh. In the future, the capacity is to be increased to up to 1 GWh. The first plant is due to be connected to the grid in 2025. Due to a lack of returns of used car batteries, this storage facility will initially be operated with brand-new batteries and will gradually switch to used car batteries in the future. The location of this plant is not yet known (Korb 2024).

2.7 Hydrogen / Electrolyser

Storing energy in the form of hydrogen has also become increasingly popular in recent years. Storage facilities are to be built in the coming years, especially in eastern Lower Saxony, where the potential is particularly high due to storage in salt caverns that were previously used commercially and the good connection to seaports. In Krummhörn, the company Uniper is planning a hydrogen storage facility with a capacity of 200,000 m³ in an underground salt cavern („HPC Krummhörn | Uniper", o. J.). Such a storage facility is also planned in Stade. Storengy Deutschland is planning two storage facilities, the first of which is to be connected to the grid in 2030 and the second in 2034. 7500 tonnes per storage facility will be enough to meet the needs of the local steelworks for two weeks (Mohl 2024). Here too, the hydrogen is to be stored in salt caverns that were previously used for commercial purposes. This location is particularly beneficial due to the 'EU hydrogen backbone' hydrogen network planned in this area („EHB", o. J.). The Lhyfe company would also like to benefit from this. A 10 MW electrolyser is to be built in Brake (Lower Saxony) in the area of the Lower Weser („Lhyfe" 2024). Other electrolysers and hydrogen projects in northern Germany can be found at the following locations:

- Hamburg Moorburg, electrolyser with 100 MW capacity, completion end of 2027 („Port of Hamburg" 2024)
- AquaVentus, hydrogen project in the North Sea, total capacity of 10 GW, several sub-projects with hydrogen pipelines and electrolysers in connection with offshore wind turbines, completion in the mid-2030s (RWE 2021).
- DoingHydrogen, electrolyser with 100 MW capacity in Rostock-Laage, completion 2027 (vc_superadmin 2023).

Figure: https://www.windindustrie-in-deutschland.de/unternehmensmeldung/enertrag-projekte-mit-insgesamt-210-mw-elektrolyse-als-ipcei-projekte-vorausgewaehlt

On 22 July 2024, FNB Gas e.V. submitted the joint application of the transmission system operators for the hydrogen core network for Germany to the Federal Network Agency. The total length of the optimised core network according to the application is 9,666 km. Of this, 802 km are accounted for by lines from 16 other potential hydrogen network operators (distribution network operators). The core network consists mainly of converted natural gas pipelines (approx. 60%). The investment costs amount to € 19.7 billion. The feed-in and feed-out capacities amount to around 100 GW and 87 GW respectively („FNB Gas", o. J.).

The northern German states of Schleswig-Holstein, Hamburg, Mecklenburg-Vorpommern, Lower Saxony and Bremen agreed on a hydrogen strategy together with several stakeholders in 2019. In this strategy, framework conditions are to be developed together with the stakeholders and the expansion of the hydrogen infrastructure is to be coordinated in four fields of action („norddeutsche Wasserstoffstrategie", o. J.).

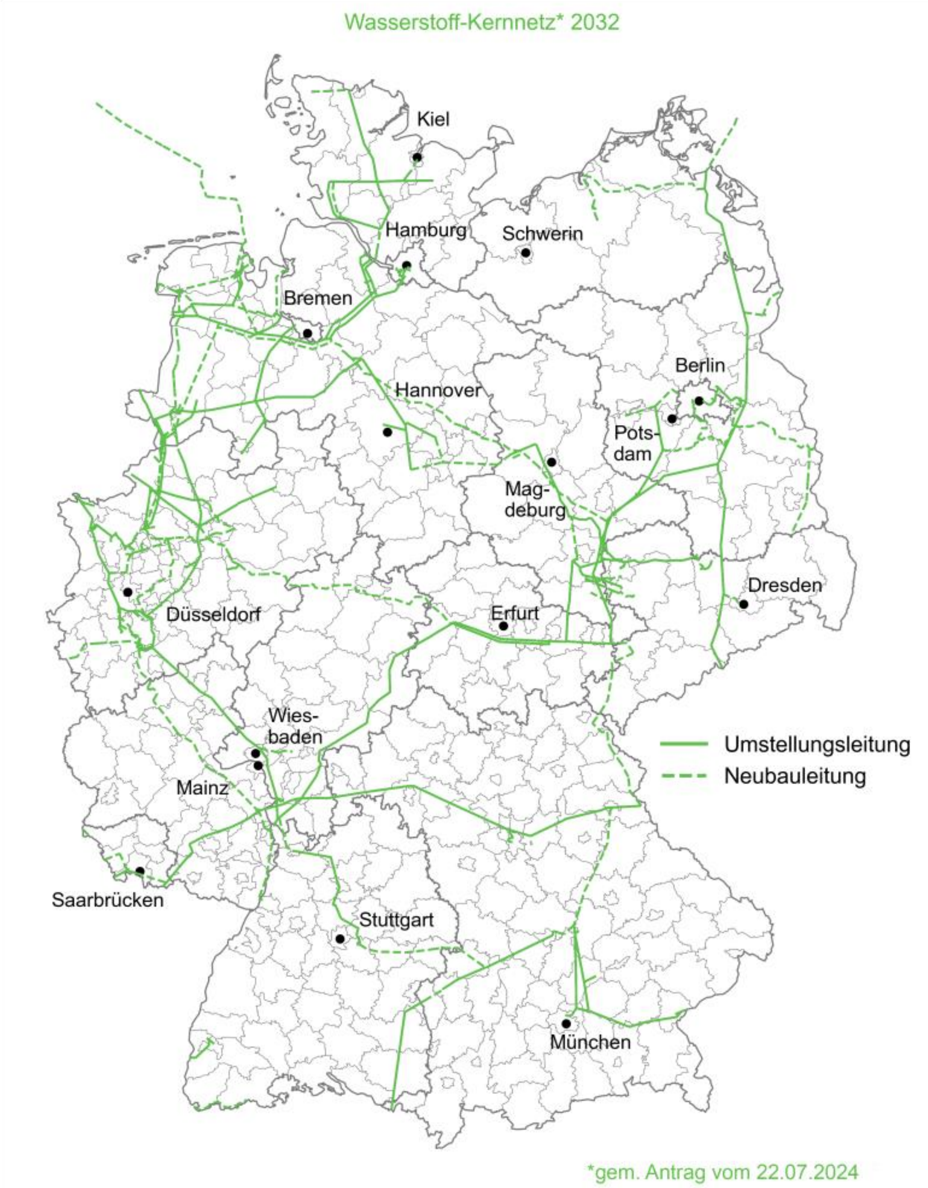

Figure: Hydrogen core network planned by 2032 (source: FNB Gas e.V.; published: https://fnb-gas.de/wasserstoffnetz-wasserstoff-kernnetz/)

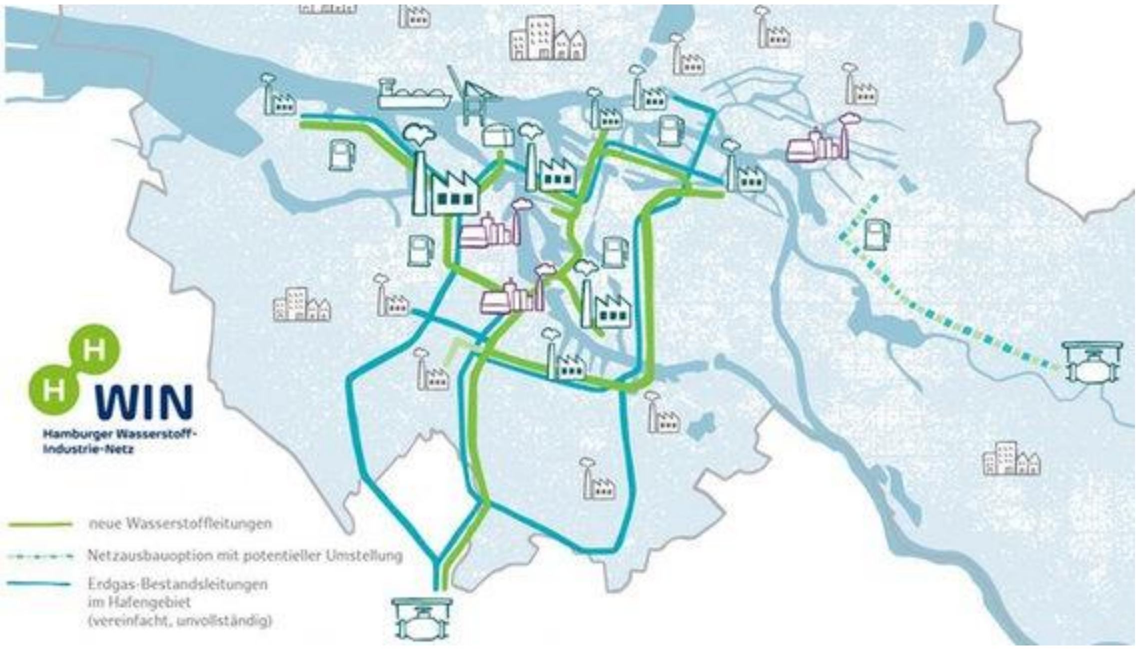

Figure 16: Hamburg hydrogen industry network (source: Hamburg hydrogen industry network; published: https://www.ndr.de/nachrichten/hamburg/Hafen-bekommt-Wasserstoff-Leitungsnetz-Baustart-2023,wasserstoff386.html)

Meanwhile, in Hamburg, a former coal power plant in Moorburg is to be equipped with an electrolysis plant. The electrolyser with a capacity of 100 MW is being built by Hamburger Energiewerke and the company Luxcara and is being subsidised with € 250 million by the City of Hamburg and the federal government. The plant will be operated by the company Gasnetz Hamburg. A 40 km long hydrogen distribution network is also planned as part of the project. Construction is due to start in 2025 and the electrolyser should be completed by 2027 (BUKEA und BWI 2024).

The German government's power plant strategy published in February 2024 is also important for the expansion of hydrogen storage and the use of green hydrogen. Five gas-fired power plants with a total capacity of 12.5 GWh are to be built by 2030 to make the electricity market more flexible and ensure sufficient balancing energy. These are to be converted to run on hydrogen in the years 2032-2038 (Action 2024).

2.8 Power-to-Heat

Power-to-heat systems also play an important role in achieving climate targets. They can replace fossil primary energies in the provision of heat. Six plants are planned or already in operation for this purpose. The transmission system operator 50Herzt plays a decisive role here. In order to keep the electricity grid stable and create further flexibility options, 50Hertz is financing the construction of power-to-heat plants. When electricity production is high, heat is produced from the electricity, which is then fed into the existing district heating grids („Power-to-Heat: aus Strom wird Wärme" 2022).

A plant with a heat output of 80 MW was realised in Wedel near Hamburg and part of the Hamburg district heating system in 2023 (Hamburger Energiewerke, o. J.).

Other plants can be found in Hamburg-Billstedt with a capacity of 5 MW (energie-experten, o. J.), Parchim, with a capacity of 2 MW (ENERGIEN 2021), Stralsund with a capacity of 6.5 MW (Gustedt 2021), Rostock with a capacity of 20 MW (Stadtwerke Rostock, o. J.) and in New Brandenburg with a capacity of 30 MW (Maksimenko 2019). The operators of the plants are mostly the local energy suppliers, in Hamburg, for example, Hamburger Energiewerke.

2.9 Flexibilization of Production / Power-to-X

Flexibilisation of production can be achieved through so-called Power-to-X processes. This refers to the conversion of energy and storage in the form of other substances, such as hydrogen. Storage in hydrogen is the most common form of Power-to-X process. Other types are the production of synthesis gases or ammonia to produce fuels for the traffic and transport sector that can be burnt in a climate-neutral way (BauNetz, o. J.).

Research in Germany is focussing on hydrogen and its production, transport and storage. Hydrogen will primarily be used for processes that have a high thermal energy requirement. These include, for example, steel or glass production. The still expensive electrolysis process and the need for rare metals and earths in the construction of the electrolysers have so far posed challenges for this process. Some PtX projects are being subsidised by KfW, a German development bank. The PtX Development Fund and the PtX Growth Fund enable European companies based or operating in Germany to apply for funding (KfW, o. J.).

Specifically, several projects are planned in northern Germany in connection with ammonia terminals. However, this does not involve a plant for the production of ammonia, but rather terminals that can store and store imported ammonia. In the Hamburg harbour area, a terminal is planned to be commissioned by 2027 to import and store ammonia in Hamburg (Port of Hamburg 2022). Something similar is to happen in Brunsbüttel in Schleswig-Holstein. From 2026, up to 300,000 tonnes of ammonia are to be imported and distributed annually at an RWE plant (RWE, o. J.). In Wilhelmshaven, bp is planning an ammonia terminal with an annual capacity of 130,000 tonnes. The terminal is scheduled for completion in 2028 (bp, o. J.).

3 Reasons for investing in storage infrastructure

3.1 Market situation and price development

When looking at the market situation of the various storage systems, battery storage systems still play a pioneering role. Due to the expansion of renewable energies, the ramp-up of battery storage systems will increase steadily over the next few years. This is also supported by the current price trends for battery storage systems themselves and the falling installation costs for renewable energies. In 2013, a battery storage system still cost over $806 per kWh; in 2024, the price was around per $115 kWh (BloombergNEF 2024). The size of the storage systems plays a decisive role in the prices. As a rule of thumb, the larger the storage system, the more favourable the price per kWh. The total market share of battery storage systems is estimated at USD 114,05 billion (Fortune Business Insights 2024). This currently equates to EUR 110.91 billion.

The picture is somewhat different for electrolyser systems. Here, too, a further increase in expansion and the number of systems is expected in the coming years. As of December 2023, there are 92 electrolysers from 17 manufacturers in Germany. The global market share in 2023 is USD 2.8 billion, or EUR 2.72 billion. Market growth is also forecast here in the coming years. Falling prices for electrolysis systems and, as with battery storage systems, the increasing growth in renewable energies will also play a role. Rising demand for green hydrogen, particularly for heavy industry, aviation and shipping, will also make electrolyser systems more attractive (Global Market Insights, o. J.).

Both storage solutions will most likely continue to grow in the coming years and thus increase their market share. As a result, prices per kWh will fall and electricity from renewable energies can be stored more easily.

3.2 Legal situation and current storage strategy

The authorisation procedures for storage solutions in Germany vary depending on the type of energy storage system. The construction of battery storage systems generally only requires a simple planning application procedure, which is approved in accordance with the provisions of the German Building Code (BauGB) (BMI, o. J.-a) and the respective state building regulations. In addition, electrolysers must be inspected in accordance with the Federal Immission Control Act (BImSchG) (BMI, o. J.-b). Pumped storage power plants must be authorised in accordance with the Water Resources Act (WHG) (BMI, o. J.-c). This is also required for heat storage facilities that work with substances hazardous to water.

Special consideration is given to the various storage facilities for electricity. Storage facilities are not legally regarded as such. Although the term appears occasionally in legal texts, storage facilities are regarded as consumers at the moment of storage and as producers at the moment of withdrawal. This repeatedly causes confusion, particularly regarding grid charges and the EEG levy. The industry is calling for a clear and standardised regulation („Rahmenbedingungen Stromspeicher Deutschland", o. J., 7 ff.).

This topic is also addressed in the electricity storage strategy of the Federal Ministry of Economic Affairs and Climate Protection (BMWK) on December 8th, 2023. The cancellation of double grid charges for electricity storage systems will be suspended until 2029. The EEG surcharge for electricity storage systems is also to be changed to prevent double costs and the loss of subsidies due to grey electricity shares in the electricity grid. Overall, the electricity storage strategy does not only consist of changes to the legal framework; a total of 18 fields of action are being considered. These range from financial incentives for construction and operation to the removal of legal barriers to authorisation and support for research. Financial incentives are to be achieved by reducing construction cost subsidies. These must be paid by operators of electricity storage systems to the grid operators in order to be connected to the grid. In future, no construction cost subsidies are to be paid at system-relevant grid connection points. The research field of action should be promoted with a focus on bidirectional charging, especially for the batteries of electric vehicles. Together with intelligent electricity systems such as smart meters, consumption is to be controlled depending on the load and the grid is to be further relieved (BMWK 2023).

(For further information about the electricity storage strategy follow this link)

3.3 Business models

3.3.1 Ensure the operation of the transmission networks through storage:

Grid operators have to ensure the stable operation of the energy grid at a frequency of 50 Hertz. This challenge has increased in recent years due to the intermittency of renewable energy systems. To ensure a stable grid, power plants have had to be shut down at times when energy production exceeds energy demand. This influences public opinion on the energy revolution and reduces the potential of renewable power plants. Grid operator 50Hertz is therefore building power-to-heat plants in several of its areas of responsibility. This increases the share of renewable energy in the heat supply and keeps power plants running where they would've been shut down in the past. This also has an impact on the price of heat, as renewable energy is used during periods of surplus production, resulting in a lower price per kWh. Therefore, the implementation of storage solutions or Power-to-X facilities can have a positive impact not only on grid operators, but also on end consumers (Baumgarte, Glenk, und Rieger 2020).

3.3.2 Increase their own use by storing self-generated electricity:

Another business case for energy storage is the use of self-generated electricity, which can then be stored. This increases the self-sufficiency of the local power grid. When energy production is higher than energy demand, this excess energy can be stored for times when energy production is lower than demand. This not only facilitates self-sufficiency, but also reduces costs in the local energy system. At times when energy demand is higher than production, electricity prices are usually higher. Not having to buy electricity because of storage will lead to lower energy costs in general. This is particularly the case for battery storage due to its fast payback time (Schmitt 2023).

The municipality of Bordesholm in northern Germany pushed the limits of self-sufficiency in November 2019. For one hour, the municipality disconnected itself from the regional energy grid and tested its supply using renewable energy sources and a large 15 MWh storage unit. The test was successfully supported by the Technical University of Cologne (Waffenschmidt u. a., o. J.).

3.3.3 Improve the selling price on volatile markets by storing self-generated electricity:

It is particularly interesting for private investors to build storage units to improve the selling price of (self-generated) electricity. In case of high energy production from volatile renewable energy systems, the energy can be stored in the storage unit, either by using own renewable power plants or by buying the energy when market prices are lower due to overproduction. When energy demand is higher than production, the stored energy can be sold when prices are higher due to high demand. This potential can be further enhanced when electricity prices are negative (Baumgarte, Glenk, und Rieger 2020).

3.3.4 Receive compensation for stabilizing the transmission networks through storage:

With higher volatility in the energy system due to increased use of renewable energy sources, stabilising the frequency and voltage level of the energy grid becomes more important. For this reason, the balancing energy market has been introduced into the European energy market. The first phase automatically stabilises the frequency within a few seconds. The second phase kicks in if the first phase fails to stabilise the frequency. This is also automatic and lasts from a few seconds to 15 minutes. The third phase follows if the second phase was unsuccessful and lasts up to 60 minutes.

Financially, this market is an interesting area for private storage operators. The energy that is retained and used for the first phase of control is subsidised. In addition, energy supplied for the second and third phases will be paid at market value. However, this does not have a negative impact as the prices for balancing energy are above normal market prices. In addition, energy that is stored during over-production is usually cheap, whereas energy that is withdrawn from a storage unit due to lack of production usually results in higher prices (EHA 2024).

3.3.5 Value creation for municipalities:

Another advantage of building and implementing storage solutions in combination with renewable power plants is the local value chain. Local construction companies will be contracted to provide the infrastructure and facilities, and planning institutions will be contracted to develop new plans. Newly created storage and power plants will create more jobs, add value to the area and increase the attractiveness of a community. Further municipalities will profit from taxes being paid by storage operators (Hildebrand u. a. 2023).

Further links for additional information:

- roland_berger_energy_storage_final.pdf
- Battery Charts - (rwth-aachen.de)

„§ 51 EEG". 2023. 2023. https://www.gesetze-im-internet.de/eeg_2014/__51.html.
„§ 51a EEG". 2023. 2023. https://www.gesetze-im-internet.de/eeg_2014/__51a.html.
Action, BMWK-Federal Ministry for Economic Affairs and Climate. 2024. „Agreement on Power Station Strategy". 5. Februar 2024. https://www.bmwk.de/Redaktion/EN/Pressemitteilungen/2024/02/20240205-agreement-on-power-station-strategy.html.
„Aquila Clean Energy". 2024. Aquila Clean Energy EMEA. 26. August 2024. https://www.aquila-clean-energy.com/news/aquila-clean-energy-emea-launches-construction-of-one-of-germanys-largest-and-most-advanced-battery-storage-projects-in-schleswig-holstein/.
„Batteriespeicher in Jardelund | ABE-Gruppe". o. J. Zugegriffen 9. Januar 2025. https://abe-gruppe.de/batteriespeicher-in-jardelund/.
Baumgarte, Felix, Gunther Glenk, und Alexander Rieger. 2020. „Business Models and Profitability of Energy Storage". *iScience* 23 (10): 101554. https://doi.org/10.1016/j.isci.2020.101554.
BauNetz. o. J. „Power-to-X-Technologien | Gebäudetechnik | Erneuerbare Energien | Baunetz_Wissen". Baunetz Wissen. Zugegriffen 16. Januar 2025. https://www.baunetzwissen.de/gebaeudetechnik/fachwissen/erneuerbare-energien/power-to-x-technologien-5560444.
BloombergNEF. 2024. „Lithium-Ion Battery Pack Prices See Largest Drop Since 2017, Falling to $115 per Kilowatt-Hour: BloombergNEF". *BloombergNEF* (blog). 10. Dezember 2024. https://about.bnef.com/blog/lithium-ion-battery-pack-prices-see-largest-drop-since-2017-falling-to-115-per-kilowatt-hour-bloombergnef/.
BMI. o. J.-a. „BauGB - nichtamtliches Inhaltsverzeichnis". Zugegriffen 16. Januar 2025. https://www.gesetze-im-internet.de/bbaug/.
———. o. J.-b. „BImSchG - nichtamtliches Inhaltsverzeichnis". Zugegriffen 16. Januar 2025. https://www.gesetze-im-internet.de/bimschg/.
———. o. J.-c. „WHG - nichtamtliches Inhaltsverzeichnis". Zugegriffen 16. Januar 2025. https://www.gesetze-im-internet.de/whg_2009/.
BMWK. 2023. „Stromspeicher-Strategie", Dezember.
bp. o. J. „Wilhelmshaven green hydrogen hub | bp in Deutschland". Deutschland. Zugegriffen 16. Januar 2025. https://www.bp.com/de_de/germany/home/wilhelmshaven-hydrogen-hub.html.
Bücker, Till. 2024. „So läuft der Ausbau der Erneuerbaren Energien". tagesschau.de. 5. Februar 2024. https://www.tagesschau.de/wirtschaft/energie/erneuerbare-energie-ausbau-stromerzeugung-100.html.
BUKEA, und BWI. 2024. „Umrüstung des Kraftwerks Moorburg zum Elektrolyseur schreitet voran". The official website of the Port of Hamburg. 13. Juni 2024. https://www.hafen-hamburg.de/de/presse/news/umruestung-des-kraftwerks-moorburg-zum-elektrolyseur-schreitet-voran/.
„Bundesnetzagentur - Kraftwerksliste". 2024. November 2024. https://www.bundesnetzagentur.de/DE/Fachthemen/ElektrizitaetundGas/Versorgungssicherheit/Erzeugungskapazitaeten/Kraftwerksliste/start.html.
Doppler-Roth, Regina. 2019. „Bordesholm blieb konstant unter Strom". *KN*, 2. Dezember 2019.
EHA. 2024. „Regelenergie & der Regelenergiemarkt – alle Informationen". EHA. 1. Oktober 2024. https://www.eha.net/blog/details/regelenergie-der-regelenergiemarkt.html.
„EHB". o. J. Zugegriffen 16. Januar 2025. https://www.ehb.eu/.
energie-experten. o. J. „Hamburg: Power-to-Heat-Anlage als Schlüsselkonzept". energie-experten. Zugegriffen 16. Januar 2025. https://www.energie-experten.org/projekte/hamburg-power-to-heat-anlage-als-schluesselkonzept.
ENERGIEN, ERNEUERBARE. 2021. „‚Nutzen statt Abregeln': Power-to-Heat-Anlagen gehen in Betrieb". 1. Dezember 2021. https://www.erneuerbareenergien.de/transformation/netze/nutzen-statt-abregeln-power-heat-anlagen-gehen-betrieb.
———. 2023. „Mehr als die Hälfte des 2023 verbrauchten Stroms aus Erneuerbaren". 16. Dezember 2023. https://www.erneuerbareenergien.de/energiemarkt/energiemaerkte-weltweit/mehr-als-die-haelfte-des-2023-verbrauchten-stroms-aus-erneuerbaren.
———. 2024. „Intilion baut zusammen mit Purpel Energy vier große Netzspeicher". 27. März 2024. https://www.erneuerbareenergien.de/transformation/speicher/intilion-baut-zusammen-mit-purpel-energy-vier-grosse-netzspeicher.
„Erneuerbare Energien in Zahlen". 2024. *11.2024*, November, 44, 45.

„FNB Gas". o. J. Zugegriffen 16. Januar 2025. https://fnb-gas.de/wasserstoffnetz-wasserstoff-kernnetz/.
Fortune Business Insights. 2024. „Marktgröße, Anteil, Wachstumsbericht für Batterieenergiespeicher, 2032". 30. Dezember 2024. https://www.fortunebusinessinsights.com/de/industrie-berichte/batteriespeichermarkt-100489.
Global Market Insights. o. J. „Elektrolyt Marktgröße & Teilen | Wachstumsanalyse, 2023-2032". Global Market Insights Inc. Zugegriffen 16. Januar 2025. https://www.gminsights.com/de/industry-analysis/electrolyzer-market.
„‚GREGY' Interconnector". o. J. Copelouzos Group. Zugegriffen 16. Januar 2025. https://www.copelouzos.gr/en/service/gregy-interconnector/.
Gustedt, Volker. 2021. „Weiterer Baustein für mehr Klimaschutz: 50Hertz und Stadtwerke Stralsund starten Power-to-Heat-Anlage". 17. Dezember 2021. https://www.stralsund.de/shared/Nachrichtenportal/Archiv/2021/12/Weiterer-Baustein-fuer-mehr-Klimaschutz-50Hertz-und-Stadtwerke-Stralsund-starten-Power-to-Heat-Anlage.html.
Hamburger Energiewerke. o. J. „Power-to-Heat Wedel und Dradenau". Hamburger Energiewerke. Zugegriffen 16. Januar 2025. https://unternehmen.hamburger-energiewerke.de/wissen-themen/sektorenkopplung/power-to-heat-wedel.
Henning, Sandra. 2021. „Redispatch-Maßnahmen & Kosten im Strommarkt". energie-experten. 1. Juni 2021. https://www.energie-experten.org/erneuerbare-energien/oekostrom/stromnetz/redispatch.
Hermann, Sebastian. 2024. „(AGEE-Stat)", Dezember.
Hildebrand, Jan, Valentin Jahnel, Irina Rau, und Steven Dr. Salecki. 2023. „Die Energiewende in Kommunen - Zusammenhänge von Regionaler Wertschöpfung, Lokaler Akzeptanz und Finanzieller Beteiligung".
„Holcim (Deutschland) AG und E.ON AG stellen Machbarkeitsstudie für Pumpspeicherwerk Lägerdorf vor". 2013. 8. März 2013. https://www.holcim.de/kommunikation/pressemitteilungen/pressemitteilung/article/holcim-deutschland-ag-und-eon-ag-stellen-machbarkeitsstudie-fuer-pumpspeicherwerk-laegerdorf-vor.
„HPC Krummhörn | Uniper". o. J. Zugegriffen 16. Januar 2025. https://www.uniper.energy/de/hydrogen-pilot-cavern.
„Installierte Leistung | Energy-Charts". o. J. Zugegriffen 16. Januar 2025. https://energy-charts.info/charts/installed_power/chart.htm?l=de&c=DE&legendItems=1w2wa.
„Karte Energieverbrauch in der Industrie". o. J. Zugegriffen 16. Januar 2025. https://service.destatis.de/DE/karten/EnergieverbrauchIndustrie2022.html.
KfW. o. J. „PTX-Plattform | KfW Entwicklungsbank". Zugegriffen 16. Januar 2025. https://www.kfw-entwicklungsbank.de/Unsere-Themen/PtX/.
Korb, Julian. 2024. „VW will industrielle Großspeicher bauen". 7. Juni 2024. https://www.zfk.de/energie/strom/vw-will-industrielle-grossspeicher-bauen.
Lewicki, Pawel. 2023. „Netzausbau". Text. Umweltbundesamt. Umweltbundesamt. 2. August 2023. https://www.umweltbundesamt.de/themen/klima-energie/energieversorgung/netzausbau.
„Lhyfe". 2024. *Lhyfe* (blog). 1. Februar 2024. https://de.lhyfe.com/presse/lhyfe-baut-im-niedersachsischen-hafen-brake-die-erste-kommerzielle-grune-wasserstoffanlage-norddeutschlands/.
Maksimenko, Artjom. 2019. „50 Hertz errichtet Neubrandenburger Power-to-Heat-Anlage". www.energate-messenger.de. 29. November 2019. https://www.energate-messenger.de/news/197896/50-hertz-errichtet-neubrandenburger-power-to-heat-anlage.
Mohl, Ariane. 2024. „Storengy Deutschland will einen Wasserstoffspeicher im Raum Stade errichten". 15. Juni 2024. https://www.zfk.de/energie/gas/storengy-deutschland-will-einen-wasserstoffspeicher-im-raum-stade-errichten.
„Netzentwicklungsplan Strom | Netzentwicklungsplan". o. J. Zugegriffen 16. Januar 2025. https://www.netzentwicklungsplan.de/.
„Netztransparenz > Über uns > Aufgaben". o. J. Zugegriffen 9. Januar 2025. https://www.netztransparenz.de/de-de/%C3%9Cber-uns/Aufgaben.
„norddeutsche Wasserstoffstrategie". o. J. Zugegriffen 16. Januar 2025. https://norddeutschewasserstoffstrategie.de/wp-content/uploads/2020/11/norddt-H2-Strategie-final.pdf.
„NordLink". o. J. TenneT. Zugegriffen 16. Januar 2025. https://www.tennet.eu/de/projekte/nordlink.

Port of Hamburg. 2022. „Erstes Importterminal für grünen Ammoniak kommt nach Hamburg“. The official website of the Port of Hamburg. 17. November 2022. https://www.hafen-hamburg.de/de/presse/news/erstes-terminal-fuer-gruenen-ammoniak-kommt-nach-hamburg/.
„———“. 2024. 13. Juni 2024. https://www.hafen-hamburg.de/de/presse/news/umruestung-des-kraftwerks-moorburg-zum-elektrolyseur-schreitet-voran/.
„Power plants: Geesthacht - Vattenfall“. o. J. Zugegriffen 16. Januar 2025. https://powerplants.vattenfall.com/de/geesthacht/.
„Power-to-Heat: aus Strom wird Wärme“. 2022. Solarenergie: Informationen zu Photovoltaik und mehr. 10. Mai 2022. https://solarenergie.de/hintergrundwissen/solarenergie-nutzen/sektorenkopplung/power-to-heat.
„Projektseite Bollingstedt | ECO STOR“. o. J. Zugegriffen 9. Januar 2025. https://www.eco-stor.de/de/investment/Projekt%20Bollingstedt.
„Projektseite Schuby | ECO STOR“. o. J. Zugegriffen 9. Januar 2025. https://www.eco-stor.de/de/unsere%20speicher/Projekt%20Schuby.
„QuartalszahlenQ4_2023.pdf“. o. J. Zugegriffen 16. Januar 2025. https://www.bundesnetzagentur.de/SharedDocs/Downloads/DE/Sachgebiete/Energie/Unternehmen_Institutionen/Versorgungssicherheit/Engpassmanagement/QuartalszahlenQ4_2023.pdf?__blob=publicationFile&v=2.
„Rahmenbedingungen Stromspeicher Deutschland“. o. J. Zugegriffen 16. Januar 2025. https://cms.law/de/media/local/cms-hs/files/publications/publications/cms_rahmenbedingungen-fuer-stromspeicher-in-deutschland.
RWE. 2021. „RWE“. 23. Juli 2021. https://www.rwe.com/forschung-und-entwicklung/wasserstoff-projekte/aquaventus/.
———. 2024. „Investitionsentscheidung getroffen: RWE baut Offshore-Windparks mit 1,6 Gigawatt in der deutschen Nordsee“. 27. Mai 2024. https://www.rwe.com/presse/rwe-offshore-wind-gmbh/2024-05-27-investitionsentscheidung-rwe-baut-offshore-windparks-mit-1600-mw/.
———. o. J. „Import von grüner Energie: RWE errichtet Ammoniak-Terminal in Brunsbüttel“. Zugegriffen 16. Januar 2025. https://www.rwe.com/presse/rwe-ag/2022-03-18-import-von-gruener-energie-rwe-errichtet-ammoniak-terminal-in-brunsbuettel/.
Schmitt, Alex. 2023. „Revenue Potential for Battery Storage Systems on the Power Market - Current Developments“. *Energy BrainBlog* (blog). 2. November 2023. https://blog.energybrainpool.com/en/revenue-potential-for-battery-storage-systems-on-the-power-market-current-developments/.
„SMARD | Der Strommarkt im Jahr 2024“. 2025. 2. Januar 2025. https://www.smard.de/page/home/topic-article/444/215556.
Stadtwerke Rostock. o. J. „Power-to-Heat Anlage | Stadtwerke Rostock“. Zugegriffen 16. Januar 2025. https://www.swrag.de/wir-fuer-hier/fuer-die-region/power-to-heat.
„SuedLink“. o. J. TenneT. Zugegriffen 16. Januar 2025. https://www.tennet.eu/de/projekte/suedlink.
„Übertragungsnetzbetreiber (ÜNB)“. o. J. Zugegriffen 16. Januar 2025. https://www.next-kraftwerke.de/wissen/uebertragungsnetzbetreiber.
vc_superadmin. 2023. „APEX Group“. *doing hydrogen | DE* (blog). 7. Februar 2023. https://www.doinghydrogen.com/gruener-wasserstoff-made-in-mv-apex-group-errichtet-100-mw-elektrolyseanlage-in-rostock-laage/.
Waffenschmidt, Eberhard, Silvan Rummeny, Frank Günther, Felix Klenner, und Paul Robert Stankat. o. J. „Inselnetzbetrieb der Gemeinde Bordesholm mit einer Großbatterie“.
„Was sind negative Strompreise und wie entstehen sie?“ o. J. Zugegriffen 15. Januar 2025. https://www.next-kraftwerke.de/wissen/negative-strompreise.
Wilke, Sibylle. 2024. „Endenergieverbrauch nach Energieträgern und Sektoren“. Text. Umweltbundesamt. Umweltbundesamt. 2. April 2024. https://www.umweltbundesamt.de/daten/energie/energieverbrauch-nach-energietraegern-sektoren.
„Zweites WEMAG-Batteriespeicherkraftwerk geht in Schwerin ans Netz | www.wemag.com“. 2017. 14. Juli 2017. https://www.wemag.com/aktuelles-presse/zweites-wemag-batteriespeicher-kraftwerk-geht-schwerin-ans-netz.

20.09.2024

Carbon driven energy equilibrium at the municipal scale – Energy Equilibrium

Framework conditions for energy infrastructure in Latvia

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1 Assessment of Latvia's electricity generation capacity and consumption

1.1 Development to date

Latvia's energy system is made up of various forms of energy production, distribution, and consumption, with a major focus on hydropower and other renewable resources. Latvia produces a large amount of its electricity from renewable energy sources. The three main hydropower facilities on the Daugava River—Plavinas, Kegums, and Riga—account for a substantial amount of the nation's electricity production. The country is renowned for its considerable hydropower capacity. With plans to increase the share of wind and solar energy in the future, Latvia also uses biomass, wind, and solar energy to a lesser extent. Natural gas, which is mostly imported from nearby nations, helps bridge energy shortages, especially when hydropower output is low.

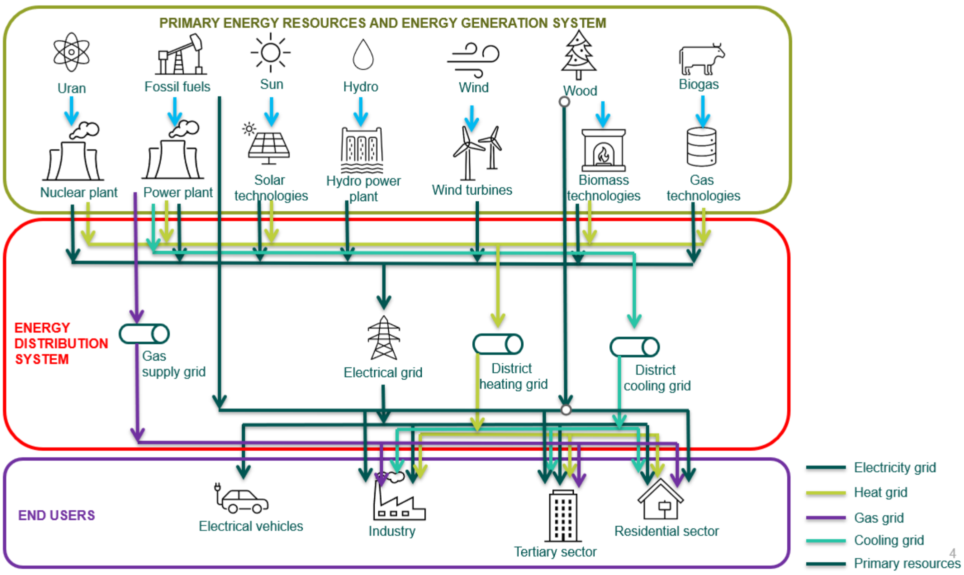


Fig.1. Energy system concept

Latvia has connections to both the wider European energy network and its Baltic neighbours, Estonia and Lithuania, making it possible to import and export electricity. Even though Latvia produces a sizable portion of its electricity domestically from renewable sources, particularly during the winter, it imports electricity to meet demand when local production is insufficient.

In Latvia, district heating systems are the main source of energy for the heating industry, particularly in urban areas where biomass plays a big part. To cut carbon emissions, a large number of district heating systems have shifted from using fossil fuels to biomass. Nonetheless, individual rural homes continue to heat with wood, coal, or imported natural gas.

With the intention of boosting the proportion of renewable energy in its overall energy mix and enhancing energy efficiency, Latvia is dedicated to the energy and climate goals set forth by the European Union. The nation's Nation-al Energy and Climate Plan (NECP), which focusses on grid modernisation, energy storage, and wind and solar development, lays out plans to meet higher renewable energy targets by 2030.

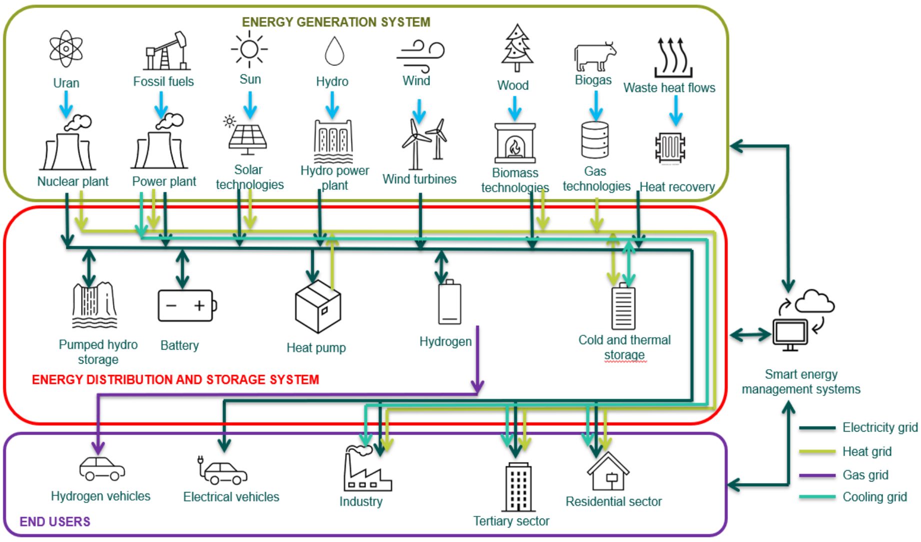


Fig. 2. Smart Energy System

Overall, efforts to strike a balance between energy security, affordability, and sustainability are continuing to move Latvia's energy system towards a more sustainable and renewable-based model.

The electricity generation capacities in Latvia from renewable energy sources are shown in Figure 3. The largest contribution to total electricity generation comes from the three existing Daugava hydroelectric power station cascades, which provide Latvia's base electricity capacity. Until 2021, the wind power generation capacity was only 70 MW, but in 2022 it increased to 136 MW, as a new wind farm was opened. A sharp increase in solar energy capacity was observed in 2022. As the geopolitical situation in Europe worsened, more and more residents began to think about individual energy independence. In addition, the state offered support for the installation of solar panels in households. As a result, Figure 3 shows that the total installed capacity of solar panels increased several times over.

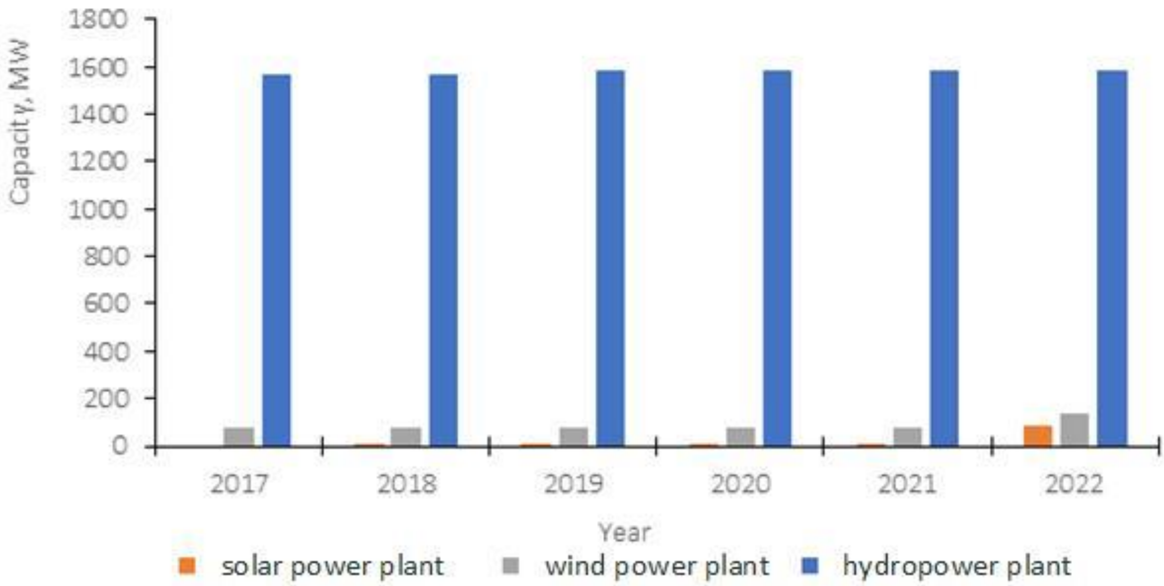


Fig.3. Latvia's renewable energy generation capacities from 2017 to 2022.

The amount of electricity generated from renewable energy sources is highly dependent on the season and weather conditions. Currently, the largest contribution to electricity generation comes from hydroelectric power plants (HPPs). As is known, the operation and output of HPPs depend on the severity of winter and the water inflow from the Daugava River. If there is no water, there is nothing to generate from, which means that in dry summers, the amount of electricity produced in Latvia is several times lower, while during the spring flood period, locally produced electricity fully meets the demand. Potentially, Latvia's electricity output from renewable energy sources could be increased by installing additional generation capacities for wind and solar power, which, as seen in Figure 4., are currently very small.

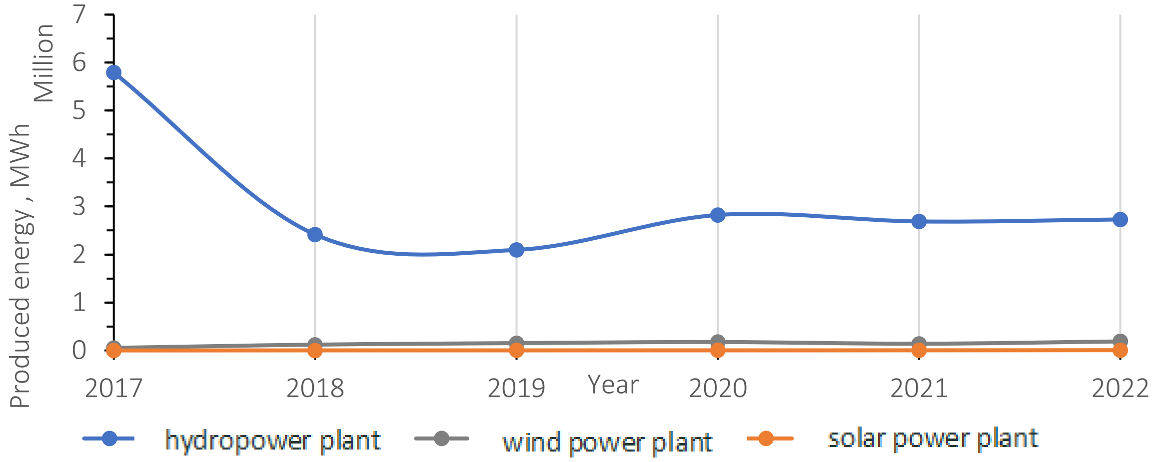


Fig.4. Electricity generated (MWh) by types of renewable energy sources (2017–2022).

Until now, Latvia has relied on electricity generated by hydroelectric power plants (HPPs), and the country's overall policy also included the development of thermal power plants (TPPs), as natural gas was a relatively cheap resource. It should be noted that electricity consumption increases every year, driven by the growing electrification of the world, which necessitates consideration of additional power capacity. In this regard, considering the climate neutrality goals, additional generation capacity can be obtained from renewable energy sources (RES).

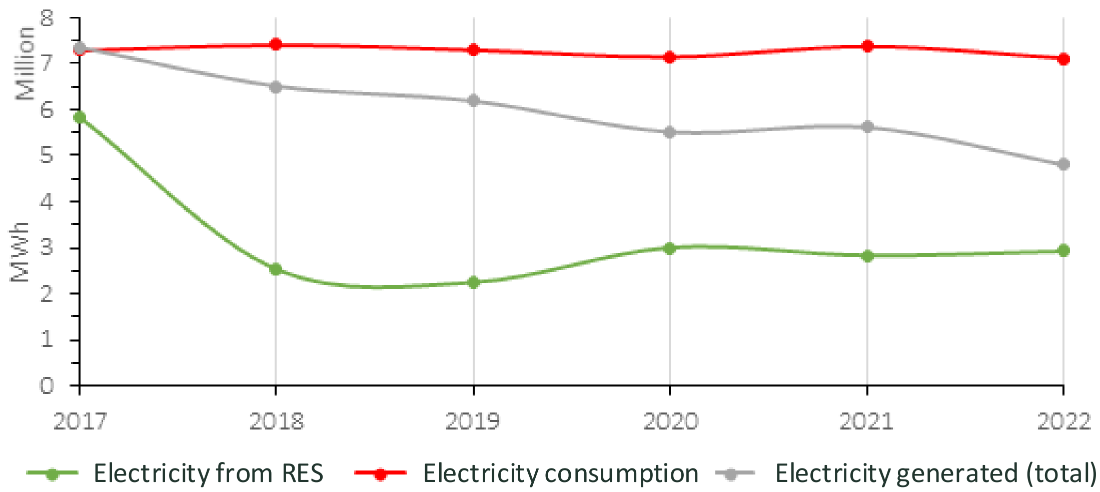


Fig.5. Total electricity generated in Latvia, from renewable energy sources, and total electricity consumption (2017–2022), MWh.

Figure 5. shows Latvia's total electricity consumption (MWh), total electricity produced, and electricity generated from RES (water, solar, wind). The year 2017 was rich in precipitation, which allowed more electricity to be produced from water resources at the Daugava HPPs, as the Daugava's water inflow was sufficient. A portion of the energy was produced by TPPs, even creating electricity surpluses—a positive balance. After 2017, the amount of electricity generated decreased, leading to a need for more imports. The graph in Figure 5 shows that approximately half of the electricity Latvia needs can be provided by RES, with additional volumes generated by TPPs, and the remaining difference imported.

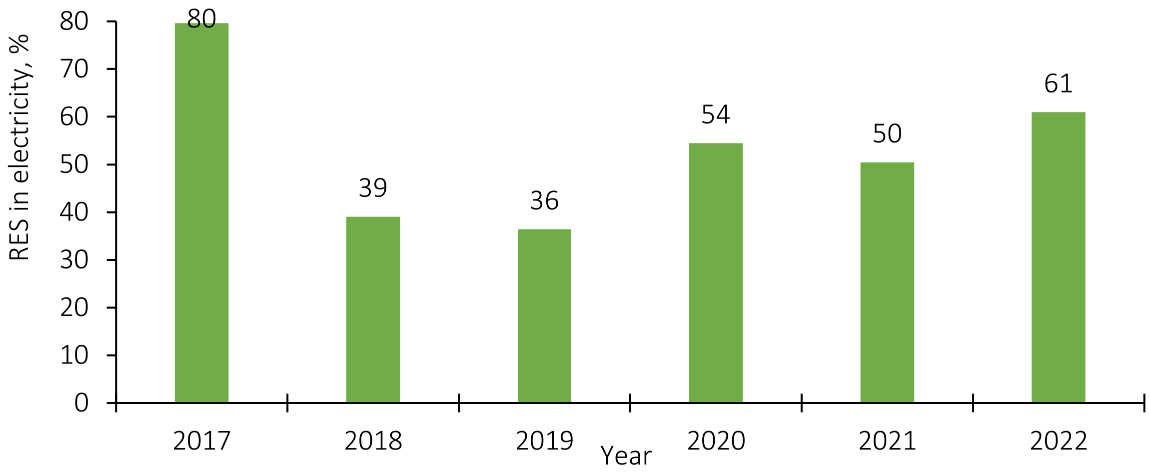


Fig.6. Share of renewable energy sources (RES) (%) in total electricity generation, 2017–2022

On average, depending on the season, which greatly affects electricity generation from renewable energy sources (RES), approximately 40 to 50 % of the total required electricity in Latvia is generated from RES (see Figure 6.).

2 Energy Infrastructure

2.1 Organisation of Electricity Grid (Transmission Network)

Latvia's electricity transmission network is overseen by Augstsprieguma tīkls (AST), which serves as the national electricity transmission system operator (TSO). AST is tasked with managing the high-voltage transmission grid to ensure a stable and secure electricity supply throughout the country. It also manages interconnections with neighbouring countries like Estonia, Lithuania and plays a role in the Baltic grid system.[1], [2]

The main characteristics of the transmission network are the number of step-down substations and high-voltage distribution points in each area, which in turn is determined by the specific electricity demand in that area. The network also includes appropriate transmission lines (330 kV and 110 kV), meeting both reliability and cost-efficiency criteria for electricity supply. Based on these criteria, the transmission network is considered near optimal with potential for further development. Currently, the electricity transmission network consists of 1,346.43 km of 330 kV lines and 3,893.54 km of 110 kV lines, along with 25 transformers at 330 kV and 248 transformers at 110 kV, with a total installed capacity of 9,020.5 MVA. For more efficient operation, the maintenance units are organized geographically: [20]

- 3 substation groups for the operation of 330/110 kV substations and distribution points: Salaspils, Krustpils, Daugavpils, Viskaļi (Jelgava), Brocēni, Grobiņa, Valmiera, Gulbene, Rēzekne, Sloka, Ventspils, and in Riga – Right Coast and Left Coast, with one base substation in each group.
- 6 line districts for the operation of 330/110 kV transmission lines: Riga district, Krustpils district, Daugavpils district, Brocēni district, Grobiņa district, and Valmiera district.

Fig.6. Diagram of Latvia's 330 kV and 110 kV Electrical Networks.

The 330 kV network in Latvia's energy system serves as the central link between the northern and southern parts of the Baltic states' energy systems. All 330 kV substations, except "Daugavpils," have dual power supply. The 110 kV network follows a loop configuration. Most 110 kV substations are equipped with two transformers and have dual feeding.

To ensure the safe operation of Latvia's power system, the efficient functioning of the electricity market, and to address equipment aging, Latvia's Transmission System Operator (TSO) is reconstructing and modernizing high-voltage substations and electricity distribution points. In line with the energy system development trends in Latvia and neighboring countries, the TSO evaluates and makes decisions regarding the development of Latvia's transmission system interconnections and the need for internal network strengthening and modernization. The electricity transmission network is being developed according to Latvia's Transmission System Development Plan and the European Ten-Year Network Development Plan.

Between 2020 and 2029, the following projects will be implemented to develop the Latvian and Baltic electricity networks [20]:

- Third electricity interconnection between Latvia and Estonia;
- Transmission line connection "Riga TEC-2 – Riga HPP";
- Reconstruction of the existing 330 kV interconnections between Estonia and Latvia;
- Synchronization of the Baltic states with the European electricity grids and desynchronization from the Russian unified energy system.

2.2 Distribution System Operators (DSOs) in the Electricity Grid

In Latvia, the electricity grid is primarily managed by Sadales tīkls, the largest distribution system operator that serves 99% of the country's territory [2]. This company is in charge of the medium- and low-voltage electricity grids, ensuring that electricity is delivered from the high-voltage transmission grid to residential, commercial, and industrial consumers [3].

The transmission system operator Augstsprieguma tīkls is responsible for the development of the transmission network, the reliability of electricity transmission, the stability of the power system and the quality of electricity and ensures it in accordance with technical and economic requirements and modern technologies.

Adequate electricity transmission interconnections are one of the most important preconditions for the optimal functioning of the electricity market. The Latvian electricity market, like the Baltic energy market as a whole, is currently connected to the common European energy market by two sea cables connecting the Estonian and Finnish energy systems, Estlink I with a transmission capacity of 350 MW and Estlink II with a transmission capacity of 650 MW, the Lithuanian-Polish interconnector LitPol Link 1 with a transmission capacity of 500 MW and the Lithuanian-Swedish interconnector "NordBalt" with a transmission capacity of 700 MW. [21]

2.3 Stakeholders Active in Energy Storage (Electricity)

Both public and private energy companies, such as AST and Latvenergo, participate in the sector. Independent renewable energy producers are considering different ways to add energy storage to solar and wind generation.

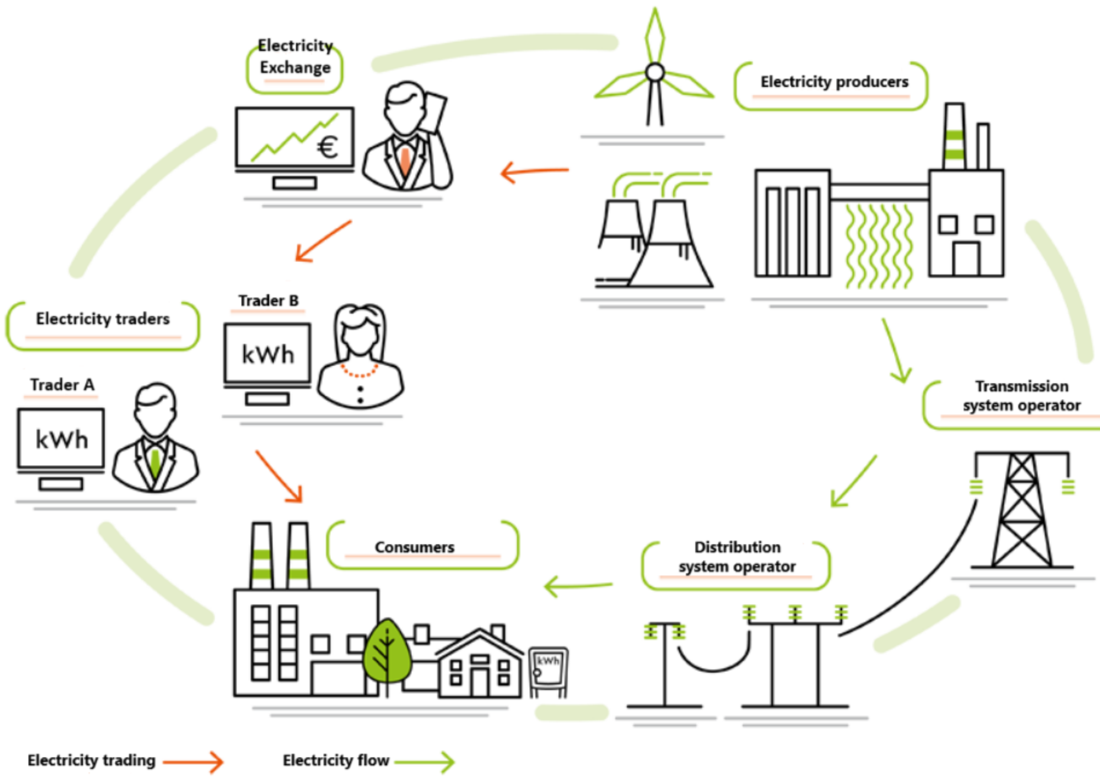


Fig.7. Interaction between electricity producers, traders and consumers

There are several companies in Latvia which sell electricity to market participants. In 2021, five largest electricity traders in the whole retail market by volume were JSC "Latvenergo", JSC "Enefit", JSC "Ignitis Latvija", JSC "Tet" and JSC "AJ Power".

The Latvian transmission system operator, JSC "Augstsprieguma tīkls," has signed agreements with 12 wind and solar power developers to connect renewable energy projects with a total capacity of over 1,100 megawatts (MW) to the transmission network. This exceeds the current installed solar and wind power capacity in Latvia by more than 150%. By the end of the year, it is expected that connection agreements with eight more renewable energy developers, with a combined capacity of 796 MW, will be finalized.

"Currently, the majority of electricity in Latvia is generated by hydroelectric power plants, but there is significant potential for wind and solar energy. The reserved capacity in the transmission network for renewable energy (RES) projects is 6 gigawatts (GW), and more connection agreements are being signed as power stations are being built. We anticipate that by the end of 2025, several solar power plants with a total installed capacity of over 500 MW will be connected." [22]

From the stations that have already signed transmission network connection agreements, 721 MW will be generated by solar power plants, 320 MW by wind power plants, and 60 MW by a hybrid project combining a solar power plant and an energy storage battery system. The largest planned solar power plant, with a capacity of 199.8 MW, will be built in the South Kurzeme region near Cīrava, while the largest planned wind power plant, with a capacity of 158.8 MW, will be located near Lejasstrazdi in the Dobele region.

Overall, eight power stations are expected to be connected to the transmission network next year, with the remaining four scheduled for 2026. By the end of 2025, the newly connected solar and wind power stations will have a capacity of 540 MW, with an additional 560 MW expected by 2026. In August, solar power plants generated 66 GWh, or 21% of the total electricity fed into the grid, marking the highest amount of solar energy production in Latvia's history, according to a market review prepared by AST.

Latvian transmission system operator Augstsprieguma tīkls (AST) and German company Rolls-Royce Solutions GmbH (Rolls-Royce) have started cooperation on the construction of Battery Energy Storage Systems (BESS), which are essential for the reliability of the Latvian power system. Rolls-Royce will install the battery system at the AST substations in Rezekne and Tume with a total capacity of 80 MW and a storage capacity of 160 MWh, currently one of the most powerful and largest battery systems in the European Union.[23]

2.4 Role of Local Authorities for Energy Storage (Connection to Electricity)

Local authorities in Latvia are increasingly involved in energy storage, especially in promoting decentralized renewable energy production and integrating storage solutions. Municipalities take charge of the planning and permitting processes for renewable energy and storage initiatives. They collaborate with private companies to set up small-scale energy storage systems within communities, which boosts local energy resilience and efficiency.

Local authorities play an important role in promoting regional development, which is why it is important to raise awareness of energy efficiency and climate change among local authority staff [5].

The strategic documents of the Latvian Association of Local Governments do not set a common target for the construction of electricity storage facilities, but the municipalities are interested in greater energy independence and economic development.

Heat storage

Article 2 of Energy Law provides that local governments, within the framework of their administrative spatial plan, may determine the development of heat supply and issue binding regulations, taking into account the regulations on the protection of the environment and cultural monuments, as well as the possibilities of utilization and cogeneration of local energy resources, and assess the security and long-term marginal costs of heat supply, which means that the application of the concept of heat energy storage highly depends on the local government of the respective area, but there is no precise regulation on heat energy storage. [6]

Regarding land use the regulations on municipal territorial development planning documents stipulate that each municipality develops its own Sustainable Development Strategy and indicates the expected land volumes for the creation and improvement of infrastructure [7].

2.5 Role of Hydrogen and Power-to-X in Today's Energy (Electricity) System

Hydrogen and Power-to-X technologies are still in the early stages within Latvia's energy system, yet they are seen as crucial components for future energy transition strategies. Additionally, Power-to-X, which involves converting electricity into other energy forms like hydrogen or methane, is being investigated to stabilize the grid and improve energy storage capabilities, particularly as the share of renewable energy continues to grow.

Hydrogen

To contribute to achieving climate and energy goals, Latvia is also exploring the potential of hydrogen. In addition to transport, Latvia is also exploring the potential of hydrogen in other sectors, such as electricity generation. As Latvia uses biomass extensively for heat and power generation, biomass-derived hydrogen is another potential way to harness this technology. However, hydrogen can be expensive to produce, store and distribute, especially if it is produced from renewable sources.[8] And still hydrogen is not mentioned in the Energy Law [9].

Concerning the possible utilization of hydrogen technology in Latvia, there have been public statements indicating that Jelgava is considering the production and storage of hydrogen. In May 2023, the Jelgava City Council and "Fortum" entered into a memorandum of intent, initiating collaborative research efforts to assess the technical aspects and economic viability of extracting and utilizing hydrogen. The objective is to enhance the transportation systems of Jelgava municipality companies in the future by incorporating green hydrogen electric buses and hydrogen electric waste removal vehicles, thereby achieving zero-emission operations. [10]

A study was launched in 2022 in collaboration with the Latvian Hydrogen Association to refine hydrogen project concepts and assess key indicators for its utilization in Latvia. The estimate suggests that by 2030, approximately two terawatt hours (TWh) of hydrogen will be consumed, with the figure rising to almost 37 TWh by 2050.[11]

JSC "Latvenergo" is actively working on implementing a pilot project focused on hydrogen and anticipates a growing interest among businesses and collaborative partners in Latvia to procure renewable hydrogen derived from sustainable resources. JSC "Latvenergo's" hydrogen initiative envisions the production of environmentally friendly hydrogen using a polymer electrolyte membrane electrolysis system, with electricity sourced from variable generation, the Daugava hydroelectric power plant, TEC-2 solar panels, or the planned JSC "Latvenergo" wind power plant.[11]

H2Value project is being implemented within the framework of the European Regional Development Fund's Interregional Innovation Investment Instrument (I3) program for the period 2021-2027, under grant agreement No. 101083881. It is a new financial instrument designed to support innovative investments, promote the economy through green technologies, and foster sustainability in the industry and transport sectors.[12]

The establishment of the Latvian Hydrogen Association in 2005 marked a commitment to advancing the adoption of the Hydrogen Economy within Latvia's economic landscape. The association's primary aim was to harness local natural energy resources and utilize hydrogen as a versatile energy carrier. By doing so, it sought to enable the smooth functioning of the energy, transportation, and industrial sectors in the country while minimizing environmental impact. Additionally, the association sought to promote the adoption of eco-friendly energy consumption and production methods. [13]

In the summer of 2023, the association "Green and Smart Technology Cluster" together with 43 partners from Finland, Estonia, Lithuania, Latvia, Poland, Germany, Denmark, Sweden, France, and Norway will initiate the implementation of a five-year project called "BalticSeaH2" or "Baltic Sea Cross-Border Hydrogen Valley." The project aims to create the first and largest transnational hydrogen ecosystem in the region, transforming the energy circulation economy and promoting a faster transition to renewable energy production, storage, and utilization in Europe. The project is co-funded by the European Union's "Horizon Europe" program. The "Green and Smart Technology Cluster" and The Freeport of Riga represent Latvia in the project. [14]

There is an association called "H2 energokopiena" in Latvia. The main objective of the association is to establish unique public and private sector partnerships in the form of an energy community. The community is engaged in the production and storage of energy from renewable sources (electricity, heat energy, hydrogen, and other types of energy), as well as in trading, sharing, consumption, and accumulation of energy. Additionally, the association provides services such as charging/refueling of zero-emission vehicles, energy efficiency services, or other energy-related services.[15]

2.6 Business Models for Energy (Electricity) Storage

Latvia has recently been actively exploring and developing business models for energy storage, in particular electricity storage, in line with its renewable energy targets and the European energy transition goals. While a number of business models have been established in Latvia, the market is still evolving, and the regulatory framework and investment incentives are still being developed.

2.7 Organisation of Other Storage

There is a growing interest in developing biomethane storage solutions to ensure a reliable supply during peak demand periods. Latvia also has a comprehensive district heating system, especially in urban areas, where thermal storage is crucial for managing heating needs [16].

Biomethane

Over the next three years, Latvia plans to sell biomethane produced locally, and Latvijas Gāze plans to inject it into the national gas network [17].

The European Energy Efficiency Fund (EEEF) is working with Latvian energy company Virsi-A to finance and develop a biomethane plant in Latvia, which is scheduled to start operations at the end of 2025. The plant will use anaerobic digestion to convert agricultural manure into biomethane, which will then be fed into the Latvian national gas grid. The plant aims to produce 60 GWh of biomethane per year, effectively replacing up to 5.6 million cubic metres of natural gas. [18]

On 2 July 2024, the Latvian Cabinet of Ministers approved the REPowerEU Recovery Fund Support Programme, allocating EUR 134.4 million for energy investments to improve Latvia's energy security and stability. An ambitious part of the programme includes the construction of Latvia's first regional biomethane injection point in Džūkste, with a budget of €1.5 million. To support biomethane production, Conexus Baltic Grid has developed a smart system that allows producers located far from the gas transmission grid to compress biomethane, transport it in mobile containers and inject it into the central grid. [19]

3 References

[1] "BRIEFLY ABOUT THE GROUP - Latvenergo." Accessed: Sep. 12, 2024. [Online]. Available: https://latvenergo.lv/en/par-mums/isuma-par-koncernu

[2] "Electricity | SPRK." Accessed: Sep. 12, 2024. [Online]. Available: https://www.sprk.gov.lv/en/content/electricity

[3] "Par mums." Accessed: Sep. 12, 2024. [Online]. Available: https://sadalestikls.lv/lv/kas-mes-esam

[4] P. Kurzweil and O. K. Dietlmeier, "Elektrochemische Speicher," Elektrochemische Speicher, 2015, doi: 10.1007/978-3-658-10900-4.

[5] "Is the key role of local authorities acknowledged?"

[6] "Enerģētikas likums." Accessed: Sep. 18, 2024. [Online]. Available: https://likumi.lv/ta/id/49833-energetikas-likums

[7] "Noteikumi par pašvaldību teritorijas attīstības plānošanas dokumentiem." Accessed: Sep. 18, 2024. [Online]. Available: https://likumi.lv/ta/id/269842-noteikumi-par-pasvaldibu-teritorijas-attistibas-planosanas-dokumentiem

[8] L. Zemite et al., "A COMPREHENSIVE OVERVIEW OF THE EUROPEN AND BALTIC LANDSCAPE FOR HYDROGEN APPLICATIONS AND INNOVATIONS," Latvian Journal of Physics and Technical Sciences, vol. 60, no. 3, pp. 33–53, Jun. 2023, doi: 10.2478/lpts-2023-0016.

[9] "Enerģētikas likums." Accessed: Sep. 18, 2024. [Online]. Available: https://likumi.lv/ta/id/49833-energetikas-likums

[10] "Elektrība bez kaitīgām emisijām. Jelgavā domā par ūdeņraža ražošanu un uzkrāšanu | LA.LV." Accessed: Sep. 18, 2024. [Online]. Available: https://www.la.lv/zalais-kurss-uz-energijas-uzkrasanu

[11] "Arī Latvijā ir iespējas ražot ūdeņradi no atjaunojamajiem resursiem." Accessed: Sep. 18, 2024. [Online]. Available: https://www.retv.lv/raksts/ari-latvija-ir-iespejas-razot-udenradi-no-atjaunojamajiem-resursiem

[12] "Latvijā un Igaunijā pārbaudīs zaļā ūdeņraža potenciālu." Accessed: Sep. 18, 2024. [Online]. Available: https://uzladets.lv/vidzeme-parbaudis-udenraza-potencialu/

[13] "Latvian Hydrogen Association – Hydrogen technologies and research." Accessed: Sep. 18, 2024. [Online]. Available: https://h2lv.eu/lv/

[14] "Zaļo un viedo tehnoloģiju klasteris kopā ar vēl 43 partneriem īstenos projektu 'BalticSeaH2' | Green-Tech Latvia." Accessed: Sep. 18, 2024. [Online]. Available: https://greentechlatvia.eu/lv/2023/02/istenos-projektu-balticseah2/?cn-reloaded=1

[15] L. IT, "H2 energokopiena, 40008319136 - par uzņēmumu," Lursoft IT, 2024.

[16] K. Lebedeva, L. Migla, and T. Odineca, "Solar district heating system in Latvia: A case study,"

J King Saud Univ Sci, vol. 35, no. 10, Dec. 2023, doi: 10.1016/j.jksus.2023.102965.

[17] "Energy of the future – biomethane | Latvijas Gāze." Accessed: Sep. 18, 2024. [Online]. Available: https://lg.lv/en/news/energy-of-the-future-biomethane

[18] "European Energy Efficiency Fund teams with a Latvian energy company and developers to finance a biomethane production plant in Latvia - European Energy Efficiency Fund eeef." Accessed: Sep. 18, 2024. [Online]. Available: https://www.eeef.lu/news-detail/european-energy-efficiency-fund-teams-with-a-latvian-energy-company-and-developers-to-finance-a-biomethane-production-plant-in-latvia.html

[19] "Latvia to invest EUR 134.4 million in energy security and biomethane production | Ministru kabinets." Accessed: Sep. 18, 2024. [Online]. Available: https://www.mk.gov.lv/en/article/latvia-invest-eur-1344-million-energy-security-and-biomethane-production?utm_source=https%3A%2F%2Fwww.google.com%2F

[20] "LATVIJAS NACIONĀLAIS ENERĢĒTIKAS UN KLIMATA PLĀNS 2021. – 2030. GADAM" Accessed: Sep 21, 2024 [Online] NEKP empl_220120_nekp20301_0.docx (live.com)

[21] "Elektroenerģijas pārvade un sadale | Ekonomikas ministrija (em.gov.lv)" Accessed: Sep 21, 2024 [Online] https://www.em.gov.lv/lv/elektroenergijas-parvade-un-sadale

[22] "12 lieljaudas atjaunīgo elektrostaciju būvniecība" Accessed: Sep 21, 2024 [Online] Šogad plānots uzsākt 12 lieljaudas atjaunīgo elektrostaciju būvniecību :: Dienas Bizness (db.lv)

[23] "Energosistēmas drošumam Latvijā tiksuzstādītas Eiropā jaudīgākās elektroenerģijuuzkrājošas bateriju sistēmas" Accessed: Sep 21, 2024 [Online] https://www.ast.lv/lv/events/energosistemas-drosumam-latvija-tiks-uzstaditas-eiropa-jaudigakas-elektroenergiju-uzkrajosas

1 Expansion path of renewable energies

1.1 Development to date

Lithuania has set ambitious targets under the National Energy Independence Strategy to contribute to the Energy Union and the EU's 2030 energy and climate policy goals, with a target of 45% of final energy consumption to be from renewable energy sources.

The largest share of renewable energy comes from solid biofuels, such as firewood and wood and agricultural residues for fuel. In 2022, biofuels accounted for 51.8% of electricity and district heating consumption, and 34.1% of household consumption. Energy producers produced 67.2% of all heat produced in power plants and boiler houses and 17.1% of all electricity produced in power plants from biofuels.

In 2022, Lithuania's existing wind farms, together with small wind farms, generated 1.5 TWh of electricity, representing just over a third of the country's total electricity generation, or 11.3% of electricity consumption.

Renewable solar power plants generated 342.2 million kilowatt hours (kWh) of electricity in 2022, or 79.4% more than in 2021.

Hydropower plants generated 464.4 million kWh of electricity in 2022, 21% more than in 2021.

In 2022, electricity generation from biogas increased by 1.3% compared to 2021, reaching 158.7 million kWh.

The use of biofuels reduces environmental pollution. Two types of biofuels are used in Lithuania: biodiesel and bioethanol. In 2022, 113,200 tonnes of biodiesel and 30,500 tonnes of bioethanol were used in the transport sector.

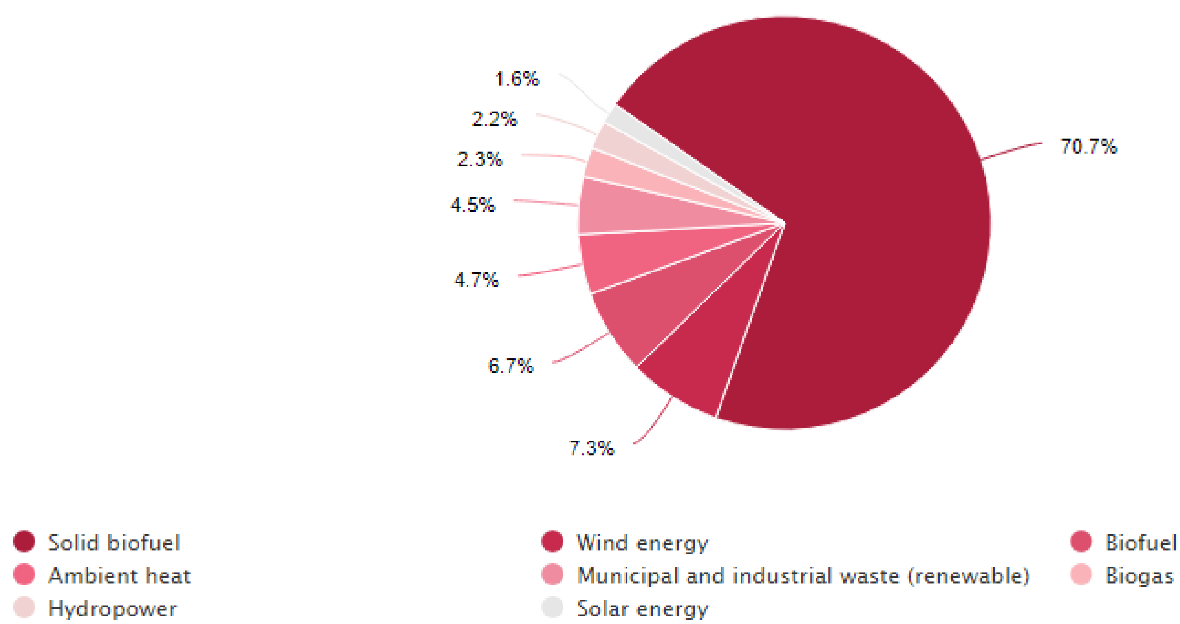


Figure 1: RES consumption structure in 2020, in percent (Source: Atsinaujinantys energijos ištekliai - Oficialiosios statistikos portalas)

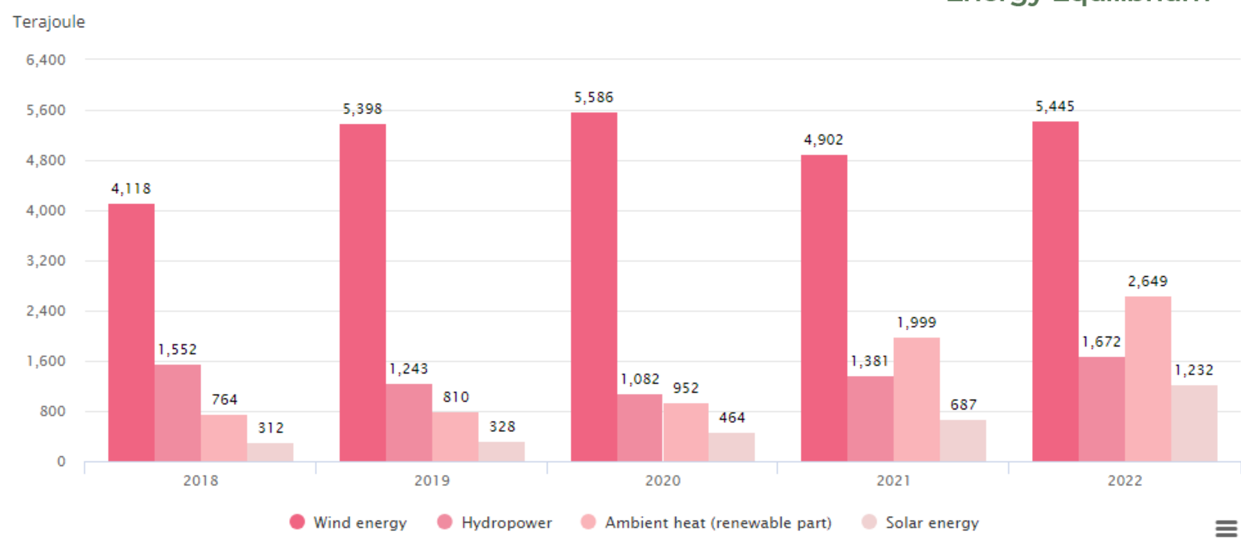


Figure 2: ***Gross consumption by type of renewable energy, 2018–2022, in Terajoule*** *(Source: Atsinaujinantys energijos ištekliai - Oficialiosios statistikos portalas)*

The share of renewable energy sources in consumption during 2018-2022 is presented in Table 1

Table 1: The share of RES in consumption 2018-2022, ***in percent*** *(Source: Atsinaujinantys energijos ištekliai - Oficialiosios statistikos portalas)*

	2018	2019	2020	2021	2022
In final gross energy consumption	25.5	25.5	27.4	28.1	29.6
In final energy consumption for heating and cooling	46.0	47.4	50.2	48.6	51.8
In gross consumption of electricity	18.4	18.8	20.2	20.9	25.5
In final energy consumption in the transport sector	4.3	4.0	5.5	6.7	6.3

Further development: In the first half of the year 2024. solar and wind power plants generated almost 70% more electricity than in the same period in 2023 and twice as much as in 2022. Preliminary data show that these plants will generate 2.31 GWh of electricity in 2024. This compares with 1.36 GWh in 2023 and 1.00 in 2022.

Also in the year 2024. the renewable energy sources' allowed generation capacity on the grid increased by one fifth to 2 885 MW on 1 July. and the national electricity generation doubled to fully cover the country's population's electricity needs in half a year. This was recorded on Sat. On 11 March and 3 May.

According to Litgrid's (Lithuania's electricity transmission system operator) preliminary data. in the first half of the year 2024, the national electricity generation amounted to 3 783.4 GWh, of which RES accounted for 2 990.1 GWh. The generation was dominated by wind power plants with 1.703.1 GWh, thermal power plants with 793.3 GWh, solar power plants with 627.4 GWh, hydropower plants with 539.0 GWh, biomass plants with 64.8 GWh, biogas plants with 48.8 GWh, and battery technology with 7 GWh.

According to EPSO-G. the grid's renewable energy capacity increased by 549 MW in the first half of the year 2024 from 2.336 MW to 2.885 MW. In the first quarter of the year 2024, two solar farms were connected to the grid for the first time, with a total capacity of 145 MW. (Source: Ministry of Energy of LR).

Biomethane has been fed into the transmission grid by the newly opened Tube Green biomethane plant in Pasvalys district since 2023, whose facilities have been connected to the gas transmission system following a joint project between Amber Grid and Tube Green. Around 100,000 megawatt hours (MWh) of biomethane is expected to be injected into the transmission system from the plant each year. This will represent up to 1% of Lithuania's total gas demand.

Source: [Lietuvos dujų perdavimo tinkle – pirmosios žaliosios dujos - Lietuvos Respublikos energetikos ministerija (lrv.lt).]

1.2 Expansion plans

Lithuania will generate about 75-80% of electricity demand in 2025. In 2025, green electricity production in Lithuania should reach 8 gigawatts (GW), or 75-80% of the country's consumption.
(Source: Energetikos ministras: 2025 metais Lietuva pasigamins apie 75–80 proc. elektros - LRT)

Following 2023 year's public consultation on the National Energy and Climate Action Plan 2021-2030 (NECAP) and the comments received from the European Commission, the Ministries of Energy and Environment have prepared an updated document and are resubmitting it to the general public and social partners for consultation by 5 August. The NECSAP is an action plan for the implementation of the National Climate Change Management Agenda and the National Energy Independence Strategy, implementing the objectives of the Green Deal.

According to the Environmental Protection Agency, Lithuania is on track to meet its national target of reducing greenhouse gas emissions by 21% by 2030 compared to 2005. 120 measures have already been adopted in the NECSAP for climate, with 43 additional measures foreseen, and 66 and 35 additional measures respectively for energy. Preliminary estimates suggest that a total of over €31 billion of private and public funding will be needed to implement all the measures in the NECSAP by 2030 (Fig. 3).

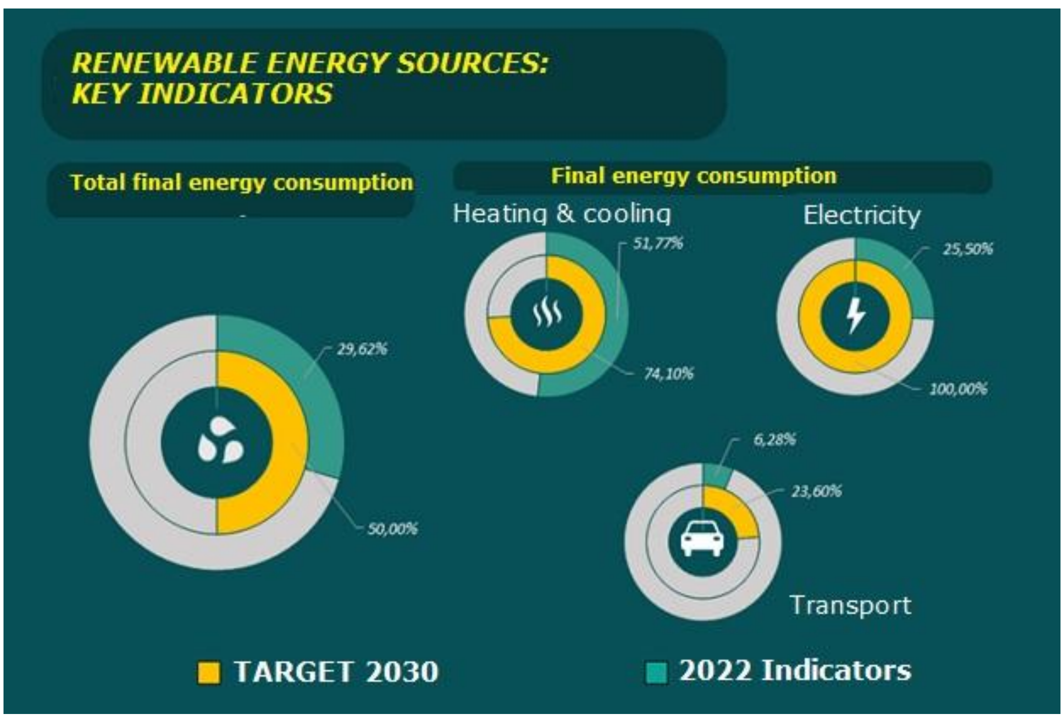


Figure 3: National Energy and Climate Action Plan 2021-2030 (Source: Lithuanian Energy Agency www.ena.lt))

Lithuania aims to reach 50% of GDP by 2030. The target for RES in final energy consumption is 50%. This will be achieved through the widespread deployment of small-scale renewable energy installations owned by private energy consumers and communities. To successfully integrate higher volumes of renewable energy and a large number of electricity generating consumers, investment in smart energy systems, including transmission, distribution and storage infrastructure, and in increasing the amount of balancing capacity needed is foreseen. (Source: Lithuanian energy agency

Source: [Aktuali AEI statistika - Lietuvos energetikos agentūra (ena.lt))]

1.3 Challenges

1.3.1 Volatility and storage requirements

The grid reservation and letters of intent, the grid reservation contracts are in place, huge deposits have been made and the solar power plants and wind farms have to be built within three years. In 2024, electricity generation from solar and wind in Lithuania is expected to reach almost 3.5 GW and more than 12 GW of capacity is currently reserved in the transmission grid for these plants.

To help businesses and citizens make decisions on the construction of renewable energy power plants, the public institution Lithuanian Energy Agency, together with the State Enterprise Registers Centre and other partners - the Ministry of Energy of the Republic of Lithuania, the electricity transmission system operator LITGRID AB, the distribution grid operator Energy Distribution Operator AB and the Military Cartography Centre of the Lithuanian Armed Forces - has developed an interactive Renewable Energy Opportunity Map. The individual data layers are published in the interactive map of the geo-information environment - REGIA - created and developed by the State Enterprise Centre of Registers (Fig. 4).

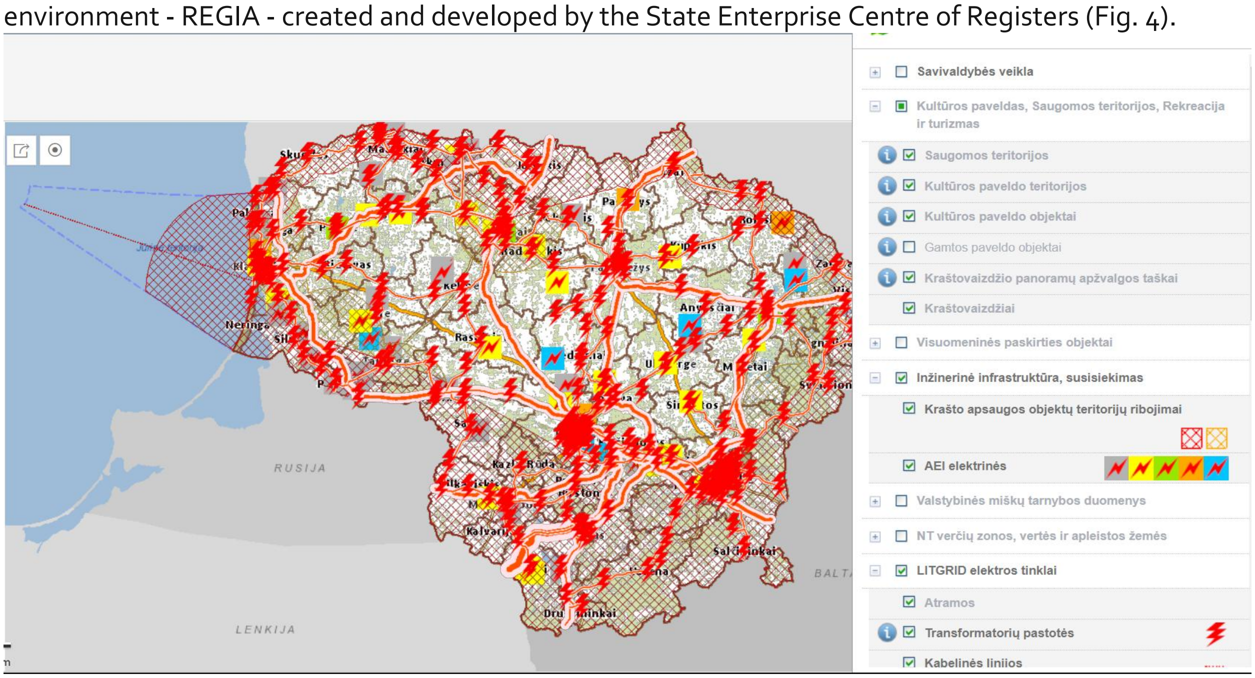


Figure 4: Renewable Energy Opportunity Map (Source: https://www.eso.lt/)

The RES map is for information only. It contains layers with information on protected areas. cultural heritage sites and objects. Lithuania's most valuable landscape areas and panoramic viewpoints where construction of RES plants may be restricted or prohibited. Areas, where the design and construction of wind power plants (tall structures) is prohibited or must be coordinated with the Lithuanian Armed Forces, are also marked. To make the RES map as useful as possible. it provides information on the electricity transmission and distribution network. such as available line capacity and the capacity of transformer substations.

The RES map provides all relevant information on the feasibility of siting a RES power plant in the envisaged location. or to check what opportunities and constraints there may be due to the availability of protected areas. cultural heritage. national security requirements. or access to electricity infrastructure. The information on the AIE map is updated periodically.

For current information on available line capacities and capacities at transformer substations, the following should be used:

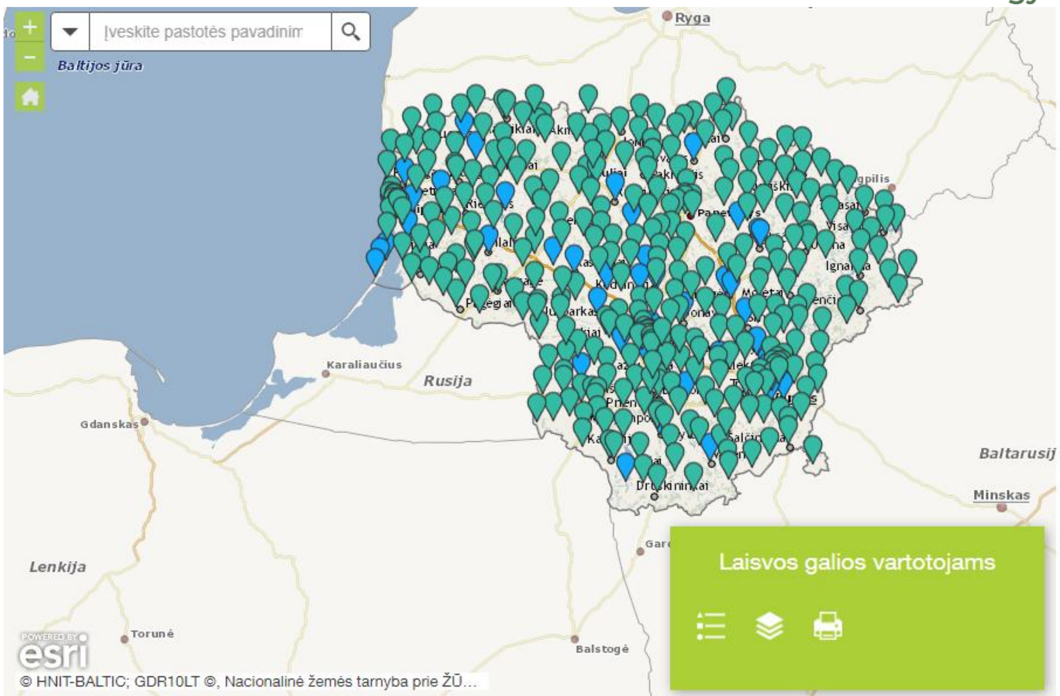
The electricity transmission system operator LITGRID AB provides the map with RES plants connection to 330-110 kW transmission network (Fig. 5);

Tipas	Laisva galia prijungimui prie PT, MW	Išduotų išankstinių prijungimo sąlygų galia, MW	Rezervuota galia pagal KP ir PS, MW	Prijungta (leistina generuoti galia) prie PT, MW
Saulės elektrinės (SE)	6926	2045	4185	162
Vėjo elektrinės (VE)	6493	3045	4200	1113
Kaupikliai	13937	3533	1698	200
Hibridinės elektrinės (hibE)		1671	2581	
Iš viso	27356	8623	10082	1475

Figure 5. RES plants connection to 330-110 kW transmission network (source: Elektros (AEI) perdavimo aplikacija (arcgis.com))

The distribution grid operator AB ESO (energy distribution operator) provides the map with Transformation substations free capacities for consumers;

The map below shows the preliminary information on the available capacities at 110/35/10 kV 110/10 and 35/10 kV transformer substations. In the absence of spare capacity, the connection of new facilities is also possible but would require a significantly higher investment for the connection service. Given this, we recommend that investors looking for potential sites for the development of facilities with high electricity demand use the preliminary information in this map as a basis for their initial assessment (Fig. 6).



- Substations with free capacities and connection of new capacities will not need significant investment related to the development of new transformation substations.

- Substations without free capacities and new connections will require the development of transformation substations, which defines significantly higher investment and longer service-providing terms.

Figure 6. Transformation substations free capacities for consumers (source: Transformatorių pastočių laisvų galių žemėlapis vartotojams - Elektros linijų žemėlapiai - ESO - Energijos skirstymo operatorius)

Transformation substations free capacities for consumers

This map is published following Article 39(24) of the Electricity Act. The purpose of the map is to provide easily accessible and transparent information on the availability of electricity networks for the development of electricity generation or energy storage capacity.

The information has been prepared based on the Description of Procedures for the Use of the Electricity Distribution Networks (hereinafter referred to as the Description or PETA) (Fig.7 and Fig. 8).

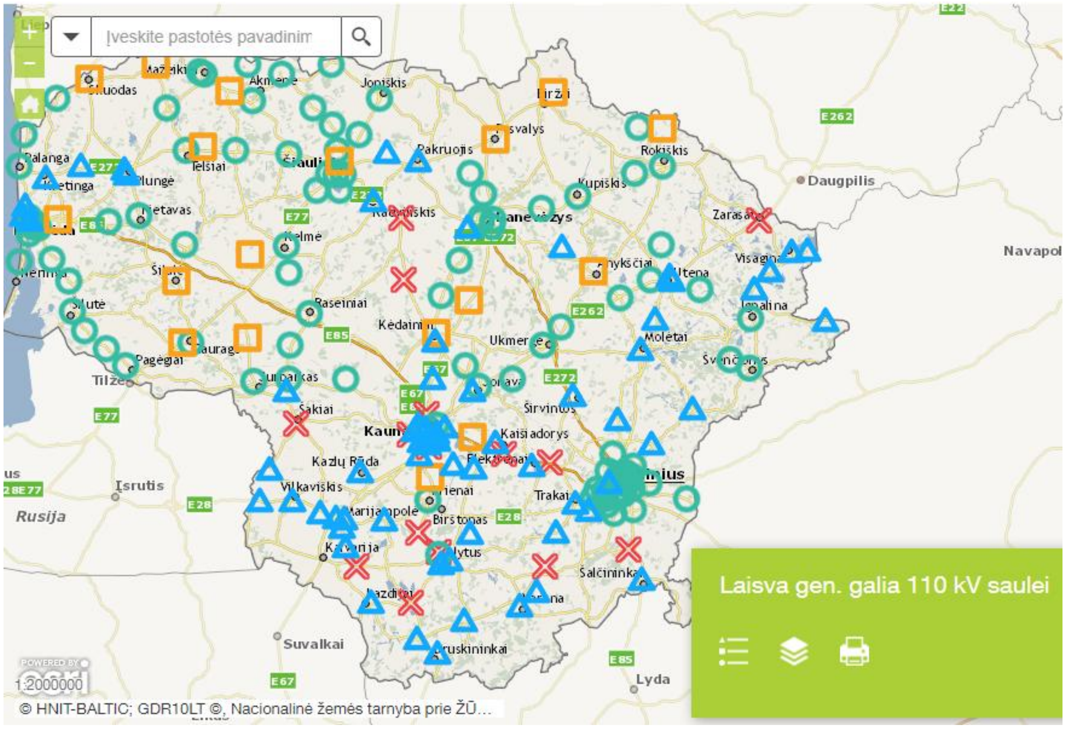


Figure 7. Transformation substations free capacities for PV producers (source: Transformatorių pastočių laisvų galių žemėlapis vartotojams - Elektros linijų žemėlapiai - ESO - Energijos skirstymo operatorius)

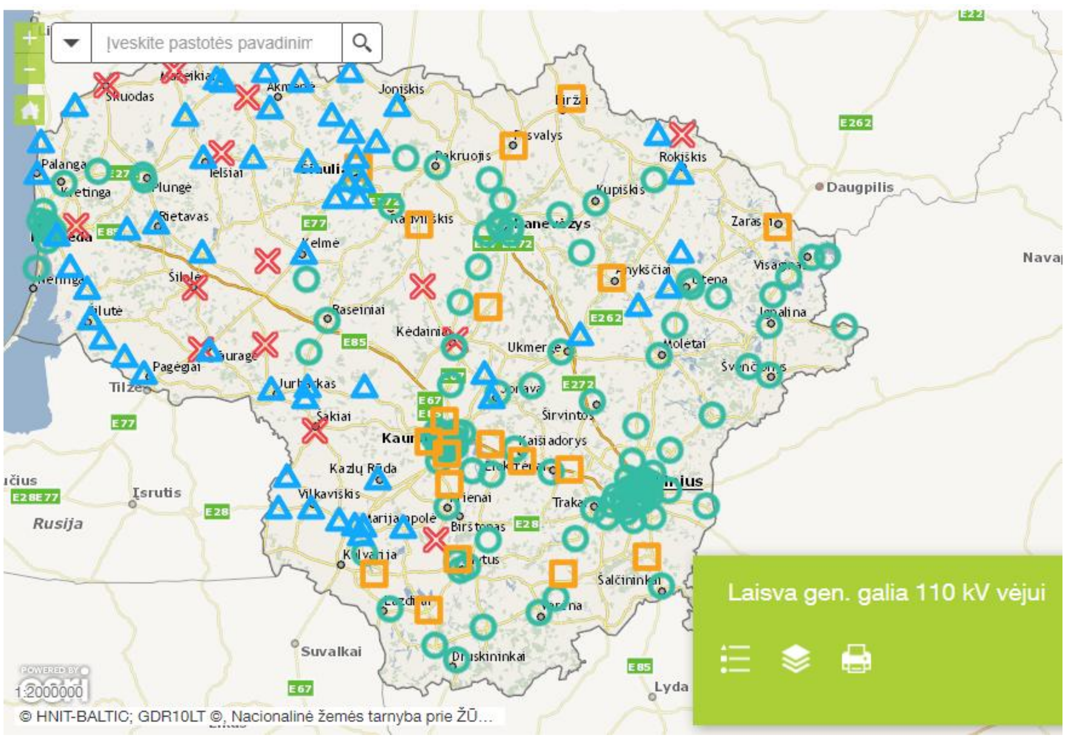


Figure 8. Transformation substations free capacities for wind producers (source: Transformatorių pastočių laisvų galių žemėlapis vartotojams - Elektros linijų žemėlapiai - ESO - Energijos skirstymo operatorius)
Here:

△ - There is free technical capacity in the ESO substation, but there is no free technical and balanced technical capacity in the LITGRID AB 110 kV grid section

□ - There is no spare technical capacity in the ESO substation, there is spare technical and balance technical capacity in the 110 kV section of the LITGRID AB grid

○ - There is free technical capacity in the ESO substation, there is free technical and balance capacity in the 110 kV section of the LITGRID AB grid

✕ - No free technical capacity in ESO substation, no free technical and balance capacity in LITGRID AB 110 kV grid section

Network Expansion Cost - an additional charge applied following the methodology approved by the State Energy Regulatory Board: if your property is located in or close to a Network Expansion Zone where ESO has previously installed more capacity than is needed for the customers connected in that area so that subsequent capacity increases and new customer connections do not require costly network reconfigurations. The prices on the map are after applying a 50% customer discount (Fig. 9).

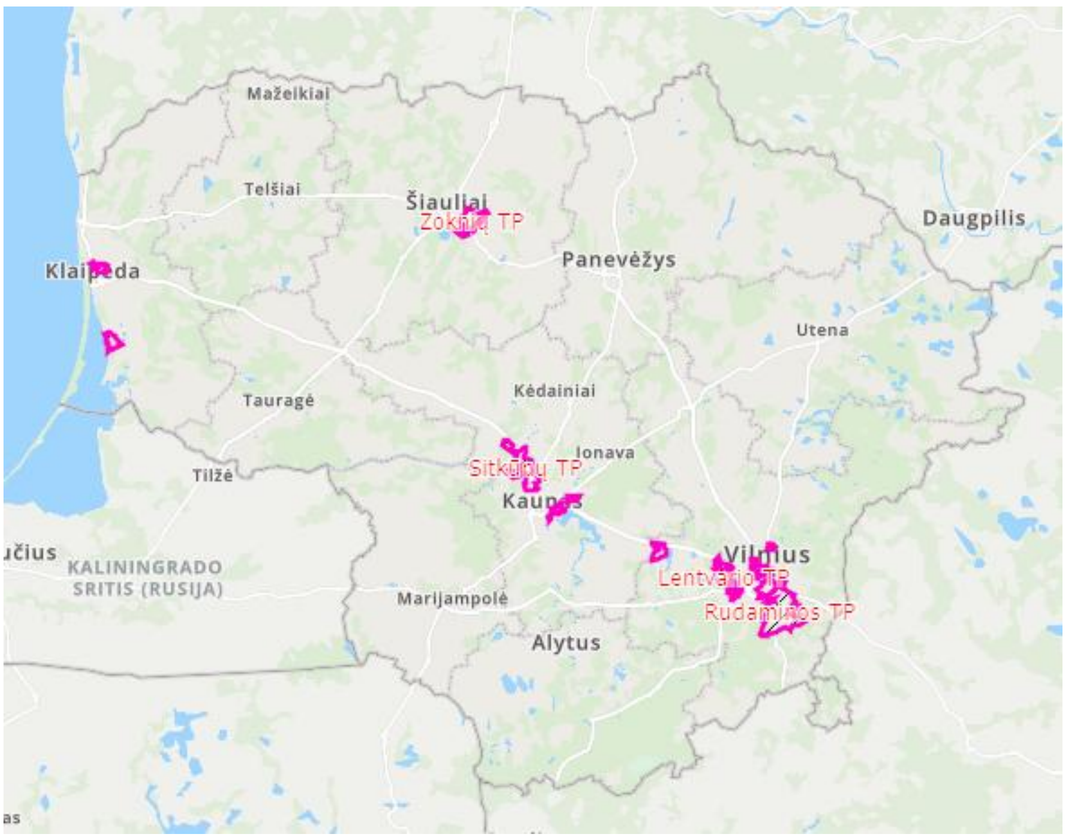


Figure 9. Grid development zones (source: Transformatorių pastočių laisvų galių žemėlapis vartotojams - Elektros linijų žemėlapiai - ESO - Energijos skirstymo operatorius)

The age of overhead and overhead electric cable lines map provides information on overhead and overhead cable lines installed more than 20 years ago. If you decide to reconstruct or relocate 0.4-10 kV electricity lines belonging to ESO that were installed more than 20 years ago, you will have to pay 50% of the total cost of the reconstruction or relocation. If you decide to reconstruct or relocate the 35 kV lines shown on the map, you will have to pay the full cost of the reconstruction or relocation work incurred by ESO (Fig. 10).

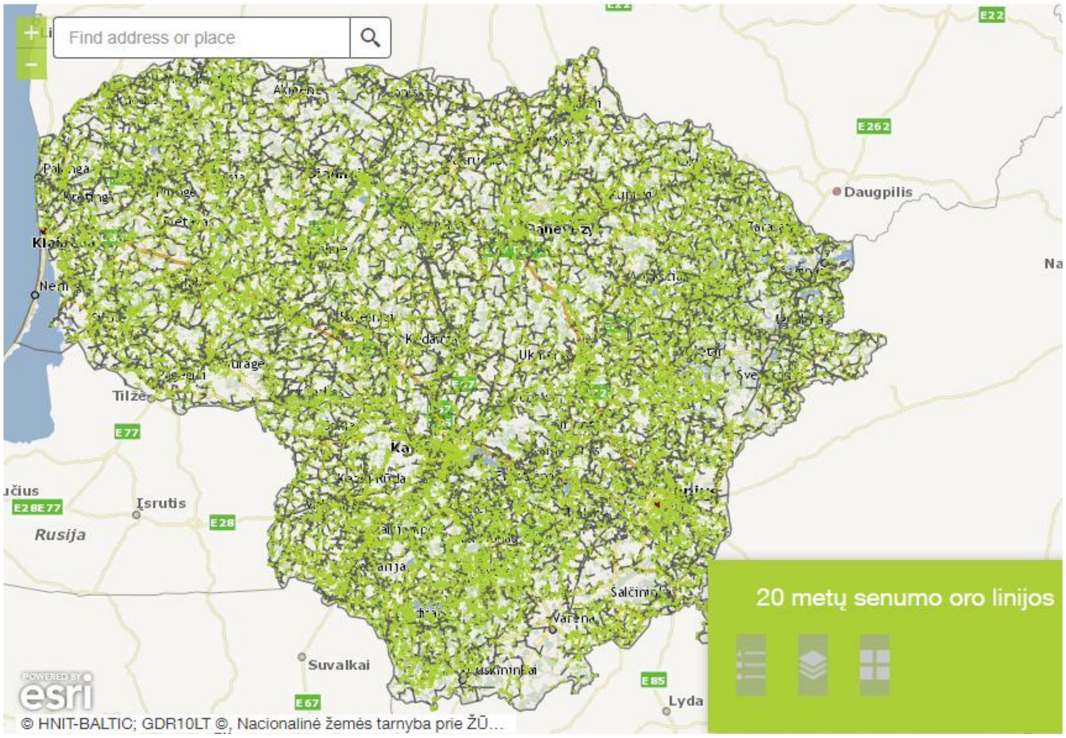


Figure 10. The Age of overhead and overhead electric cable lines (source: Transformatorių pastočių laisvų galių žemėlapis vartotojams - Elektros linijų žemėlapiai - ESO - Energijos skirstymo operatorius)

Here:

- 0,4 kV overhead electric cable lines
- 6 - 10 kV overhead electric cable lines
- 35 kV overhead electric cable lines

Measurements of power line network loads map provide preliminary information on low voltage (0.4 kV) power lines that are already connected to the maximum capacity of power plants (solar power plants) and where the connection of new power plants would require investments to increase the capacity of the grid. The grid capacity upgrades are needed to ensure that the electricity generated by the new plants meets the standard. Failure to do so would result in sub-standard electricity generation from the power plants, which significantly increases the risk of failure of the new power plant as well as of existing customer installations. For residents planning to generate their electricity, we recommend in these cases purchasing generation equipment from remote power plants, i.e. to become a remote-generating customer (Fig. 11).

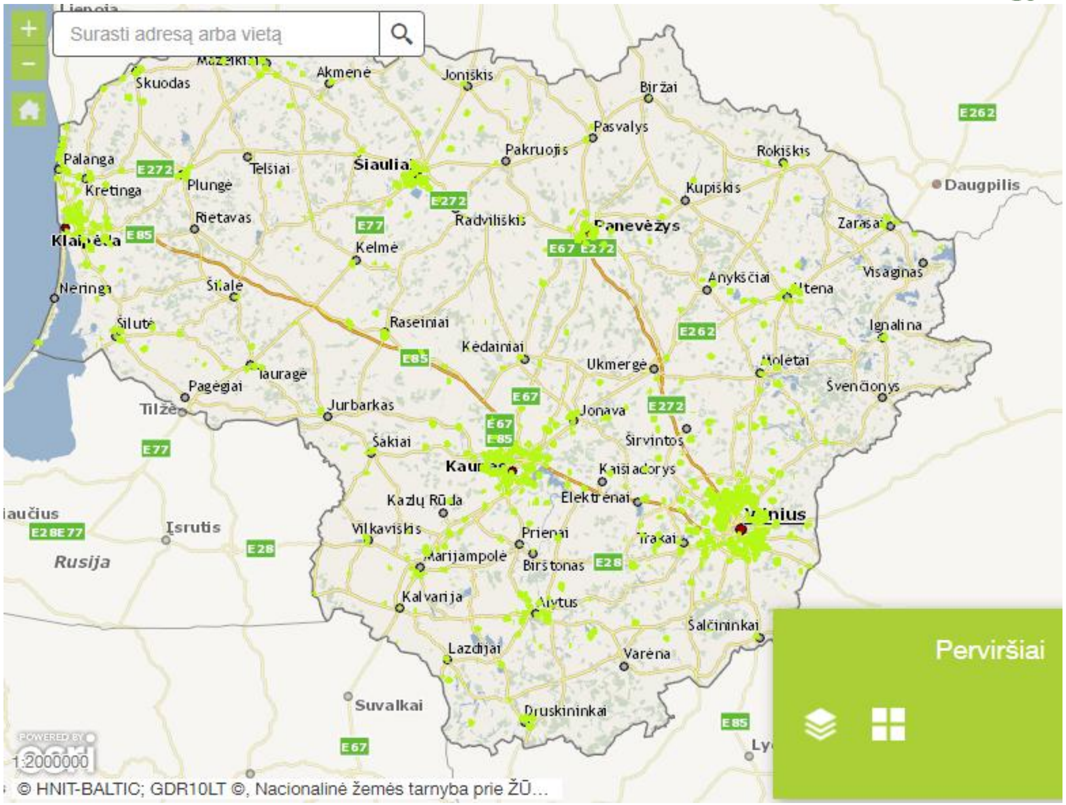


Figure 11. Measurements of power line network loads (source: Transformatorių pastočių laisvų galių žemėlapis vartotojams - Elektros linijų žemėlapiai - ESO - Energijos skirstymo operatorius

Here:

- Overhead and cable lines are already connected to the maximum capacity of power plants (solar power plants) and connecting new power plants would require investments to increase grid capacity.

1.3.1 Previous lockdown and redispatch

Historically. Lithuania's electricity system operates in synchrony with the IPS/UPS system connecting the systems of Belarus. Russia. Estonia. Latvia. Lithuania and other countries. The energy isolation of the Baltic States in the EU will only be fully eliminated once the electricity system becomes a full participant in the European electricity infrastructure. market and system. i.e. synchronously operating in the continental European electricity grids. This is being achieved through the development of legislation. the implementation of grid codes and the restructuring of the electricity system by grid operators. The synchronisation project is scheduled to be completed by February 2025 at the latest.

As part of its integration into the continental European grids and the Single European Electricity Market. Lithuania aims to ensure that all power plants from which electricity is sourced are subject to European Union-level requirements. including power plants in third countries. The aim is to prevent electricity generated in unsafe power plants. which do not comply with environmental and other international requirements and standards. from entering the European internal electricity market. The interconnection of the electricity system of the Republic of Lithuania with the CET for synchronous operation must not allow electricity from countries outside the European Economic Area to enter the electricity system of the Republic of Lithuania.

To stimulate investment in Lithuania. high-capacity power generation sources are planned by 2050. Competitive electricity prices will be one of the key factors for Lithuania to compete with other countries to attract investment in the production of new technologies and the development of future industries and services. The electrification of the energy sector and the growth in electricity demand are forecast to be the most significant trends in the energy sector. Electricity will become the new oil in energy and will open up opportunities for countries whose economies have so far been unable to rely on natural gas and oil production. The rapid development of RES generation facilities will create conditions for the emergence of new solutions and technologies in Lithuania. increase competences in the management of electricity transmission and distribution networks. create additional incentives for the emergence of new competitive sources of electricity generation. new market models and new ways of operation of market players.

Source: Sektoriaus strategija - Lietuvos Respublikos energetikos ministerija (lrv.lt)

2 Energy Infrastructure

2.1 Transmission network

"Litgrid is the electricity transmission system operator (TSO). It manages Lithuania's electricity transmission network and is responsible for its development. Its main function is to ensure the efficient and reliable operation of the Lithuanian electricity system. In this capacity. we take care of the integrity and compatibility of the country's electricity system. as well as the management. operation and coordinated development of the transmission network and interconnectors with other electricity systems (Fig. 12).

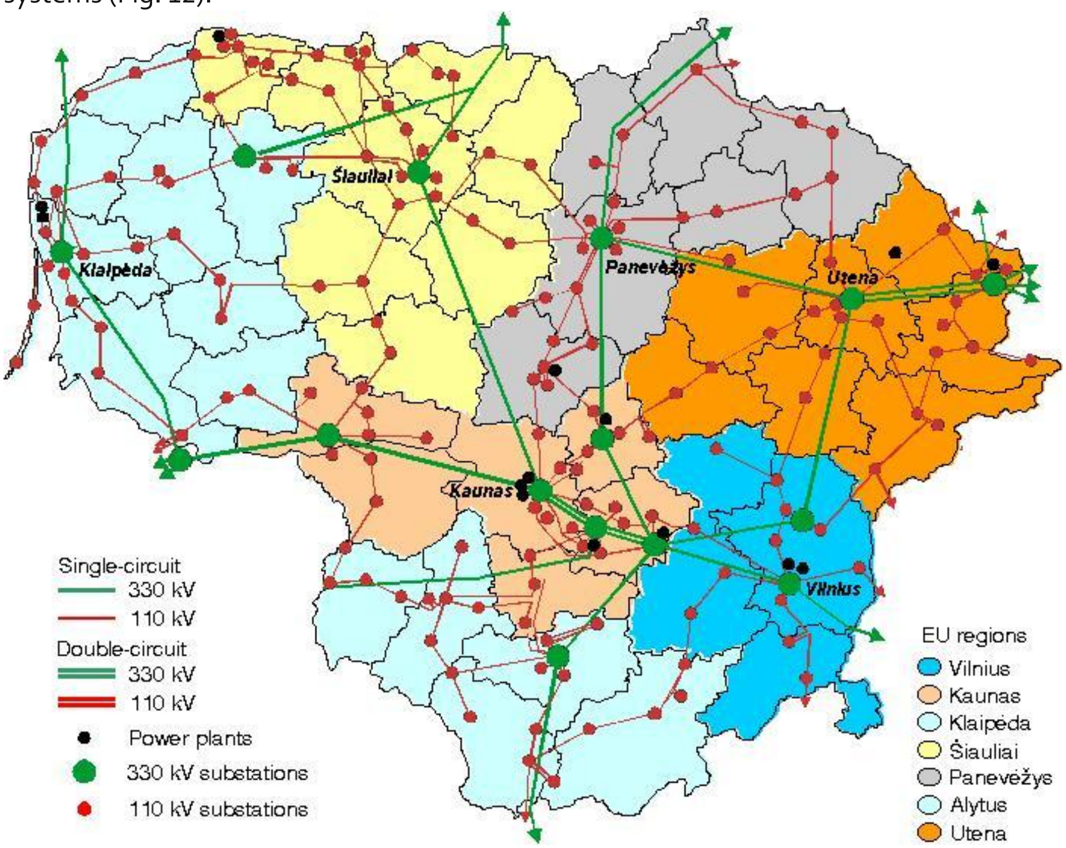


Figure 12. Map of Lithuanian Electricity Grid – Lithuania – National Energy Grids

Lithuania's 400-330-110 kV electricity transmission network comprises 239 transformer substations and switching stations and 7289.3 km of electricity transmission lines and cables. The installed capacity of 400 kV transformers is 3163.5 MW. that of 330 kV transformers is 5448.5 MW and that of 110 kV transformers is 92.6 MW.

"Litgrid plans the development of the Lithuanian electricity transmission network every year. reconstructs network facilities such as high-voltage transmission lines. transformer substations. and builds new high-voltage overhead and cable power lines. In addition. the company is implementing the country's strategic goal of reorienting the electricity system for synchronous operation with continental European electricity networks.

Lithuania's electricity transmission network is well connected to some of its neighbouring electricity systems: four 330 kV and three 110 kV lines connect Lithuania to Latvia. four 330 kV and seven 110 kV lines connect Lithuania to Belarus. three 330 kV and three 110 kV lines connect Lithuania to the

Kaliningrad region, one 300 kV DC cable connects Lithuania to Sweden and two 400 kV lines connect Poland.

The transmission scheme and key data are provided in Fig. 13 and Table 2 below.

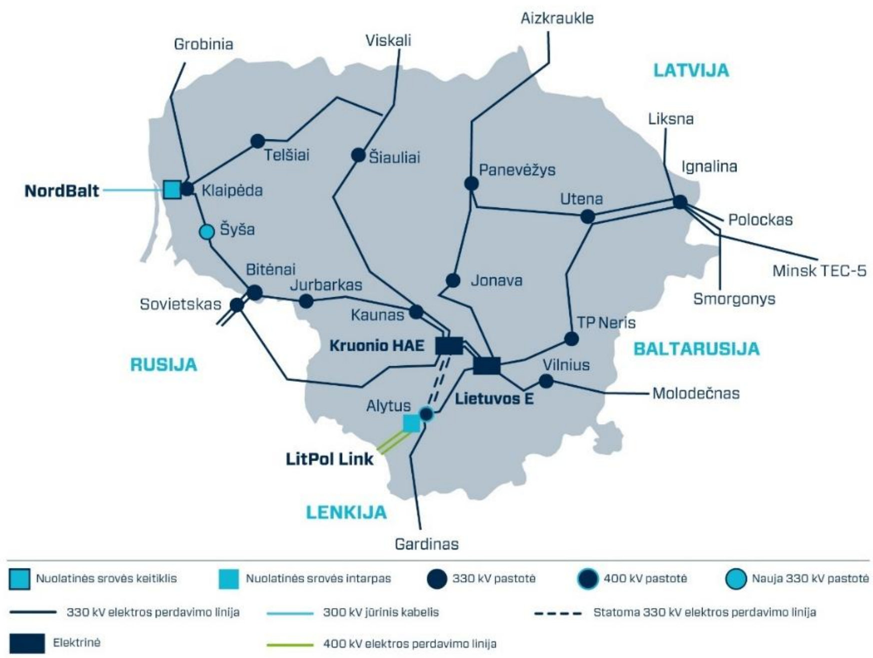


Figure 13. Electricity transmission scheme (330 kV) in Lithuania (Source: Litgrid)

Table 2:Key data on electricity transmission grid in Lithuania (Data on Dec. 31, 2022) (Source: Litgrid)

Transmission grid region		East	South	West	North	Total:
Length of Air Cable lines (by capacity), km	110 kV	1351.1	1288.7	867.1	1461.4	4968.3
	330 kV	495.0	694.0	283.5	423.3	1895.7
	400 kV	0.0	102.8	0.0	0.0	102.8
	In total:	1846.1	2085.4	1150.6	1884.7	6966.8
Length of Cable lines ((by capacity), km	110 kV	41.9	18.5	48.5	2.8	111.7
	300 kV underwater *	0.0	0.0	197.5	0.0	197.5
	300 kV terrestrial	0.0	0.0	12.9	0.0	12.9

	330 kV	0.0	0.3	0.0	0.0	0.3
	In total:	41.9	18.9	258.8	2.8	322.5
Transformation sub-stations and distribution centers, units.	110 kV	62	60	48	50	220
	330 kV	5	4	5	3	17
	400 kV	-	2	-	-	2
	In total:	67	66	53	53	239
Transformers, units	110 kV	-	-	4	-	4
	330 kV	6	7	5	6	24
	400 kV	-	3	-	-	3
	In total:	6	10	9	6	31
Transformer capacity, MVA	110 kV	-	-	92.6	-	92.6
	330 kV	1250	1350	1100	1150	4850
	400 kV	-	1800	-	-	1800
	In total:	1250	3150	1192.6	1150	6742.6
AAL converters /converter station, units		-	1	1		2
	In total:	-	1	1	-	2
AAL converters /converter station capacity, MW		-	500	700	-	1200
	In total:	-	500	700	-	1200
No of transformers in AAL converters, units	300/330 kV	-	1	-	-	1
	400 kV	-	1	1	-	2
	In total:	-	2	1	-	3
Capacity of transformers in AAL converters, MVA	300/330 kV	-	598.5	-	-	598.5
	400 kV	-	595.5	768	-	1363.5
	In total:	-	1194	768	-	1962

AAL converters/reactive capacity of converter station, MVar		-	-	350	-	350
*197,489 km – to agreed border with Swedesh operator Svenska Krafnat 134.3 km – the length of Nordbalt cable in Lithuanian territorial waters.						

19 April 2024 the total installed capacity of power plants in the Lithuanian electricity system amounted to 5442 MW. The table below shows the installed capacity of the power plants (MW) (Table 3):

Table 3:The installed capacity of the power plants in Lithuania (MW): (Source: Litgrid)

Installed capacity 2024.04.19	MW
Non-renewable resources	
Power plants with fuel mix	*338*
Kaunas CHP plants	170
ORLEN power plant	160
Petrašiūnai CHP plants	8
Natural gas power plants	*1166*
Lithuanian CHP plant (Elektrėnai complex)	1055
Panevėžys CHP plant	35
Achema CHP plant (T-1; T-2)	71
Other CHP plants	5
MSW CHP plants	68
Kruonis hidro-accumulation plant	900
Other non-renewable plants	37
Renewable resources	
Wind plants	*1284*
Onshore wind power plants on the transmission grid	1109

Onshore wind power plants on the distribution grid	175
PV plants	*1297*
PV plants on the transmission grid	145
PV plants on the distribution grid	1152
Hydro plants	*130*
Kaunas hydro plant	101
Other small hydro plants	29
Solid Biomass plants	*221*
Biogas plants	*1*
TOTAL:	**5442**

2.2. Distribution system operators / municipal utilities

"The Energy Distribution Operator (ESO), managed by the state-owned Ignitis Group, distributes electricity and gas, maintains distribution networks to ensure their reliability and efficiency, troubleshoots network faults and connects new customers. By managing infrastructure efficiently, ESO aims to enable competition in the energy market. Licensed activities include electricity distribution and natural gas distribution.

Main activities and functions: introduction of electricity and gas, operation, management and development of distribution networks, ensuring their safety and reliability, and guaranteeing the supply of electricity and gas. ESO serves 1.8 million customers throughout Lithuania. The company's service area in square kilometres amounts to 65.3 thousand km².

The main services are provided on a national scale and are as follows:

- Introduction of electricity for temporary (various events and short-term purposes up to 12 months), new objects and fast track;
- Capacity change;
- Technical electricity supply solutions for the renovation of buildings and relocation of electrical equipment;
- Lease of infrastructure assets;
- Connection of prosumers;
- Providing power line maps;
- Providing smart meter P1 interface and web service;
- EV charging.

Administrative territorial division of the Republic of Lithuania. The territorial administrative units of the Republic of Lithuania are counties and municipalities. Counties are formed from the territories of the municipalities characterized by common social, economic and ethno-cultural interests. The territory of the Republic of Lithuania currently comprises 10 counties and 60 municipalities. The majority of municipalities are divided into smaller territorial units – wards.

There are mainly two main energy-related activities, which are operating on the municipal level district heating (individual heating) as municipalities are responsible for providing heat to their population, and public transport.

District heating sector. There are 45 municipal and regional district heating companies and 14 associated partners, which operate in some towns, settlements and locations (Fig. 14).

Figure 14. Companie responsible for heat supply on municipal level in Lithuania's municipalities (Source: [Lietuvos šilumos tiekėjų asociacija (lsta.lt))](lsta.lt)

Lithuanian DH systems meet the efficiency criteria set by the European Union and are therefore considered energy-efficient. From 2021, connecting to DH systems is also encouraged by the new building requirements that have come into force, whereby district heating in Lithuania is recognized as suitable for A++ class buildings, as the majority of district heat is produced from renewable sources.

The total number of consumers is 727,000. The structure of consumers supplied with district heating remains unchanged and here residential consumers are the main consumers, consuming around 70% (5 174 GWh) of the total district heating energy supplied. State organizations purchased around 15% (1 077 GWh) and businesses another 15% (1 104 GWh) of the total heat.

The average annual heat consumption in residential buildings in 2022 was 135 kWh/m2, which is around 15% lower than in 2021 due to milder winter weather. Different buildings consume different amounts of heat to maintain the same indoor temperature. Uninsulated and non-renovated apartment buildings, where the internal heating and hot water systems have not been upgraded, consume the most heat.

Typical DH networks are presented in Fig. 15

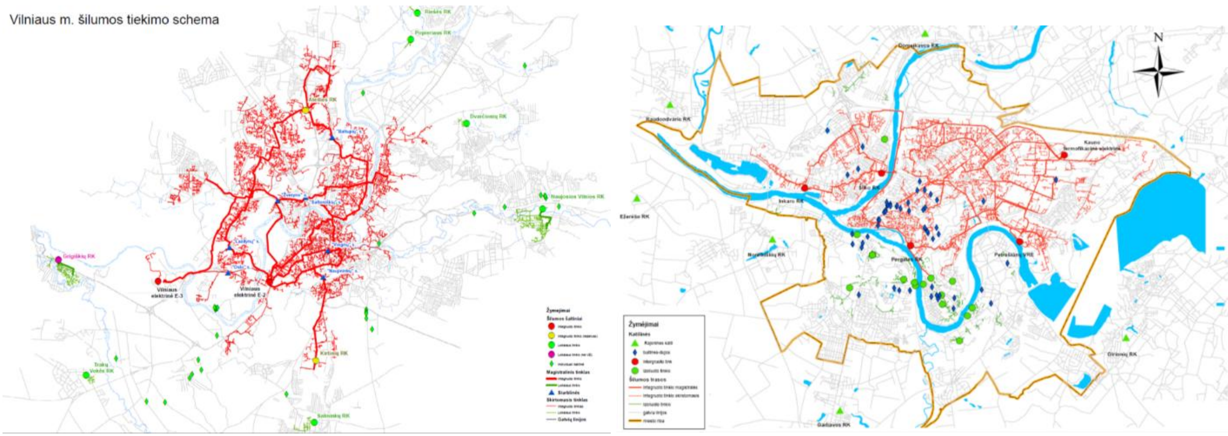


Figure 15. Typical DH networks in Lithuania's municipalities (a) Vilnius, (b) Kaunas. (Source: Lietuvos šilumos tiekėjų asociacija (lsta.lt))

Public transport. Most of Lithuania's bus fleets are owned by municipalities, but the role of the Ministry of Transport and Communications is to shape the country's transport policy. The organisation of passenger transport on local routes and the calculation and payment of compensation for preferential passenger transport is an autonomous municipal function. It is up to the municipal councils to decide whether it is better for them to maintain their bus fleets or to privatise them and purchase passenger transport services from private carriers.

The specific fare levels for the carriage of passengers on regular local transport routes are set by municipal councils. The situation of companies therefore depends primarily on the decisions taken by municipalities. The Road Transport Code stipulates that passenger tariffs must be reviewed at least once a year, the revenue generated and the obligations laid down in the public service contracts between municipalities and carriers. It is up to the municipalities to choose which public transport model, with or without competition, is the most acceptable to them.

Buses, trolleybuses and shuttles are used for public transport in Lithuania. The largest public transport systems in Lithuania are in Vilnius, Kaunas and Klaipėda.

Figure 16. Public transport map in Lithuania (Source: [Lietuvos viešojo transporto maršrutai - Visi maršrutai (visimarsrutai.lt)](visimarsrutai.lt))

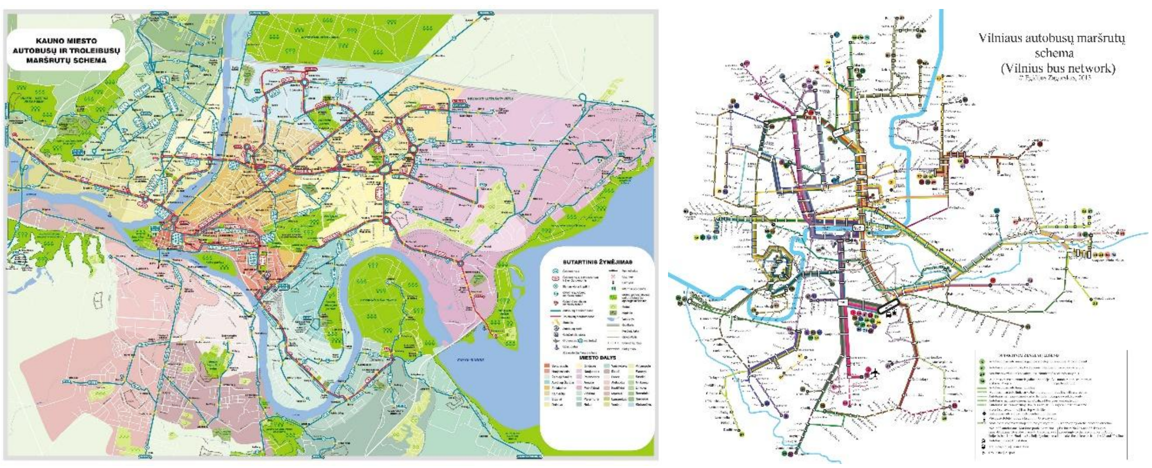


Figure 17. City Public transport schemes (a) Kaunas, (b) Vilnius (Source: https://phototrans.eu/20,72,0,Kaunas__city_transit_scheme.html ; Viešasis transportas - Vilniaus transporto maršrutų schema / Vilnius public transport network scheme (nvtka.lt))

2.3. Stakeholders active in energy storage in electricity and heat

The following electricity storage and accumulation systems are currently in operation in Lithuania:

Kruonis pumped storage power plant. The main objective of this power plant is to ensure efficient electricity generation and trading on the NordPool exchange during peak and off-peak periods, to provide balancing capacity services and to trade balancing electricity on the regional market, while allowing the use of other renewable energy sources and the development of new generation capacities in the country.

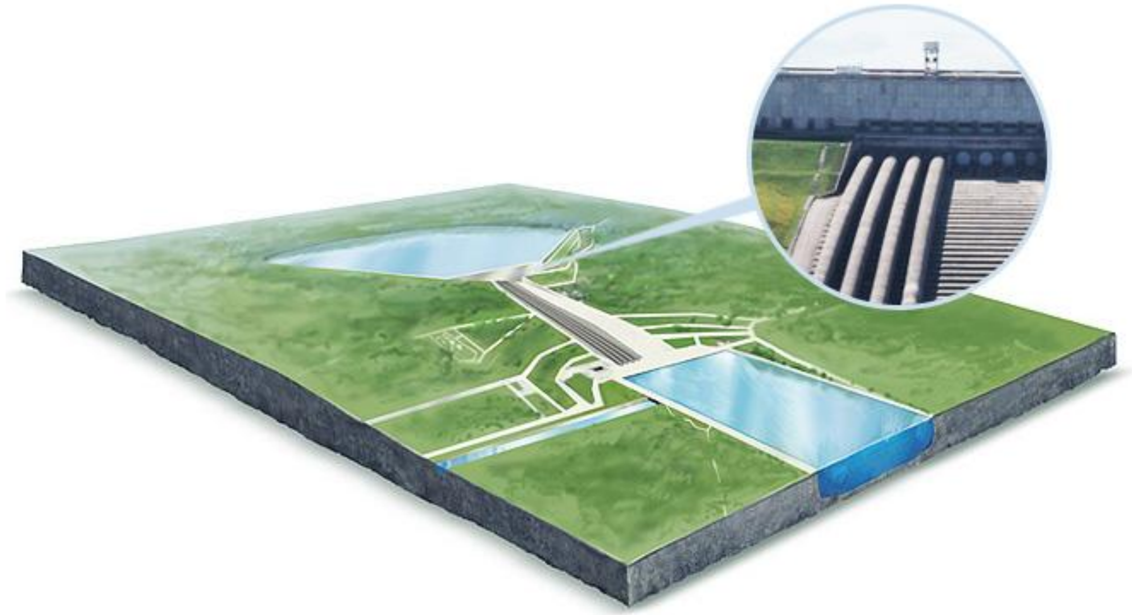


Figure 18. Kruonis pumped storage power plant (Source: [Kruonio hidroakumuliacinė elektrinė (Kruonio HAE) | Ignitis gamyba])

Additional services provided to the Kruonis HPP transmission system operator (TSO)

- The Frequency Restoration Reserve service is used when imbalances occur in the system due to imbalances between generation and consumption and when the largest grid or generation element goes offline. The frequency restoration reserve is activated within 12.5 minutes and balancing electricity can be supplied continuously for up to 12 hours on-demand to compensate for a shortage or surplus of electricity due to a system emergency. This additional balancing capacity service is provided by two units of the Kruonis HPP.

- The voltage regulation service, which is not related to frequency regulation and balancing, is provided by the Kruonis HPP units operating in synchronous compensator mode. The service is activated when the capacity of the voltage control equipment in the transmission network is insufficient to ensure the quality of electricity, i.e. when the voltages at the relevant points in the transmission network are not within the specified limits.

- A power system restart service to restore electricity generation after a complete system shutdown. In such cases, the Kruonis HPP diesel generator is started up and the capacity of Kruonis HPP is activated. It maintains the voltage in the Lithuanian transmission grid and supplies the electricity needed to restore power supply after an accident.

Main technical characteristics of Kruonis HPP

- Total capacity 900 MW, 4 units of 225 MW each.
- Cycle efficiency factor 0.74.
- Capacity in generating mode 160–225 MW. Maximum capacity 225 MW.
- Capacity in pumping mode fixed 220 MW.

KHPP is currently undergoing an expansion with the installation of Unit 5. The technical capabilities of the new unit, both in generator and pump modes, will expand the power plant's capacity utilisation

spectrum and allow the plant to participate more effectively in the common European balancing market. In addition, the new unit will ensure greater competitiveness in the provision of system services by enabling the company to participate in the market for frequency management reserve services following synchronisation with the continental European grid. Unit 5 will significantly contribute to enhancing the security of the electricity supply in the country, the reliability and stability of the electricity system, and will help to balance Lithuania's rapidly expanding, but uneven, generation of electricity from renewable energy sources.
Source: [Kruonio hidroakumuliacinė elektrinė (Kruonio HAE) | Ignitis gamyba]

One of the most important energy projects in terms of national security - **Europe's largest 200 MW battery system** - has been officially launched at the Vilnius Transformer Substation from October 2023, enabling it to react in just one second in the event of a disturbance and helping to ensure the uninterrupted transmission of electricity.

The system consists of four 50 MW battery parks, installed at electricity transformer substations in **Vilnius, in Šiauliai, Alytus and Utena**. They can provide continuous power for about one hour or until other sources of power generation come online, Kruonis HAE.

Recent attacks on European energy infrastructure projects show that the threats are real, making energy security an absolute necessity. Until synchronization, the system will ensure uninterrupted power supply in the event of any disturbances, the project marks a new qualitative level of grid resilience and will help Lithuania to meet one of the most important objectives before synchronisation - the ability to operate in isolated mode, i.e. autonomously.

The 200 MW and 200 MWh storage systems will contribute to the integration of renewable energy after synchronisation with the continental European electricity grid. Battery parks will then be able to store electricity from solar and wind generation above consumption levels, and, if necessary, when consumption increases, to feed back into the grid the energy stored from renewable generation sources.

Energy Cells, which has been appointed as the operator of the energy storage system, is 100% owned by the EPSO-G group of energy transmission and exchange companies. "The Ministry of Energy of the Republic of Lithuania exercises the rights and duties of the sole shareholder of EPSO-G.

There is also a number (though no statistics yet) of businesses and private consumers, which have installed PV plants. State support is being provided for residential batteries up to 10 kW capacity.

Future development

Construction **of two geothermal thermal power plants** in Lithuania could start by 2028, as planned by Lavastream and Sage Geosystems. Currently, the first plant is planned for Klaipėda and the second for Gelgaudiškės. Negotiations are currently underway with the municipalities of Klaipėda city and Šakiai district, both for the land and for the possible connection of the plants to the heat network.

Lavastream plans to install a thermal power plant with a capacity of around 30 MW in Klaipėda and 15 MW in southwestern Lithuania by 2028, as well as a geothermal-geological long-range electricity storage system. These plants will use new geothermal technology, which involves creating a reservoir at a depth of 3 to 6 kilometres and then injecting water or other liquid into it, which is warmed by the ground. This heated fluid would then be used for heating purposes.

The technology could also act as energy storage to help "balance" solar and wind farms. In the future, Lavastream plans to enable the installation of geothermal-geological storage with a potential of 1 GW. The thermal potential of geothermal power plants in Lithuania is estimated at 20 GW, while the potential of geothermal power plants for electricity generation is over 2 GW.

Source: [Vakarų Lietuvoje iki 2028 m. gali būti įrengtos 2 šilumos jėgainės (ve.lt)]

Some municipal district heating companies, using biofuels for heat generation, are planning and already installing **thermal storage** to smooth out fluctuations in demand in the event of sudden temperature changes during the winter, thus covering daily demand fluctuations. These are mainly DH companies in the largest cities like Vilnius, Kaunas, Klaipėda, as well as some smaller companies.

2.4. Role of local authorities for energy storage in connection to electricity

Municipalities have an important role to play in the implementation process by increasing the use of renewable energy sources. It's not just wind and solar power plants that are speeding up progress in municipal sustainable energy development. The contribution of each municipality is crucial to achieving the goals set out in the National Energy Independence Strategy and the National Energy and Climate Action Plan of Lithuania - to reduce greenhouse gas emissions, increase energy efficiency and promote the wider use of renewable energy sources. Municipalities elaborate municipal Energy and Climate Action Plans and are responsible for their implementation.

The capacity of renewable energy power plants in Lithuania in 2023 has been growing rapidly: at the end of last year, the capacity of wind power plants exceeded 1,200 MW, while solar power plants exceeded 1,000 MW. The results of the Lithuanian Energy Agency's fifth annual assessment of municipalities' sustainable energy development in the past year show. how municipalities are promoting the use of renewable energy sources. energy efficiency improvements. sustainable mobility and access to energy services. Wind energy development can't be implemented in all municipalities due to various environmental, national defence, protected areas and landscape and city restrictions. The distribution of photovoltaic plants is more even. Due to the defined growth of the number of purchased electric vehicles, municipalities also invest in the growing number of charging stations.

Municipal property tax rates do not hinder the development of RES and are not a determining factor for developers in deciding which municipalities to develop RES projects. On the contrary, the property tax revenue allows municipalities to spend more on reducing energy poverty. The annual Municipal

Sustainable Energy Progress Assessment aims to increase the role of municipalities in the energy field, to encourage their engagement and benchmark their progress, and to inform the public about it.
Source: www.ena.lt

2.5. Role of hydrogen and power to x in today's energy (electricity) system (if any and relevant)

Biomethane and green hydrogen. The first plants supplying biomethane to the natural gas grid have started operating, and green hydrogen will also be produced from biomethane. The development of biomethane would allow Lithuania to increase the use of renewable energy sources, reduce waste in agriculture and industry, and provide an economic boost to Lithuania's biogas sector.

By cleaning and upgrading biogas, biomethane can be produced with a methane concentration of 91%, which meets the quality requirements for natural gas. Biomethane can be fed into natural gas networks. for use in the transport sector.

Hydrogen production by electrolysis will be one of the key measures that will create the conditions for the further development of RES capacity in Lithuania. The aim is to install at least 350 MW of electrolysis or other technologies for green hydrogen production by 2030 and to produce at least 34,000 tonnes of green hydrogen per year. Five Lithuanian cities will also use green hydrogen in public transport and have at least one hydrogen-powered train. In addition. 15 per cent ammonia by 2030. of ammonia needed for fertiliser production. will be produced from green hydrogen.
Source : Pradžia - Lietuvos Respublikos energetikos ministerija (lrv.lt)

Hydrogen. The project "Assessment of Underground Hydrogen Storage in Lithuania: The Study of the Chemical and Mechanical Reactions of Geo-Hydro to Underground H2 storage and leakage" was launched in 2024 and should be completed in 2026.

Although H2 is a very efficient fuel, there are many challenges associated with its use. As H2 is a very light gas, a large storage volume is required, therefore, To effectively deploy H2-based technologies in Lithuania, H2 storage needs to be addressed. Underground gas storage has been common in Europe and even in Lithuania, methane is stored in an underground (Inčukalno UGS) form in summer, In Latvia, for winter use. Depleted gas fields, oil fields and saline aquifers offer the possibility of storing large quantities of gas, and these underground porous formations can be used to store large quantities of hydrogen. Thanks to Lithuanian geology, such opportunities exist in Lithuania both on land and offshore. Depleted hydrocarbon reservoirs and deep saline aquifers in the Lithuanian basin have already been explored for CO_2 storage in the past, these reservoirs are equally suitable for hydrogen storage.

Source: Požeminės vandenilio saugyklos Lietuvoje įvertinimas: Geo-Hidro cheminių ir mechaninių reakcijų į požeminę H2 saugyklą ir nuotėkį tyrimas - Kauno technologijos universitetas | KTU

2.6. Business models for energy (electricity) storage

All energy projects in Lithuania are usually implemented with financial support:

Businesses and public sector companies with their own solar or wind farms can apply for support to install electricity storage facilities. The amount of e.g. the recent call is €48 million. In total, the Ministry of Energy has planned more than €150 million for legal entities' energy storage facilities in the year 2024.

Private and public legal entities, which already have or are planning to install solar or wind power plants, will be able to apply for support for an energy storage facility with a capacity of 4 MWh or more.

Today, solar and wind power already provide the majority of all electricity generation in Lithuania. and batteries are the cheapest way to balance the electricity system. compensating for the imbalance between solar and wind generation. It also makes it possible to even out electricity price peaks for all electricity consumers, which is why the state consistently supports businesses, the public sector and citizens to invest in energy self-sufficiency. As the number of solar and wind power plants grows in the country, there is also a growing interest from generation consumers to become an active participant in the balancing market and to invest in batteries, so support for these installations is particularly relevant.

Currently, 4,294 unique legal entities are operating 15,000 generating consumer facilities. The announced support measure will be administered by the Environmental Project Management Agency (EPA). Private and public sector legal entities can also benefit from the current calls for support of almost €600 million to install solar or wind power plants or to buy from parks. These are administered by INVEGA (the state-established financial institution with the following main objectives: provide financial services and implement and manage financial and other forms of financing business).

Esamiems ir būsimiems saulės ir vėjo elektrinių savininkams – 48 mln. Eur Energetikos ministerijos parama baterijoms - Lietuvos Respublikos energetikos ministerija (lrv.lt)

2.7. Organisation of other storage (biomethane. heat) if relevant

The Tube Green biomethane plant in Pasvalys has started operations and will produce 100,000 megawatt hours (MWh) of biomethane per year. This would be enough to supply 110,000 people in Lithuania with gas for a whole year or to fully meet 26% of the country's gas-powered transport needs. The biomethane production project is being implemented by Tube Green together with bioethanol and biogas producer Kurana. The investment amount of the project is EUR 15 million. Part of the investment is financed by the Climate Change Programme.

Tube Green biomethane plant, in cooperation with Amber Grid, Lithuania's gas transmission system operator, the biomethane plant has been connected to the country's gas transmission network and is already supplying biomethane to the system. Tube Green plans to expand its activities in the future by considering the possibility of launching the production of synthetic fuels and green hydrogen. There are also plans to expand biomethane production capacity, allowing other biomethane producers to bring their biomethane to Tube Green and pump it into the main gas pipeline.
Source: https://www.vz.lt/pramone/2023/09/18/pasvalyje-veikti-pradeda-15-mln-eur-kainavusi-biometano-gamykla#ixzz8iOSTjJky

A call for proposals to install biomethane gas production and purification facilities is launched. This measure has been allocated €11.8 million from the Recovery and Resilience Facility. Projects will be selected through a competitive selection process according to the priority selection criteria set out in the project financing conditions. Projects can qualify for a funding intensity of up to 45%. Projects will have to be implemented by Q1 2026.
Source: Paskelbtas kvietimas vystyti biometano gamybos ir valymo įrenginių įrengimo projektus - Lietuvos Respublikos energetikos ministerija (lrv.lt)

Transport sector. On July 1, 2024, a total of 23,003 passenger electric vehicles (M1 category) were registered in Lithuania, of which 13,481 were pure electric vehicles and 9,522 were externally charged hybrids. There were also 473 light commercial electric vehicles (category N1) on the register, of which 467 were pure electric vehicles and 6 were externally recharged hybrids. According to the Lithuanian Energy Agency, in June 2024, 733 light passenger electric vehicles were registered in the Lithuanian Road Vehicle Register (of which -363 were pure electric vehicles and 370 were externally charged hybrids). This is 19.45% less than in May this year, but 2.52% more than in June 2023.

One of the objectives of the National Energy and Climate Action Plan of the Republic of Lithuania for 2021-2030 is to increase the use of renewable and alternative fuels in the transport sector and to promote sustainable intermodal mobility. Currently, the transport sector is lagging behind the most. The objective is to achieve a 15% share of renewables in the transport sector by 2030.

The Law on Alternative Fuels of the Republic of Lithuania stipulates that by 2025. M1 electric vehicles must account for at least 10 per cent and N1 electric vehicles must account for at least 30 per cent of annual purchase transactions. Lithuanian legislation defines electric vehicles as vehicles that use electricity as the source of motor power. Electric vehicles can be either pure electric vehicles (BEVs - Battery Electric Vehicles). or externally charged hybrids (PHEVs - Plug-in Hybrid Electric Vehicles). which also have an internal combustion engine. which can be used to travel longer distances.
Source: www.ena.lt

Construction of the first charging park for electric vehicles started on the country's main road from Vilnius-Kaunas-Klaipėda in 2024. The Eldrive Lithuania charging park will be the first of its kind on a major national road and will be able to charge 40 electric cars at a time. The park is scheduled to be operational in the first quarter of 2025. Lithuania is aiming to have around 120,000 electric cars by 2030. A convenient and well-developed charging station infrastructure is a key prerequisite for this ambitious goal. The launch of an electric vehicle charging park on one of our most important highways marks a new trend in the development of such facilities and will significantly contribute to the development of the national infrastructure. To ensure convenient travel by electric vehicles in Lithuania. Around 60,000 public and private charging stations are needed.

Five 200 kW stations, each with two charging bays, are to be built on 1.5 ha of land. The first phase of the project will be completed next summer with five more 400 kW stations with two charging bays, bringing the total number of charging bays in the park to 20. The next phase of the park's development will be the installation of high-power charging bays as well as a number of charging points for trucks or buses.

This place on the road will allow drivers of electric cars to travel from Vilnius or Kaunas to Klaipėda or Palanga and back. Most of the electric cars on the road in Lithuania can cover a range of 250-350 kilometres. Eldrive Lithuania's investment in this charging fleet will amount to just over two million euros. The project is being implemented in partnership with Reitan Convenience Lithuania, a company that operates coffee shop chains. Currently, there are more than 1,000 slow (AC) charging stations and around 300 fast (DC) charging stations in our country.
Source: Pagrindiniame šalies kelyje pradedamas statyti pirmasis elektromobiliams skirtas įkrovimo parkas - Lietuvos Respublikos energetikos ministerija (lrv.lt)

Carbon driven energy equilibrium at the municipal scale – Energy Equilibrium

Summary Report on the Energy Infrastructure (Poland)

Prepared by J.Ł., IMP PAN

Interreg Baltic Sea Region
Co-funded by the European Union
ENERGY TRANSITION
Energy Equilibrium

1 Organization of electrical grid – transmission network

The electricity transmission network in Poland is managed by **Polskie Sieci Elektroenergetyczne SA (PSE)**, which is the sole transmission system operator (TSO) in the country. The entire power system in Poland and throughout Europe (excluding the frequency of railway electric traction in Germany and four other countries) operates at a frequency of 50 Hz.

1.1 Key Components of the Transmission Network

1.1.1 High-voltage transmission and distribution lines:

Transmission lines transport electricity over long distances from power plants to substations. They operate at high voltages to reduce energy loss during transmission (750 kV, 400 kV, 220 kV). High-voltage distribution network (110 kV) is part of the distribution network, however, due to the way it works, it is largely identical to the transmission network. Its work is mostly coordinated by the TSO.

Substations: These facilities step down the high voltage electricity to lower voltages suitable for distribution to homes and businesses (especially the main power supply points, Główne Punkty Zasilania (GPZ) in Polish). RES installations are also connected to GPZ, such as the Jasna wind farm of Stadtwerke München in the municipality of Mikołajki is connected to GPZ Gdańsk-Błonia by an underground 110 kV high-voltage cable network. These substations also play a crucial role in managing the flow of electricity and maintaining grid stability.

National Power Dispatch Centre: This center is responsible for the real-time management of the power system, including balancing supply and demand, and ensuring the stability and reliability of the grid.

1.2 Responsibilities of PSE

Quality and security of supply: PSE ensures the continuous and reliable supply of electricity across the country. This involves maintaining and upgrading the transmission infrastructure to meet demand and prevent outages.

Network sufficiency: PSE is tasked with ensuring that the transmission network has sufficient capacity to handle current and future electricity demands.

Commercial balancing: PSE operates the national central commercial balancing mechanism, which involves managing the financial transactions related to electricity supply and demand.

European cooperation: As part of the European Network of Transmission System Operators (ENTSO-E), PSE collaborates with other TSOs to maintain the stability of the interconnected European electricity system (German 50Hertz Transmission GmbH, Swedish Svenska kraftnät, Czech ČEPS, a.s., and Lithuanian Litgrid).

1.3 Legal and Regulatory Framework

PSE operates under the guidelines set by the Energy Law of April 10, 1997, which outlines the responsibilities and standards for transmission system operators in Poland. The company is appointed by the President of the Energy Regulatory Office (Urząd Regulacji Energetyki (URE)) to perform its functions until December 31, 2030.

1.3.1 Distribution system operators in electrical grids

In Poland, the electricity distribution network is managed by several key distribution system operators (DSOs):

- **PGE Dystrybucja**: This is the largest DSO in Poland, serving a significant portion of the country (central and eastern part of Poland).
- **Tauron Dystrybucja**: Another major player, Tauron Dystrybucja, covers a large area in southern Poland.
- **Enea Operator**: Serving the western part of Poland, Enea Operator is known for its efforts in grid modernization and the implementation of smart metering systems.
- **Innogy Stoen Operator**: This DSO operates mainly in Warsaw and its surroundings, focusing on urban electricity distribution and the deployment of advanced metering infrastructure.
- **Energa Operator**: Operating primarily in the northern regions (especially in Pomerania), Energa Operator focuses on integrating renewable energy sources into the grid and enhancing grid reliability (the largest share of renewable energy sources (RES) in electricity production among Polish DSOs) and, similarly to Enea Operator, on implementing smart metering systems. This is the most interesting DSO from the point of view of the Energy Equilibrium project.

These DSOs are responsible for maintaining and upgrading the distribution networks, ensuring reliable electricity supply to homes and businesses, and integrating new technologies to improve efficiency and sustainability. Their networks operate hierarchically: high voltage (110 kV), medium voltages (mainly 15 kV), to distribute electricity from substations to local distribution points, and finally low voltage (phase voltage 230 V; recipients requiring higher power are supplied from a three-phase network with a phase-to-phase voltage of 400 V).

1.3.2 Stakeholders active in electricity storage

The owners and operators of electricity storage facilities are both TSO and DSOs. This applies to both pumped-storage power plants (the largest of them in Żarnowiec, with an installed capacity of 716 MW, owned by PGE) and electricity storage facilities based on lithium-ion batteries (including the one that PGE is building in Żarnowiec, with a target power of no less than 200 MW and a capacity of 820 MWh, thus creating a Commercial Hybrid Energy Storage facility).

The report prepared by the President of the Energy Regulatory Office discusses the current state of energy storage in Poland as of May 2024. It highlights that there are 12 energy storage facilities with a capacity of at least 50 kW, but not exceeding 10 MW integrated into the transmission and distribution networks (1,465 MW). The report also mentions that since the introduction of regulations in 2021, energy storage facilities with a capacity greater than 10 MW require a license from the URE. The total installed capacity of electricity storage facilities for the five largest distribution system operators and the transmission system operator is 4,200 MW (however, in the main capacity market auctions for 2021–2028, 7.6 GW was reported for existing and modernized storage facilities, as well as 1.9 GW for new units based on lithium-ion batteries).

The above report does mention several challenges and limitations related to energy storage in Poland:

Regulatory Barriers: The need for licenses for energy storage facilities with capacities greater than 10 MW can be a hurdle for some projects.

Integration Issues: Ensuring that energy storage systems are fully integrated with the transmission and distribution networks can be complex and time-consuming.

Ownership Restrictions: The 2023 amendment to the energy law restricts system operators from owning, building, or managing energy storage facilities unless specific conditions are met and approved by URE, which can limit the development and deployment of these systems.

Approval Processes: The process of getting energy storage facilities recognized as fully integrated with the network involves multiple decisions and can be lengthy, with some applications still under review.

These challenges highlight the need for continued regulatory adjustments and technological advancements to fully leverage the potential of energy storage in Poland.

1.4 The role of local authorities in electricity storage

In short – local authorities do not play any role in electricity storage systems. Their role of hydrogen and Power-to-X installations in today's energy system is practically negligible; a complex of electrolyzers is being built only in Konin, which are to be powered by a biomass power plant being built next to the decommissioned brown coal power plant (however, this is doubtful in an area of structural drought).

1.5 Business models for energy (electricity) storage

Generally, the following some common business models for electricity storage could be presented:

- **Demand Charge Management**: This model targets commercial and industrial customers who face high demand charges. Energy storage systems are used to reduce peak demand, thereby lowering electricity bills.
- **Grid-Scale Renewable Power Integration**: Large-scale energy storage systems are deployed to store excess energy generated from renewable sources like wind and solar. This stored energy can be released when generation is low, ensuring a stable supply.
- **Small-Scale Solar-Plus-Storage**: Residential and small commercial customers combine solar panels with battery storage. This setup allows them to store excess solar energy generated during the day for use at night or during power outages.
- **Frequency Regulation**: Energy storage systems help maintain the balance between supply and demand on the grid by quickly absorbing or releasing energy to stabilize frequency.
- **Energy Arbitrage**: This involves buying electricity when prices are low (usually during off-peak hours) and storing it for sale when prices are high (during peak hours).
- **Backup Power**: Energy storage systems provide backup power during outages, ensuring continuous operation for critical infrastructure and services.
- **Transmission and Distribution Deferral**: Energy storage can defer or eliminate the need for expensive upgrades to transmission and distribution infrastructure by managing load and reducing congestion.
- **Ancillary Services**: Energy storage systems provide various ancillary services to the grid, such as voltage support, spinning reserve, and black start capabilities.

These models highlight the versatility and economic potential of energy storage in different segments of the electricity market. There are four types of initiatives in this area, especially city-scale renewable energy systems. These systems, combined with storage, can significantly enhance urban energy resilience and sustainability:

- **Public-Private Partnerships (PPP)**:Collaboration between government entities and private companies to fund, build, and operate RES-plus-storage systems.
- **Utility-Owned Systems**: Utilities invest in and manage large-scale renewable energy and storage projects, integrating them into their existing infrastructure.
- **Community Energy Projects**: Local communities invest in shared renewable energy and storage systems, benefiting from collective ownership and shared savings.

- **Energy-as-a-Service (EaaS)**: Companies provide renewable energy and storage solutions as a service, with cities paying for the energy consumed rather than the infrastructure.

1.6 The organization of other energy storage systems

Heat storages are not yet very common in Poland, but there are some examples, like facilities of PGE. PGE Energia Ciepła already has heat storage systems in its combined heat and power plants (CHP), e.g. in Toruń, whose task is to optimize the production profile of electric power in cogeneration and to use peak power in transitional periods. The company also completed two research projects related to cooling networks, e.g. in Zielona Góra.

A heat accumulator has been in operation at the Białystok CHP Plant (Enea) since December 2011, with basic parameters:

thermal power – 130 MW,

max. amount of stored heat – 780 MWh (water temperature of 40 - 98 °C),

working capacity of 12,000 m^3, total 13,000 m^3,

loading speed 3,000 m^3/h and discharging 2,000 m^3/h.

There is a big heat storage system with total capacity of 30,000 m^3 at the Siekierki CHP Plant (PGNiG Termika) in Warsaw, since 2009.

The most interesting solution seems to be the implementation of the Power-to-Heat (P2H) technology, which uses the ability to store surplus electricity in the form of heat, using a cooperating electrode boiler and heat accumulator. This has already been partially implemented at the Gdańsk CHP Plant (PGE Energia Ciepła), i.e. two electrode boilers, with a capacity of 35 MW each, and a heat storage tank is planned.