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Carbon driven energy equilibrium at the municipal scale – Energy Equilibrium

GoA 1.3 - Build first prototype of an Energy Equilibrium platform

D 1.3 Final report

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Interreg Baltic Sea Region
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ENERGY TRANSITION
Energy Equilibrium

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1 About the Energy Equilibrium project

1.1 Context and challenge

To compensate the variability and non-controllability of seasonally generated renewable energy (RES) (daily fluctuations in solar radiation intensity, wind speed, etc.) development of sufficient energy storage infrastructure in the regions will play a major role in transforming RES supply potential into reality. However, local public authorities that are responsible for creating an enabling policy environment for RES infrastructure development in regions encounter numerous challenges and uncertainties in deploying sufficient energy accumulation that often remain unanswered due to a lack of knowledge and on-site capacity, which in turn significantly hinders the regional path to climate neutrality.

The project aims to identify renewable energy potential in local energy systems and to support local public authorities in decision-making regarding the development of sufficient renewable energy infrastructure in the region, including the integration of energy storage.

1.2 Aim of the Energy Equilibrium project

This project aims to develop an Energy Equilibrium Platform – an interactive and easily applicable tool to support municipalities and energy suppliers in decision-making related to the development of efficient action plans to accelerate local RES utilization in the region. Energy Equilibrium Platform will help municipalities to:

1) Identify the most optimal RES storage development strategy and its impact on energy flexibility in the region;
2) Help to determine the key factors affecting energy equilibrium (balance between the produced and the consumed energy) in the region;
3) Help to develop policy mechanisms and action plans to enhance local RES in the region;
4) Help to anticipate risks and avoid making expensive mistakes (e.g. investing in inappropriate technological solutions).

2 Prototype of the Energy Equilibrium platform

2.1 Aim of development of the prototype

The goal of this activity is to build the first prototype of the main output of this project - the Energy Equilibrium Platform. This platform will serve as an energy modelling and policy simulation tool for municipalities to develop the most optimal RES strategies for the region, including the development of energy storage infrastructure. The goal of the Energy Equilibrium Platform is to support the decision-making process of local public authorities in developing future action plans for renewable energy and sustainability in regions.

Building a prototype for the Energy Equilibrium Platform is crucial for several reasons, given its role as an energy modeling and policy simulation tool for municipalities. Below are some key reasons why building a prototype is important in the project context:

- **Validation of Concept:** A prototype allows stakeholders to validate the concept and functionality of the Energy Equilibrium Platform. It ensures that the envisioned features and capabilities align with the actual needs and requirements of municipalities and other target groups.
- **User Feedback:** By creating a prototype, we can obtain valuable feedback from potential users, such as local public authorities, energy suppliers, renewable energy associations, and other key target groups. This feedback is crucial in improving and adjusting the platform, making it more user-friendly and aligned with the specific needs and challenges faced by municipalities who will be the main users of the platform.
- **Identifying Issues Early:** The prototype serves as a testing tool to identify any technical or usability issues early in the development process. Addressing these issues at the prototype stage is more cost-effective than making changes after the full development of the platform.
- **Demonstration of Functionality:** The prototype can be used to demonstrate the core functionalities of the Energy Equilibrium Platform. This demonstration is valuable for securing stakeholder engagement and support, as it provides a tangible representation of how the platform will contribute to the decision-making process for renewable energy and sustainability.
- **Iterative Development:** Prototype development supports an iterative development approach, allowing for significant improvements based on ongoing feedback and testing. This iterative process is essential for adapting to evolving requirements and incorporating new insights gained during the development phase.
- **Enhanced Communication:** The prototype serves as a visual and tangible communication tool for stakeholders, fostering a better understanding of the platform's capabilities. This can facilitate more effective communication between municipality representatives, energy managers and engineers, and other stakeholders.

Development of Energy Equilibrium platform contributes to the overall efficiency, effectiveness, and acceptance of the final product among its intended users.

Three group model prototype versions were developed and approbated in group model building session (GoA 1.4.) in order to fine-tune the model:

- Energy Equilibrium first platform prototype from first group model building activity available here: https://exchange.iseesystems.com/public/testlearntestsagain/model-rtu-campus/index.html
- Energy Equilibrium second platform prototype from the second group model building activity included energy production and storage segments only available here: https://exchange.iseesystems.com/public/testlearntestsagain/municipality-model/index.html#page1
- Energy Equilibrium third platform prototype from the third group model building activity included added segments of building energy demand and is available here: https://exchange.iseesystems.com/public/testlearntestsagain/municipality-model/index.html#page1

Based on the developed model prototype versions the final output of the project – Energy Equilibrium platform will be built and piloted in the BSR municipalities. Piloting activities will be implemented in Work Package 2.

2.2 Aim of this report

This deliverable is the representation of the prototype of the project's main output – Energy Equilibrium platform. Deliverable is summarised in a comprehensive report which describes key approach used in model development. Deliverable provides an overview of the main structure of the model, model boundaries and assumptions, main technologies included, and data utilized. Moreover, the report describes the model development process chronologically and presents the features of the model interface. A walkthrough example is demonstrated to explain the Energy Equilibrium platform prototype utilization in practice.

The report outlines the key assumptions and approach for the project's system dynamics model. The report provides insights into the backend of the system dynamics modelling and demonstrate the interface of the model visible to the public. Specific details and assumptions of the system dynamics will be further developed and described in the next phases of project implementation once the municipality piloting is complete.

3 Energy Equilibrium system dynamics model structure

3.1 System dynamics modelling

The computational programmes of system dynamics (SD) enable the modelling of complex, time-variable, dynamic processes. SD theory is based on the study of dynamic, time-dependent behaviour and the modelling of the underlying structure of behaviour. By analysing the system structure and the mutual interaction of the individual system components, one can understand the causal relationships of the driving forces of the system, which in turn makes it possible to define where and what influence is required to improve the overall performance of the system. SD modelling can be used in a broad spectrum for the analysis of complex systems in various fields - social and natural sciences, engineering sciences and technological processes. The use of SD modelling in the energy sector has increased over the last decade.

In this project, system dynamics modelling is used to reproduce the energy system of the municipality. The model takes into account energy inflows and outflows by including energy production, consumption, and storage. System dynamics modelling allows to investigate and solve complex challenges such as the regional energy transition and decarbonisation. SD takes into account the system behaviour of a municipality and the underlying structure of this system. Model was built using Stella® Architect software – a leading computer simulation-based systems thinking and dynamic modelling software. Model was developed by the lead partner of the Energy Equilibrium project in the scope of the purchased licence of Stella® Architect software. The overall model building consists of several steps that are outlined in Fig. 3.1.

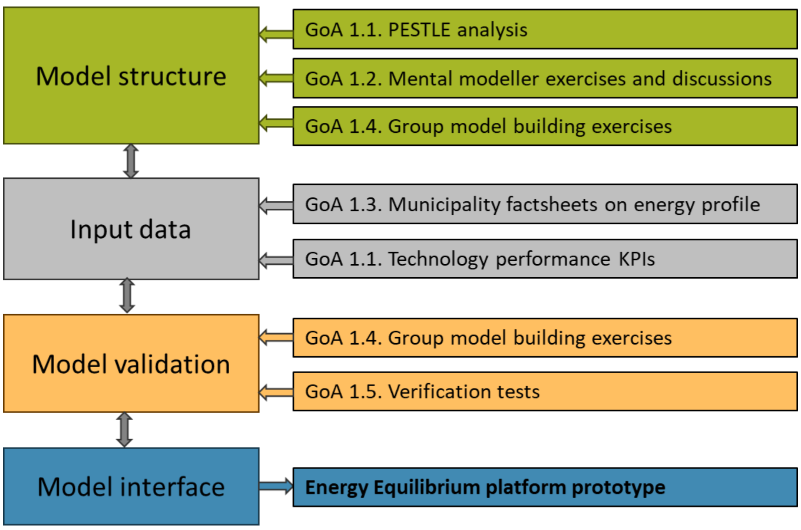


Fig. 3.1. Development process of system dynamics model for the Energy Equilibrium platform.

At first model structure is defined. Model structure is determined, improved and supplemented through various activities. In the Energy Equilibrium project, the primary structure of the system dynamics model drew upon the extensive experience of the lead partner in developing SD models within the context of energy transition. Additionally, it was informed by the comprehensive insights generated through active collaboration with project partners throughout the course of the project. The determination of the model structure was informed by insights gleaned from the PESTLE analysis conducted on energy storage technologies (as outlined in GoA 1.1), mental model exercises, and stakeholder discussions (detailed in GoA 1.2). Furthermore, the structure was shaped by the valuable input derived from group model building sessions implemented as part of the project (described in GoA 1.4).

The input data provided by the municipalities also played an important role in the development of the model. To build the platform prototype, the municipalities were required to provide data on the structure of their current energy system in the region - information on the main sources of electricity and heat in the region, which technologies are currently in use and how energy is generated and delivered to the different sectors (industry, households and other sectors). The project partners worked closely with the municipalities to collect all the necessary information. In general, the model contains a lot of input data related to the performance indicators of the technologies, investment costs, energy prices, emission factors and others. This data is obtained from the technology catalogues, scientific literature and other relevant sources.

Furthermore, model is validated and tested by the target groups and stakeholders of the project. Model is validated by verification tests run at the backend and more importantly – through group model building sessions. During the sessions target groups were able to raise concerns related to model structure and reliability of the produced simulation results (see more in GoA 1.4. report). Feedback obtained from target groups was evaluated and relevant suggestions were integrated in the model. Finally, model interface through which Energy Equilibrium platform prototypes are accessed by the general public is obtained. Interface functionality is improved by the feedback received from group model building sessions.

3.2 Model boundaries

Model includes energy demand in all the main end-consumer sectors such as households (distributed by the single family and multifamily buildings), public sector (municipality infrastructure), industry, services, agriculture, transport sectors. Main input data on energy consumption in these sectors is taken from the municipality provided data in the “Municipality factsheets” (for more information see GoA 1.5.). However, it should be taken into account that modelling is done only in the positions where data was available. In the missing data segments modelling can be performed based on the assumptions.

Model includes and replicates the municipal energy profile which includes electricity and heat demand distributed by the main sectors, transport energy consumption, electricity and heat produced by the municipal power plants and local district heating networks, as well as existing energy storage solutions. Model simulations are based on five-year historical data (2018-2022) provided by the municipalities.

Model simulation time step is one year. Total simulation period is extended to year 2050, considering that energy infrastructure solutions are long-term development projects. Total simulation time frame can be easily changed and adjusted in the model.

The solutions developed in the model are not directly comparable to the solutions developed at the engineering design level. When developing a project, a detailed study of the situation should be carried out, solutions should be developed that correspond to each building separately. Generalizations and assumptions have been made in the research stage of the modelling. Model represents the results obtained under defined boundary conditions. The level of detail of the model allows changes to be made both in the initial model structure according to research conditions and in the development of scenarios, taking into account some specific solutions, as well as changes in input indicators such as tariffs, and others.

3.3 Model structure

The overall model comprises a collection of distinct sub-models each addressing specific aspects of the system. These sub-models encompass heat demand, electricity demand, heat supply and storage, electricity supply and storage, energy efficiency impact, energy production and technology costs, as well as calculations of heat and electricity balances, storage forecasts and potentials and many others. Furthermore, the model incorporates historical data for various parameters, such as solar radiation, electricity consumption, electricity prices, and outdoor air temperature.

General structure of the model is illustrated in the Figure 3.2. Model structure consist of the four main pillars – energy demand, energy resources, energy production, and energy storage. Energy demand pillar consist of the electricity and heat demand in the main sectors of the economy – household sector (single family buildings, apartments), public sector (municipality infrastructure including buildings, public street lighting and other consumers), industrial sector, services sector (commercial), and agricultural sector.

Moreover, energy demand is also complemented by the transport sector demand which includes fuel consumption of municipal vehicles, public transport, and private cars. The main drivers of energy demand in municipalities are represented by socio-demographic factors such as population growth and the number of inhabited households. The total population size is a primary driver of energy demand in a municipality. A larger population generally means more residential, commercial, and industrial activities, all of which contribute to increased energy consumption. The total number of households is a key determinant of residential energy demand. Each household consumes energy for lighting, space heating, cooling, cooking, and electronic devices. Model considers initial population size and allows to model scenarios based on growth or decline in total population size of the municipality.

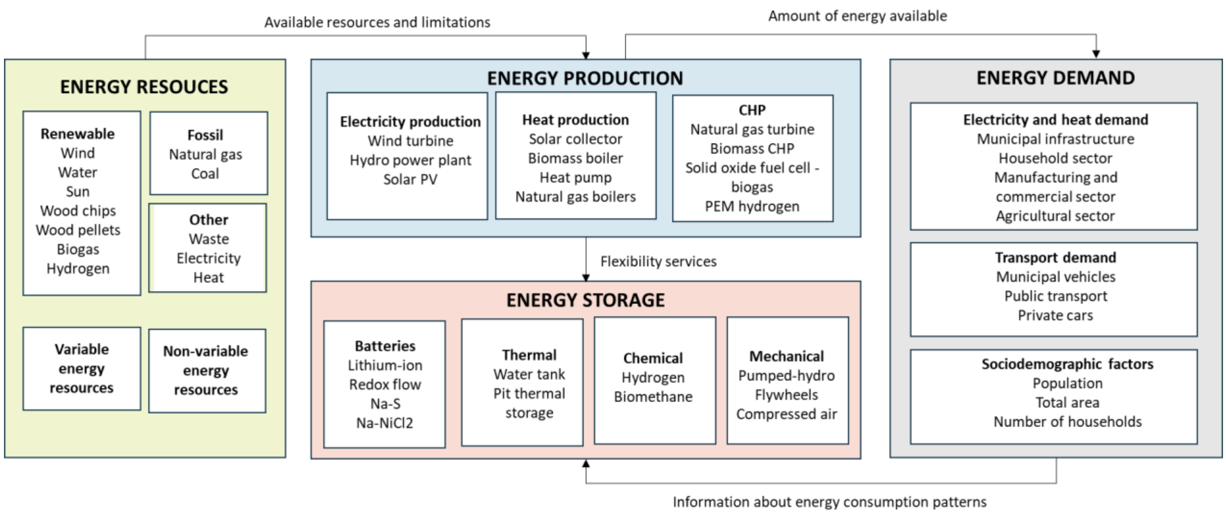


Fig. 3.2. General structure of the system dynamics model.

The structure of the model revolves around understanding and optimizing energy dynamics within a municipality. This involves a comprehensive analysis of energy demand, which serves as a crucial indicator for energy consumption patterns, thereby providing valuable insights for the energy supply infrastructure. The energy supply in the municipality is delineated into three fundamental pillars: energy resources, energy production technologies, and energy storage technologies. The energy resources pillar serves as a repository listing all available fuels utilized in electricity or heat production. These fuels are categorized as either variable (subject to weather changes) or non-variable energy sources (ensuring a consistent supply). This categorization provides vital signals regarding resource availability and limitations specific to the municipal region.

The energy production pillar incorporates a spectrum of technologies for electricity production, heat production, and combined heat and power (CHP). Table 3.1 lists a summary of the primary technologies embedded in the model.

Table 3.1.

Primary technologies embedded in the model.

Segment	Included technologies
Fuels	Wind, Water, Sun Natural gas, Coal Electricity, Heat Waste, Biogas Wood Chips, Wood Pellets, Straw Hydrogen
Electricity production	Onshore horizontal axis wind turbine (HAWT) Hydro power plant Utility-scale solar PV Condensing natural gas power plant
Heat production	Absorption heat pump Air source heat pump Water source heat pump Electric boiler Solar collector Natural gas boiler Wood chip boiler
CHP	Natural gas turbine Wood chips CHP Wood pellets CHP Straw CHP Solid oxide fuel cell - biogas Fuel cell proton exchange membrane (PEM) - hydrogen
Energy storage	Water tank for thermal storage Pit thermal storage Lithium-ion battery Vanadium redox flow battery Na-S battery Na-NiCl2 battery Hydrogen storage in liquid organic hydrogen carrier (LOHC)

The variability of energy resources plays a pivotal role in determining the degree of flexibility services required in the system. This pillar acts as a bridge connecting the available resources to the technologies that efficiently harness them. The energy storage pillar emerges as a critical element for maintaining equilibrium between variable energy supply and demand peaks. This pillar integrates various storage technologies and solutions, serving as a mechanism to manage surplus renewable energy production and redistribute it during periods of peak energy demand. The inclusion of diverse storage technologies in the model contributes to the efficient handling of fluctuating energy patterns.

All aspects of energy sustainability, including economic, technical, social, and environmental considerations, are incorporated into the model. Several calculations pertaining to these aspects is incorporated and taken into consideration. Table 3.2 summarizes energy sustainability dimensions integrated and represented in the model.

Table 3.2.

Energy sustainability dimensions integrated and represented in the model.

Economic Investment costs Operation and maintenance costs Technology lifetime Payback time Total system costs Energy tariffs Investment financing sources	**Technical** Capacity Efficiency Production full load hours Annual cycles Capacity order rates Technology construction time Technology specific performance indicators
Environmental Fuel emission factors Total system emissions Share of renewable energy Energy efficiency trend observation Energy decarbonization trend observation Movement to energy sustainability and climate neutrality	**Social** Information campaign Efficiency diffusion factors Expertise and Knowledge Financial Considerations Implementation and Technology Psychological and Social Factors Organizational and Leadership Support

The subsequent sections offer a deeper understanding of the different segments that comprise the system dynamics model. Five main sub-models are described generally – energy demand model, energy resources and renewable energy production model, energy production and storage model, emission model, system costs model.

3.3.1 Energy demand model

Building energy demand and renovation sub-model

The building's total heating area and a specific energy consumption indicator for both heat and electricity are the two main factors that determine the building's overall current energy consumption. To determine the overall energy consumption of non-renovated buildings, the model takes into account the percentage of non-renovated buildings from the total heating area. Table 3.4. (listed in chapter 3.4.) lists the primary specific consumption indicators that are set as baseline values and are readily customisable to the particular circumstances of the municipality. Figure 3.3 illustrate the system dynamics sub-model for building sector renovation.

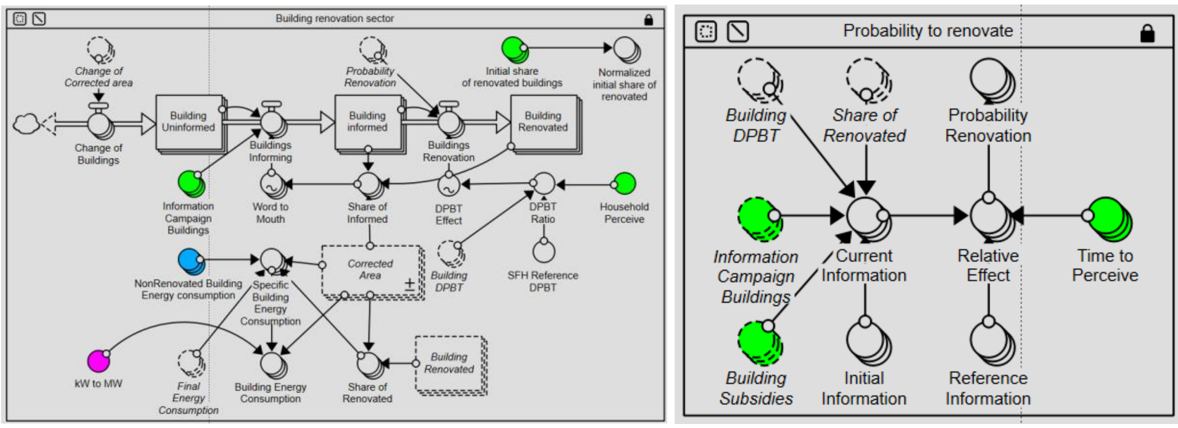


Figure 3.3. System dynamics sub-model for building sector renovation.

The energy consumption of renovated buildings is computed using data on the proportion of renovated buildings. The model takes into account a particular percentage of the building's post-renovation decrease in heat and electricity consumption. Thus, the energy consumption of renovated buildings is determined by taking into account the percentage of renovated buildings as well as the assumed reduction in energy consumption when compared to the energy consumption of non-renovated buildings. As base values model assumes the renovation savings to be 50% heat decrease and 30% electricity decrease.

The strength of the information is the key factor influencing the speed of renovation and the potential commitment to renovating the buildings. The model has a structure that makes it possible to simulate an information campaign of different strengths. Actual information campaigns are only marginally stronger than no information campaigns at all. A stronger campaign increases the number of informed buildings. The model assumes that the more buildings are informed, the higher the speed of renovation in the future.

Information campaigns can be used to accelerate the insulation process (to make people aware of the importance of insulation of buildings) (R1 loop), depending on the number of uninsulated buildings (owned by uninformed people) and the perceived number of well-insulated buildings (which creates an oral effect). When people are informed, it increases potential projects, and further in-creases demand. Increased demand increases capacity by stimulating the insulation of buildings.

Building renovation sub-model building owners decide whether to improve energy efficiency through renovation work based on several factors that influence energy efficiency. In the system dynamics model it is represented as the “Probability to renovate” factors. These factors have been identified for households (apartment), industry, services and the public (municipal) sector on the basis of the “Assessment and analysis of energy efficiency policies” research project [1]. These factors are listed in Table 3.3. The factors are merged in the following groups:

- **Expertise and Knowledge**: This encompasses the involvement of energy specialists, employee involvement, knowledge about energy efficiency, and competence in implementing energy efficiency measures. It's a key factor across all sectors, highlighting the need for specialized knowledge and skilled personnel.
- **Financial Considerations**: This includes aspects like payback time, adequacy of financial resources, knowledge of additional costs and risks, and long-term benefit perception. These factors are crucial in decision-making as they directly impact the financial feasibility and return on investment.
- **Implementation and Technology**: This point covers the resource and time intensity of implementing energy efficiency, availability of energy efficiency technologies, and house suitability for renovation. It focuses on the practical aspects of carrying out renovation projects.
- **Psychological and Social Factors**: This includes fear of repeated failure with energy efficiency measures, trust in external consultants and suppliers, positive attitude towards energy efficiency, and trust in neighbours. These factors highlight the importance of confidence, social proof, and trust in successful renovation projects.
- **Organizational and Leadership Support**: This involves the importance of energy efficiency for the company or management, leader support, and belief in the benefits. It emphasizes the role of leadership and organizational culture in driving energy efficiency initiatives.

The survey results are integrated as nonlinear relationships between the probability that the building owner wants to participate in the insulation of the building and various influencing factors. The actual value of a factor is the value of each factor at that moment in the real system. It is a variable and can be determined by conducting surveys.

Time is required for information perception, and in the model, it is depicted as the time needed for changes in the factor. It is used to calculate the perceived relative changes in the factor. The relationship between the perceived relative changes in the factor and the indicated probability of investing in energy efficiency is nonlinear. It can take various forms, depending on the relationship identified in the real system and is denoted by the elevated relative change effect on the indicated probability.

All probability factors are multiplied, and the total probability of investing in energy efficiency measures is obtained. All factors have actual and reference values from 1 to 10. The assumed time for changes in perception and the time to increase/decrease the probability in the model is set at 3 years. The total probability that owners of multi-apartment buildings will invest in energy efficiency measures is calculated as the product of all probabilities.

Table 3.3.

Energy efficiency diffusion factors (probability to renovate), retrieved from [1].

Energy efficiency diffusion impact factors for household sector	Financial benefits Long term benefit perception Manager support Leader Belief of the benefits Positive attitude towards energy efficiency Trust in neighbours Fear of losing apartment Perception of work quality Know someone living in a renovated house House suitability for renovation Inconvenience costs
Energy efficiency diffusion impact factors for industry sector	Involvement of energy specialist Employee involvement Payback time Knowledge of additional costs and risks Adequacy of financial resources Resource and time intensity of implementing energy efficiency Fear of repeated failure with energy efficiency measures Knowledge about energy efficiency Importance of energy efficiency for the company Availability of energy efficiency technologies Trust in external consultants and suppliers Competence in implementing energy efficiency
Energy efficiency diffusion impact factors for public sector	Involvement of energy specialist Employee involvement Payback time Knowledge of additional costs and risks Adequacy of financial resources Resource and time intensity of implementing energy efficiency Fear of repeated failure with energy efficiency measures Knowledge about energy efficiency Involvement of other municipalities Importance of energy efficiency to management Trust in external consultants and suppliers
Energy efficiency diffusion impact factors for services sector	Involvement of energy specialist Employee involvement Payback time Knowledge of additional costs and risks Adequacy of financial resources Resource and time intensity of implementing energy efficiency Fear of repeated failure with energy efficiency measures Knowledge about energy efficiency Importance of energy efficiency for the company Availability of energy efficiency technologies Trust in external consultants and suppliers Competence in implementing energy efficiency

Renovation financing sub-model

The model incorporates a sub-model dedicated to renovation financing, as depicted in Figure 3.4. It identifies three primary sources of energy efficiency financing: self-financing, loans, and subsidies. Notably, the model accommodates flexible parameters for the repayment of renovation loans, allowing easy adjustments to variables such as interest rates and loan terms. Table 3.5. (in chapter 3.4.) lists economic and financial base values considered in the model.

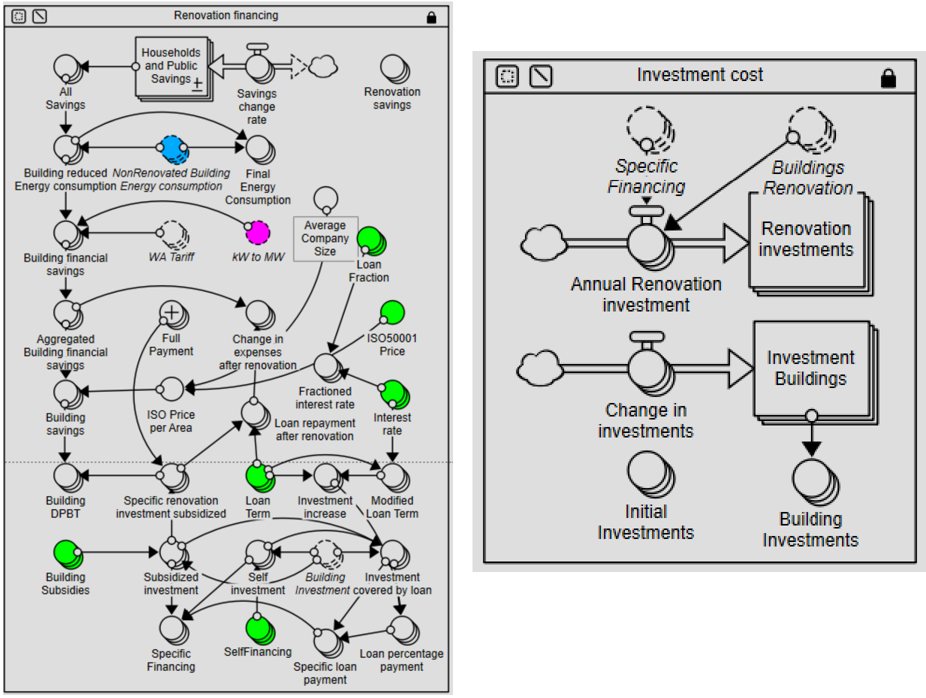


Fig. 3.4. Renovation financing sub-model structure

For a comprehensive calculation of renovation expenses, the model incorporates baseline values for building insulation costs, expressed in EUR per m^2. Table 3.5. provides a summary of these fundamental values; however, it's important to note that these figures can be readily customized to suit the unique circumstances of specific countries and municipalities. This adaptability ensures that the model remains relevant and applicable across diverse scenarios. Regarding the energy efficiency in industry model calculates energy demand based on average company size which is assumed to be 3000 m2. As base value for ISO 50001 price is 3000 EUR/year.

Transport energy demand

Transport energy demand model is illustrated in Figure 3.5. The current fleet of both public and private transportation, the distances travelled, and the specific vehicle fuel consumption all contribute to the determination of the fuel demand in the transportation sector. In order to ascertain the overall demand for private and public transport as well as the number of passenger kilometres travelled, the change in population is also taken into consideration. Several parameters, including the lifetime of the vehicle, the price of the vehicle, the costs of maintenance, and insurance, are incorporated into the calculations in order to arrive at the overall price of the vehicle per lifetime distance.

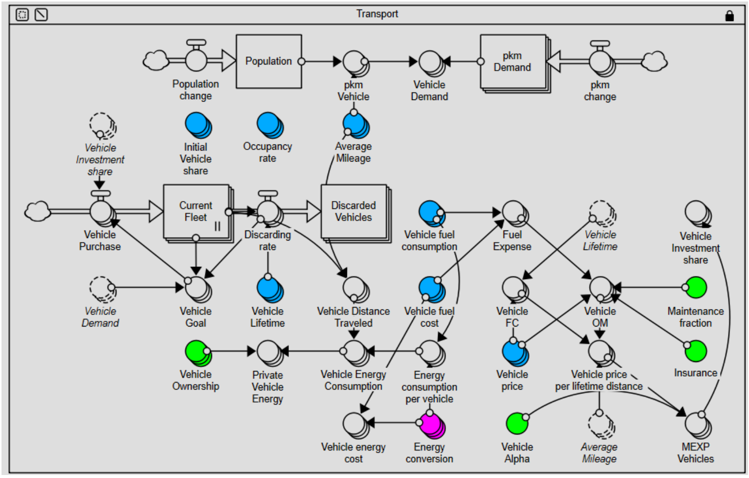


Fig. 3.5. System dynamics model structure of transport energy demand.

Table 3.12. (listed in chapter 3.4.) summarizes the main input values used in transport sector energy demand. These values are adjustable and customizable during the modelling process to adjust to the specific municipality needs.

3.3.2 Energy resources and renewable energy production model

Energy resources model is responsible for representation of the energy tariff calculation and changes in the tariff due to the changes in the used energy production fuel. Figure 3.6. illustrates the energy resources and renewable energy production sub-models.

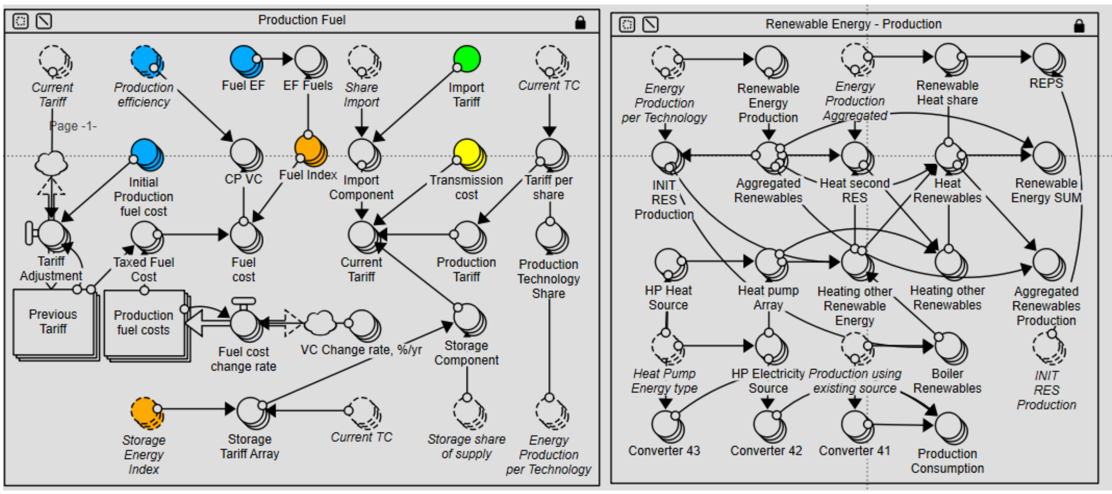


Fig. 3.6. Energy resources and renewable energy production sub-models.

This model segment calculates the production costs associated with fuel. These costs are determined by considering both variable production costs and changes in these variables. Variable costs, in turn, are influenced by the efficiency of the specific technology used in production. Additionally, the cost of fuel production is affected by the fuel emission factor and any applicable fuel tax.

The determination of costs also takes into account the potential use of storage, which plays a role in influencing the tariff associated with the fuel. Moreover, the tariff is influenced by the proportion of imported energy used to meet the demand. In essence, various factors contribute to shaping the overall cost structure, including the efficiency of production technology, emission factors, taxes, storage considerations, and the reliance on imported energy sources.

The current tariff is established through the consideration of four primary components: the energy production tariff, energy transmission costs, the energy import component, and the energy storage component. The model sets the baseline values for transmission at 60 EUR/MWh for electricity and 40 EUR/MWh for heat. While the assumed import tariff is 80 EUR/MWh, it's essential to note that these values are adjustable to accommodate specific requirements and conditions.

3.3.3 Energy production and storage model

General production and storage sub-model

The energy production and storage model comprehensively addresses all energy generation technologies and establishes storage size based on specific production characteristics, as illustrated in Figure 3.7. It takes into account the existing energy production infrastructure, considering both the operational capacity of current technologies and the potential for new installations (ordered capacity).

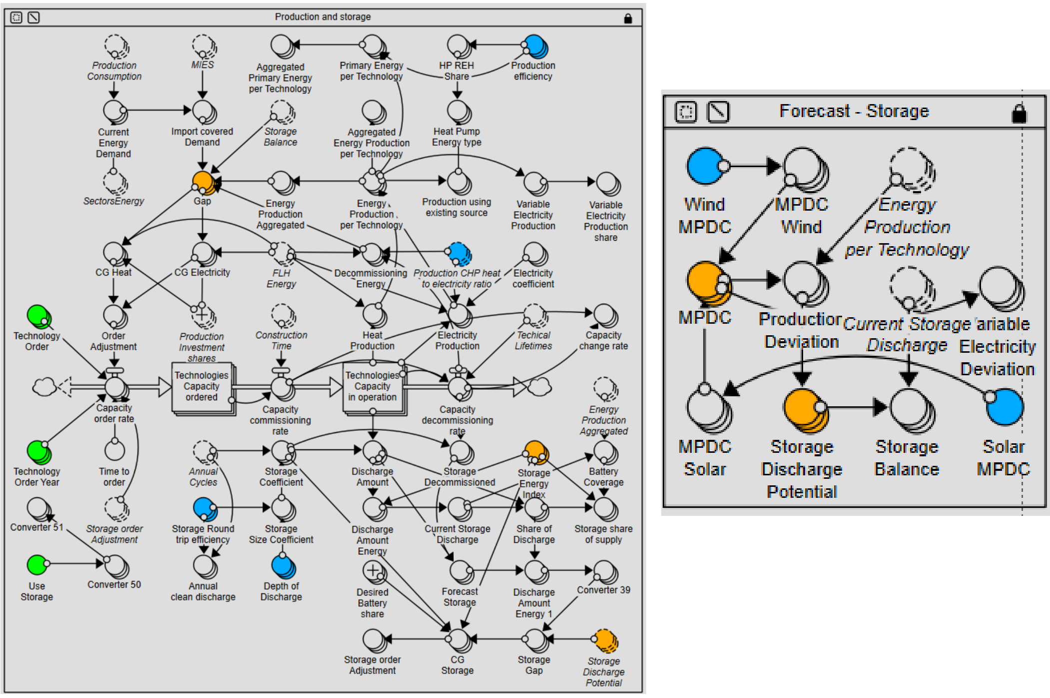


Fig. 3.7. Energy production and storage sub-model structure

The model incorporates a temporal perspective, acknowledging delays from the order phase to construction, installation, and eventual operation of technologies. Adjustments are made based on construction and ordering times, with the main flow focusing on the interplay between operational capacity and newly added capacity. The model seeks to determine a balanced approach, factoring in delays, to guide decisions on the appropriate amount of new power that should be ordered.

Annual full load hours for renewable energy sources (RES) are calculated based on climate factors such as solar irradiation and wind speed. The energy production for each technology is determined, considering the efficiency level. Production amounts are derived from the multiplication of capacity and operational hours (capacity x operation hours). For renewable energy, full load annual hours are influenced by climate data, with a normalization process based on the exponential function of price per unit of energy. The model employs the LOGIT function in system dynamics to identify the production technology with the lowest cost, setting limits to account for climate variability and the absence of storage.

The model also predicts energy storage needs, taking deviations above average solar/wind conditions into account for storage and release. It calculates the dimensions of the storage system, assessing discharge potentials and recommending suitable systems, considering production variability (e.g. peak hours).

Cogeneration sub-model

Cogeneration performance and production sub-model is separately integrated into system dynamics model, its integrated parameters are illustrated in the Figure 3.8. The cogeneration system dynamics model intricately captures the dynamics of a combined heat and power (CHP) system, considering a range of parameters for a comprehensive analysis. This model integrates crucial factors such as Production CHP Efficiency, which quantifies the system's effectiveness in converting fuel into both electricity and useful thermal energy. Cogeneration Efficiency provides an overall measure of simultaneously producing electricity and thermal energy.

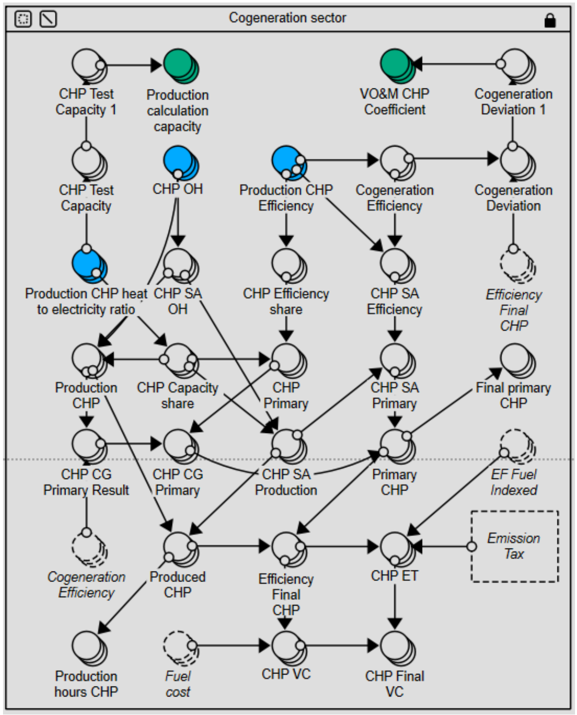


Fig. 3.8. System dynamics model structure of cogeneration sector.

Other factors such as the share of CHP efficiency, the ratio of CHP heat to electricity, the share of CHP capacity, primary CHP and many others and their relationship in the model are shown in Figure 3.8.

Switch to District Heating

Building heat consumption is typically met either through district heating or individual heating systems. As part of the energy efficiency measures, the model incorporates a transition from individual heating to district heating. Figure 3.9. illustrates sub-model for switching to district heating.

The initial focus in the model is on examining the tariff structure for both district and individual heating. By understanding the distinctions between these heating methods and assessing their respective tariffs, the model determines the ratio between them. This ratio serves as a crucial factor in deciding whether a transition is feasible. The model introduces a transition effect, represented by a curve, to depict the gradual shift of the population from individual to district heating based on the established relationship.

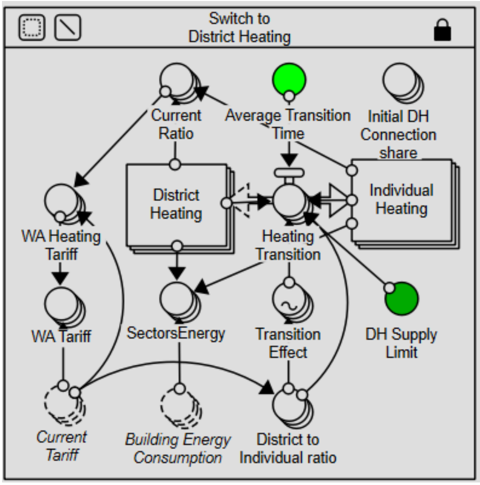


Fig. 3.9. System dynamics model structure for switch to district heating.

The transition process is contingent on the ratio; if individual heating remains economically advantageous (with a low ratio), the transition is deferred. Conversely, if the ratio is high, indicating the cost-effectiveness of district heating, the shift is activated. The model incorporates a time adjustment factor, ensuring a gradual and realistic transition. The current ratio of individual to district heating is continually assessed against the average weighted tariff. This evaluation helps estimate the average payback time for each sector, guiding decision-making for the transition process.

Hydrogen and biomethane

Hydrogen and biomethane production sub-model is illustrated in the Figure 3.10. In general, the model assumes that Electricity generation relies solely on variable sources such as solar and wind. Consequently, the operational hours for the electrolysis process are determined based on factors like average deviation, technology operating time, and power availability.

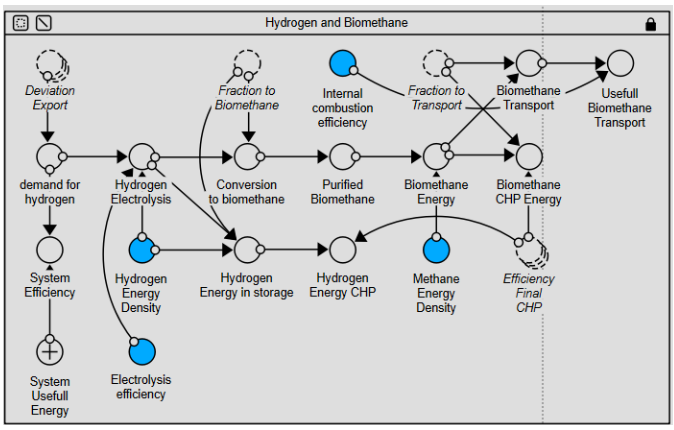


Figure 3.10. System dynamic structure of the hydrogen and biomethane production.

A portion of the produced hydrogen is utilized in the fuel cell's Combined Heat and Power (CHP) system. The allocation of hydrogen to the fuel cell is determined by evaluating the Levelized Cost of System (LCOS) for electrolysis, storage, and fuel cell costs. A comparison is made with biomethane system costs to decide the proportion directed towards biomethane production.

The biomethane mass chain is established stoichiometrically, assuming perfect efficiency. Biomethane finds applications in both CHP and transportation, with the transportation share determined by weighing the potential income from the fuel versus cogeneration plant.

In the case of Solid Oxide Fuel Cell (SOFC), the system now operates on biomethane instead of biogas. Proton Exchange Membrane (PEM) fuel cells, on the other hand, obtain required hydrogen directly from the process. In instances where hydrogen is not internally produced, the fuel cell CHP receives it externally. If biomethane is unavailable, a biogas CHP relies solely on biogas. Part of the CHP can shift to biomethane if it proves more beneficial, accounting for efficiency and cost considerations.

3.3.4 Emission model

The model includes a distinct sub-model specifically designed for calculating emissions of the energy sector, as depicted in Figure 3.11. Emissions are computed based on the emission factors associated with different fuels. Initially, emissions are determined on a per-technology basis and are subsequently aggregated to derive cumulative system emissions.

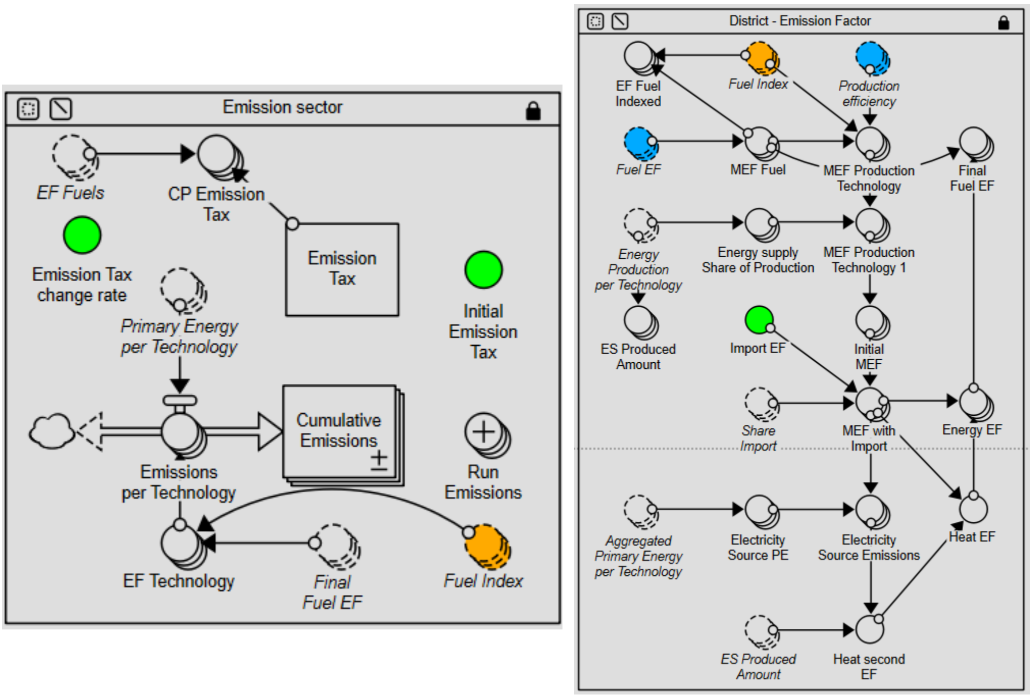


Figure. 3.11. System dynamics structure for emission calculation for entire system and district heating.

Notably, emissions for district heating are computed separately. This is because the emission factor specific to district heating does not extend to individual sectors. District heating, being a comprehensive chain of energy use, involves numerous diverse technologies. In contrast, individual heating typically relies on only one or two technologies. Therefore, the model accounts for this distinction in emission calculations, recognizing the unique complexities of district heating compared to the simpler nature of individual heating technologies.

3.3.5 System costs model

System dynamics model incorporates advanced system costs sub-model, as illustrated in the Figure 3.12. The system cost model comprehensively includes all specified costs and current tariffs. Initially, technology costs are computed individually for each technology and subsequently aggregated for the entire system. Key parameters such as discount rates, discount factors, technical lifetimes, and market tariffs are employed in determining the payback time for each technology.

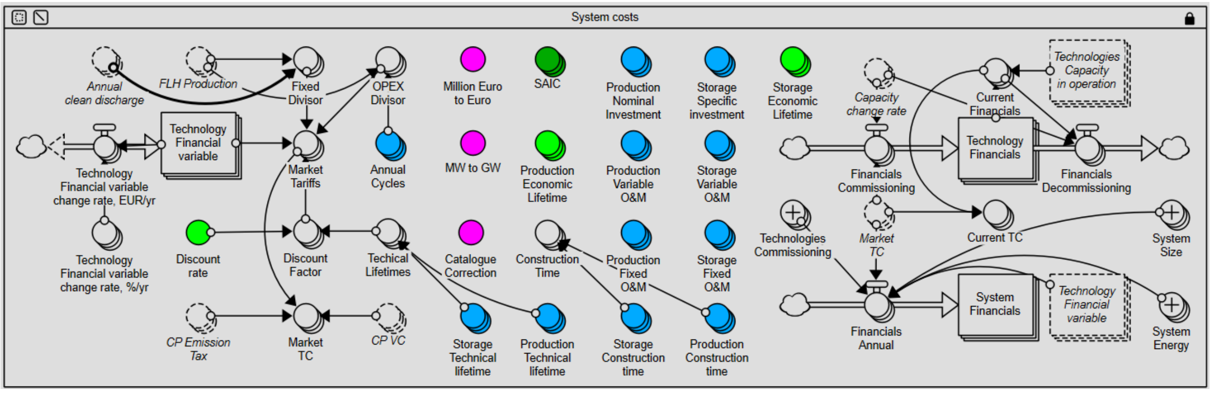


Fig. 3.12. System dynamics model structure of the system costs model.

The system cost model incorporates various factors, including fixed and variable operation and maintenance costs for production and storage, specific investment costs, technology construction times, economic lifetimes, and other critical elements. These integrated factors are utilized in economic feasibility assessments for the overall energy system within the model.

3.4 Input data

This chapter lists the primary input data used in the system dynamics model. It's important to note that all input data and assumptions are flexible and can be customized at any stage of the modelling process. The foundational values will undergo periodic review and adjustments to align with the latest available data and the specific requirements of municipalities.

Table 3.4.

Non-renovated buildings specific consumption base values

Sector	Electricity, kWh/m2	Heat, kWh/m2
Single family	20	150
Apartment	20	120
Industry	60	130
Services	35	155
Public	40	140

Table 3.5.

Loan term for renovation works, building investments for renovation works, size adjusted investment coefficient (SAIC), initial DH connection share, base values

Sector	**Loan term, years**	**Specific building investments for renovation works, EUR/m2**	**SAIC**	**Initial DH connection share, %**
Single family	10	250	1.6	50
Apartment	20	180	1.4	80
Industry	10	200	1.2	20
Services	10	200	1.2	20
Public	15	220	1.4	40

Table 3.6.

Time to perceive values for values of probabilities to renovate, retrieved from [1].

Factor	**Time to Perceive, years**
Expertise and knowledge	10
Financial Considerations	3
Implementation and Technology	10
Psychological and Social Factors	20
Organization and Leadership support	5

Table 3.7.

Energy prices of different energy sources, retrieved from [2]

	Coal, EUR/MWh	Natural gas, EUR/MWh	Wood chips, EUR/MWh	Wood pellets, EUR/MWh	Straw, straw pellets, EUR/t
2018	15.23	38.39	15.30	28.98	20.36
2019	15.35	36.49	11.13	34.08	33.14
2020	14.86	26.26	19.47	31.22	45.93
2021	18.06	32.70	25.73	30.20	58.72
2022	37.71	98.86	31.99	56.94	71.50

Table 3.8.

Energy prices of other fuels.

	Biogas, EUR/MWh [3]	Electricity from biogas, EUR/MWh [4]	Bio waste fuel, EUR/MWh (excluding taxes) [5]	Waste fuel (mixed waste and RDF), EUR/MWh (excluding taxes) [5]
Price, EUR/MWh	73.55	157.64	31.26	17.13

Table 3.9.

Emission factors of different fuels, retrieved from [6].

	Emission factor, kg/TJ	Emission factor, tCO_2/MWh
Natural gas	56100	0.202
Anthracite	98300	0.354
Coking Coal	94600	0.341
Other bituminous coal	94600	0.341
Sub-Bituminous Coal	96100	0.346
Lignite	101100	0.364
Municipal Wastes (non-biomass fraction)	91700	0.330
Municipal Wastes (biomass fraction)	100000	0.360
Industrial Wastes	143000	0.515
Waste Oils	73300	0.264
Landfill Gas	54600	0.197
Sludge Gas	54600	0.197
Other biogas	54600	0.197
Biogasoline	70800	0.255
Biodiesels	70800	0.255
Other liquid biofuels	79600	0.287

Table 3.10.

Energy production technology specific costs, retrieved from [7]

Electricity production	Initial fixed costs, MEUR/GWh	Initial variable O&M costs, EUR/MWh	Initial fixed O&M costs, EUR/MWh/yr
Onshore horizontal axis wind turbine (HAWT)	1.19	1.6	14900
Hydro power plant	5	0.035	30000
Utility-scale solar PV	0.56	0	11300
Condensing natural gas power plant	1.3	4.5	30000
Absorption heat pump	0.595	1.04	2130
Air source heat pump	0.915	1.8	2130
Water source heat pump	0.94	0.99	2050
Electric boiler	0.0744	0.957	1140
Solar collector	0.33	0.223	64.7
Natural gas boiler	0.0638	1.17	2070
Wood chip boiler	0.468	2.87	36800
Natural gas turbine	0.627	4.68	20700
Wood chips CHP	3.5	4.67	101000
Wood pellets CHP	2.39	1.83	65900
Straw CHP	3.59	2.24	130000
Solid oxide fuel cell - biogas	3.51	0	175000
Fuel cell proton exchange membrane (PEM) - hydrogen	1.38	0	69100

Table 3.11.

Energy storage technology specific costs [8]

Energy storage technologies	Initial fixed costs, MEUR/GWh	Initial variable O&M costs, EUR/MWh	Initial fixed O&M costs, EUR/MW/yr
Water tank for thermal storage	3.04	0	8.81
Pit thermal storage	0.593	0	3.07
Lithium-ion battery	520	2.13	287
Vanadium redox flow battery	638	0.957	12800
Na-S battery	330	1.91	4950
Na-NiCl2 battery	350	0.638	5250
Hydrogen storage in liquid organic hydrogen carrier (LOHC)	0.893	0.0000095	0.000038

Table 3.12.

Construction time, economic and technical lifetime base values for production and storage technologies.

	Production technologies	Storage technologies
Construction time, years	25	25
Economic lifetime, years	20	15
Technical lifetime, years	25	25

Table 3.13.

Average mileage and occupancy rate base values used in transport sector, retrieved from [9]

	Public	Private
Average Mileage, km/yr/vehicle	13000	45000
Occupancy rate, p/vehicle	2	15

4 Model prototype interface functionalities

4.1 Description and demonstration of model prototype interface

A preliminary model interface has been developed for the prototype of the Energy Equilibrium Platform. This version of the model interface (as of 28 November 2023) covers three main segments – building energy demand, energy generation and energy storage. It is a generalised model without taking any specific municipality data input.

Energy demand page

On the Building energy demand page, the user can set different parameters that drive energy demand in the different sectors. In the drop-down list user can select the respective sector (households, industry, public, services, transport, others) for which to perform modelling. Figure 4.1. illustrates buildings energy demand page of the Energy Equilibrium Platform prototype interface.

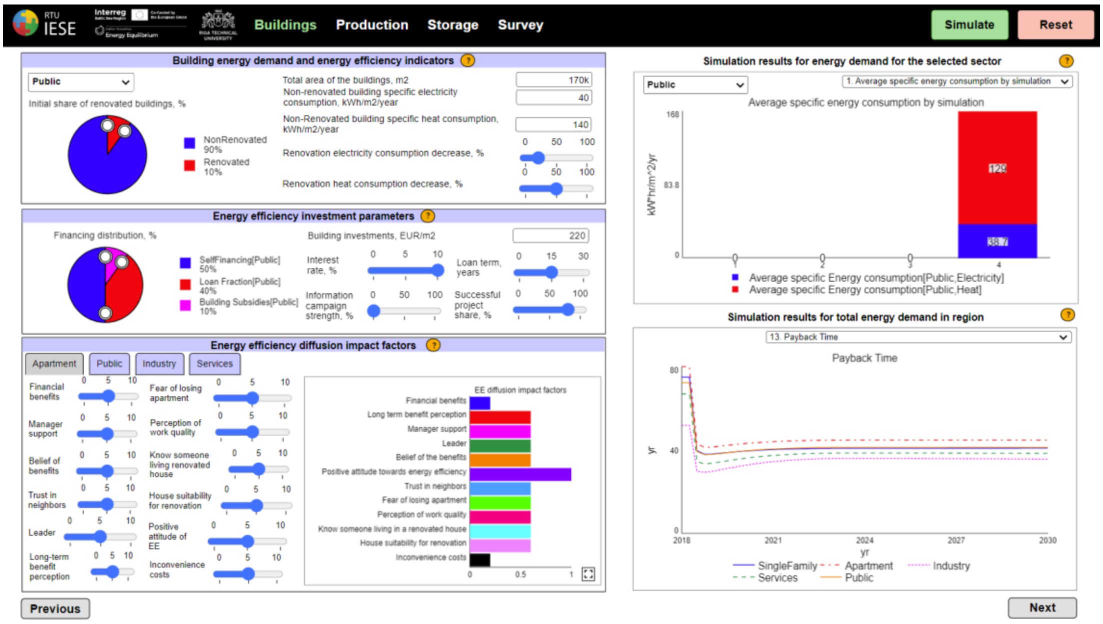


Fig. 4.1. Building energy demand page of the Energy Equilibrium platform prototype interface.

There are three main segments in the buildings energy demand page - building energy demand and energy efficiency indicators, energy efficiency investment parameters, energy efficiency diffusion impact factors. In the building energy demand and energy efficiency indicators section user needs to indicate the main building energy demand and efficiency indicators for each sector – households, public sector (municipality infrastructure), industry, and services. User can select the sector in the menu navigation tabs located on top of this section. For households sector you should specify the values for both – single family buildings and apartments by selecting the appropriate building from the drop-down list. In this section user should indicate the total area of the buildings in the specific sector and distribution of renovated and non-renovated buildings from total area. Moreover, user should specify the specific electricity and heat consumption indicators and projected decrease in energy consumption after the planned renovation activities. The values in the windows are adjustable according to your specific municipality.

In the Energy efficiency investment parameters section, you need to indicate the investment financing parameters for the renovation works. In financing distribution, user should select the share of the main sources of finances for renovation works – self-financing, loan, subsidies. Building investments window is adjustable for the values to be specified. If renovation works are financed through loan, then user is able to specify the interest rate and loan term. Information campaign strength - information measures are precisely aimed at the target audience and raise their understanding and awareness of building insulation issues. Information dissemination measures should be created as one of the overall set of energy efficiency policy measures. The strength of information measures - the impact of information measures on the formation of awareness. Successful project share represents the share of renovation projects that are successfully finalized from total project that have initially started the renovation efforts. There are some external factors that do influence successful completion such as increase of costs, unavailability of construction workers, etc.

In the Energy efficiency diffusion impact factors section user will find a list of social indicators that impact diffusion of energy efficiency. It is possible to choose initial values for those factors that affect the renovation rate of buildings in the selected sector. The values can be changed from 0 to 10 and it shows the value of each factor at the beginning of the simulation. The values can then be changed, and the impact results can be observed on the simulation results graphs.

On the Energy production page, the user can set various parameters that characterise the general energy system. Figure 4.2. illustrates energy production page of the Energy Equilibrium Platform prototype interface. For each parameter, user can find an ”information” sign highlighted in yellow. and by clicking with the mouse, on it user will find explanation of this parameter, depending on what is included in the model calculations.

The first segment in the interface on both next pages – energy production and energy storage - is the energy demand and economic parameters segment that stays unchanged in both pages. The model interface includes the following parameters that could be changed by the platform user.

Economic parameters

Energy demand mix, %. This parameter allows to select the total distribution of energy consumption in your municipality - share of heat and electricity in the total energy demand. User can change the distribution by moving the marked circles in the pie chart. It should be noted that this version of the model does not yet include transport consumption into account.

Change in energy demand, %/y. User can use this parameter to specify the projected annual change in energy demand. In the drop-down menu, you user select – electricity or heat – and specify the expected annual change accordingly by moving the slider.

Discount rate, %. This feature allows user to change the discount rate used in economic calculations. The discount rate is the interest rate used to calculate the present value of future cash flows from a project or investment.

Electricity import tariff, EUR/MWh. This parameter represents the price for the electricity purchased from the grid. By moving the slider, user can indicate the current average price of the purchased electricity.

Fig. 4.2. Energy production page of the Energy Equilibrium platform prototype interface.

Energy production technologies

Energy generation technology selection from the drop-down list. This feature allows user to select energy generation technologies that are currently in operation in municipality or for which new installations are planned. The list contains technologies for electricity and heat generation, CHP plants and technologies for hydrogen production. By pressing the button "Use technology", user indicates that the selected technology is either already installed or that its installation is planned in your municipality. Each time user selects a new technology from the drop-down list and if user wants this technology to be included in simulations, user must activate the button.

Planned newly installed capacity, MW. In this window user must indicate the planned newly installed capacities of the selected technology.

Construction Time, yr. This feature allows user to indicate the time it takes to construct and install the selected technology for newly installed capacity.

Year of order, year. In this window, user must specify the year in which the planned newly installed capacity of the selected technology was ordered (accepted for installation and ordered to the supplier).

Technology operational parameters for energy production technologies

Full-load production hours, hr/yr. Full load hours are the number of hours per year when a renewable energy asset produces electricity at its maximum capacity, i.e., installed capacity. Full load hours of the technology are determined based on its production capacity which is determined by solar radiation and wind speed. Full-load hours are a way of measuring energy that power plants create. They are used to show how many hours a plant would take to make a certain amount of energy if the plant is operating at full capacity.

Economic lifetime, yr. This feature allows user to indicate the economic lifetime of the selected technology by dragging the slider.

Technical lifetime, yr. This feature allows user to indicate the technical lifetime of the selected technology by dragging the slider.

Technology cost parameters

In the segment “Technology cost parameters” user can specify the specific investment costs and operational and maintenance costs of technology. Here in the model, there are values already taken from the Danish technology catalogue but the values in the windows are easily changeable and user can also specify projections in cost changes by dragging the sliders.

Initial fixed costs, MEUR/MW. This window allows user to specify the specific initial fixed costs of the selected technology. The slider allows user to indicate the annual change in specific initial fixed costs.

Initial variable O&M costs, EUR/MWh. This window allows user to specify the specific variable operation and maintenance costs of the selected technology. The slider allows user to indicate the annual change in specific variable operation and maintenance costs.

Initial fixed O&M costs, EUR/MW/yr. This window allows user to specify the specific initial fixed operation and maintenance costs of the selected technology. The slider allows user to indicate the annual change in specific fixed operation and maintenance costs.

Change in fixed costs, %/yr. Using this slider, you user change projection on change in investment costs.

Change in variable O&M costs, %/yr. Using this slider, user can change projection on change in variable operation and maintenance costs.

Change in fixed O&M costs, %/yr. Using this slider, user can change your projection on change in fixed operation and maintenance costs.

Energy storage technologies

On the Energy storage page, the user can set various parameters that adds energy storage technologies into the overall general energy system. In this page the principles and functionalities are the same as in the page for energy production. Figure 4.3. illustrates Energy storage page of the Energy Equilibrium platform prototype interface.

Energy generation technology selection from the drop-down list. This feature allows user to select energy storage technologies that are currently in operation in municipality or for which new installations are planned. The list contains technologies for electricity storage (different types of batteries) and heat storage (Pit Thermal Energy Storage and water tanks). By pressing the button "Use technology", user indicates that the selected technology is either already installed or that its installation is planned in your municipality. Each time user selects a new technology from the drop-down list and wants this technology to be included in your simulations, user must activate the button. In the window “Newly installed capacity” user must indicate the planned newly installed capacities of the selected technology.

Fig. 4.3. Energy storage page of the Energy Equilibrium platform prototype interface.

Technology operational parameters for energy storage technologies

Depth of Discharge, %. The depth of discharge (DoD) is a term used to quantify the extent to which the stored energy in an energy storage system is utilized during a discharge cycle. It is expressed as a percentage and represents the ratio of the amount of energy taken out of the system to the total energy capacity of the system. User can change the value by dragging the slider.

Annual cycles, 1/yr. Annual cycles represent how many times the energy storage system can be charged and discharged over the course of a year. For example, if a battery system is designed to undergo one full charge and discharge cycle per day, it would be said to have an annual cycle count of 365. This metric is important for understanding the durability and lifespan of an energy storage system, as the number of cycles it can endure can impact its overall performance and economic viability. User can change the value by dragging the slider.

Simulations

Once user has set the values for the measures, he/she wishes to implement, user can press the green button "*Simulate*" on the top right corner of the page to run the simulation. On the right user will find two sets of the results – on top of the page – simulation results for the selected technology (which user selected on the left side of the page) and on the bottom – simulation results for the entire system. On the right top corner of these graphs user can change the results you wish to view. User can run new simulations by changing the parameters and each time pressing the green button – Simulate. The results of each simulation will appear on the graphs next to the previous simulation results and user will be able to compare the achieved results. The red button "*Reset*" on the top of the page allows user to revert to the original version of the model.

Simulation results for selected technology

The simulation period of the model extends to the year 2040.

Total cost of production (TC) for the selected technology shows the cumulative total costs for the selected technology for the entire simulation period. Total cost of production includes all costs related to the installation and operation of the technology, i.e. the initial investment costs, the variable and fixed operation and maintenance costs, emission tax costs, and other costs.

The tariff components show the distribution of the total cost of production (CP) for the selected technology. Final tariff is composed of five main components – initial fixed costs (FC), variable operation and maintenance costs (VO&M), fixed operation and maintenance costs (FO&M), variable costs (VC) that include fuel costs, and emission tax.

Current price vs. Market price shows the comparison between the total costs of the selected technology at this point in time and the market price. The system behaviour shows that the market price is likely to be lower and fall faster than the current price due to factors such as the technology's learning curve and the technology's annual price decrease.

Technology installations chart shows the total capacity in operation and the capacity ordered for planned new installations for selected technology.

Storage share of supply chart shows the share of the selected energy storage technology in total energy supply in the municipality. For electricity storage technologies it shows the share from total electricity supply and for heat storage technologies it shows the share from total heat supply.

Discharge amount shows the total amount of discharged energy from the selected energy storage technology.

Simulation results for the entire system

TC System vs. Renewable energy share shows the scatter point of the simulation results obtained for the total cost of production and the respective share of renewable energy. The X-axis shows the total cost of production for the system for the entire simulation period, the Y- axis shows the total share of renewable energy for the system for the entire simulation period. The aim of the optimisation is to find the optimal solution that generates the highest share of renewable energy with the lowest total costs of production.

Renewable energy chart shows the achieved share of renewable energy for the entire system for the entire simulation period.

The cumulative emissions diagram shows the calculated cumulative emissions for the entire system for the entire simulation period.

Energy demand chart shows the distribution of the total energy demand in the municipality between total heat and electricity demand for the entire simulation period.

Energy production per technology chart shows the distribution of the produced total energy in municipality between heat and electricity.

Current tariff chart shows the calculated tariff of heat and electricity for the entire system. Tariff is calculated according to the total cost of production for the entire system.

Electricity storage potential chart shows the difference between the current electricity storage and the untapped potential for electricity storage in the municipality (the amount of excess electricity).

Heat storage potential chart shows the difference between the current heat storage and the untapped potential for heat storage in the municipality (the amount of excess heat).

The electricity and heat balances charts show the total electricity and heat flows of the system for the entire simulation period by emphasising the amount of existing excess energy, consumed renewable energy, consumed non-renewable energy, imported energy, discharged energy (DoD).

4.2 A walkthrough example on model prototype interface results

This section demonstrates the practical usage of Energy Equilibrium platform interface by showcasing the results the platform produces. An example is presented and a walkthrough the model results is placed. Below are placed the description of two exercises. The first exercise lists the parameters that should be set in the model interface representing the current theoretical characteristics of the energy system in a generalized municipality without integration of energy storage technologies. The second

List of indicators to be set in Energy Equilibrium platform prototype walkthrough example

Energy demand and economic parameters:

- Current energy demand mix is composed from 25% of electricity demand and 75% of heat demand.
- Projected change in electricity demand is: annual growth of 2%; Projected change in heat demand is: annual decrease by 1%.
- Current electricity import tariff in municipality is 50 EUR/MWh;
- Discount rate is 7%

Energy production technology parameters (1st exercise):

- Biomass CHP wood chips (*CHP Biomass WoodChips Large*) with full-load production hours of 3670 hours annually, economic lifetime of 25 years and technical lifetime of 35 years. Municipality projects change in fixed O&M costs of 1% increase annually.
- Natural gas boiler (Boiler Gas NaturalGas) with full-load production hours of 3200 hours annually, economic lifetime of 20 years and technical lifetime of 30 years. Municipality projects change in variable O&M cost to increase by 3% anually.
- PV panels (PV Utility Sun Large) with full-load production hours of 2300 hours annually, economic lifetime of 15 years and technical lifetime of 20 years. Municipality plans new installations for PV panels with a planned newly installed capacity of 2 MW which will be ordered in 2024 and construction time will be 1 year. Municipality projects change in fixed to decrease by 2% annually.

Energy storage technologies (2nd exercise)

- The energy manager is considering the possibility of installing a lithium-ion battery (*LithiumIon Electricity Large*) with a capacity of 1 MWh for electricity storage in the municipality which could be ordered in 2024.
- It is projected that the total construction time of battery would take 0.5 years. Battery would have depth of discharge rate of 35%, annual cycles – 300, and round-trip efficiency of 90%, economic lifetime of 20 years, technical lifetime of 25 years.
- Municipality projects that fixed initial costs, variable operation and maintenance costs and fixed operation and maintenance costs will stay unchanged in the future.

exercise lists the parameters that include the integration of energy storage technologies into an existing system. The simulation results show the situation in the energy system before and after the integration of energy storage. The aim of this walkthrough example is to show the different dimensions of the Energy Equilibrium Platform and to demonstrate the variety of results that the model produces.

Two sets of results are presented – results for the entire system and results for the selected technology, in this case a lithium-ion battery with a capacity of 1 MWh. The following figures should be considered as a representative illustration of the solutions offered by the Energy Equilibrium platform.

Results for the entire system

Energy Equilibrium platform prototype provides simulation results showing the total energy demand of the system, distributed by electricity and heat demand as shown in Figure 4.4. Furthermore, it also displays the energy production for each utilized technology.

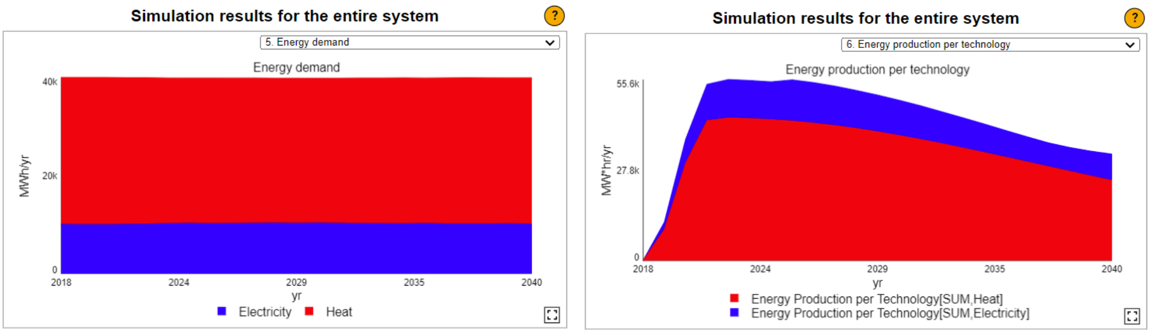
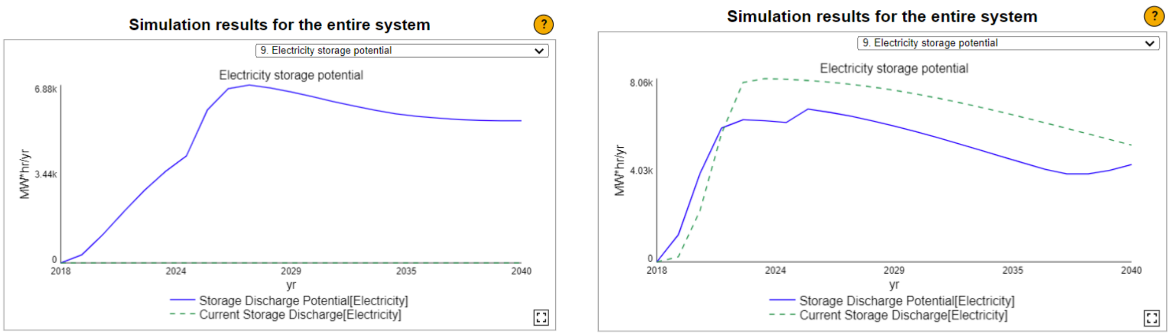


Fig. 4.4. Energy demand and production per technology

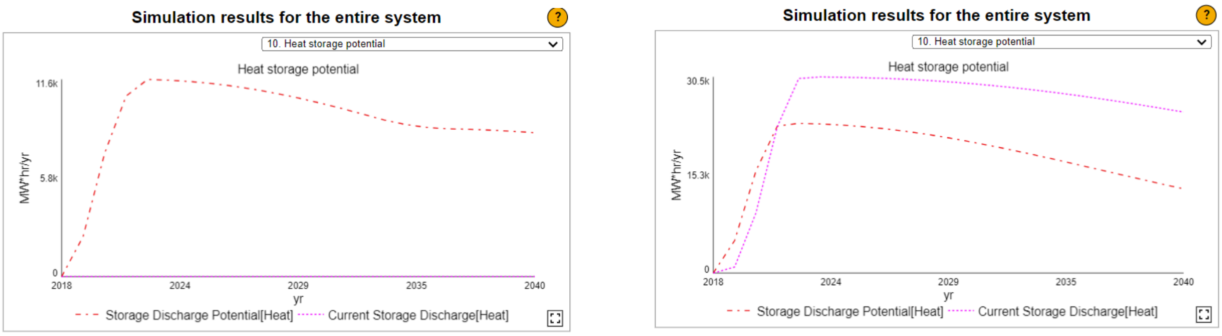
In Figure 4.5.(a), the tool furnishes data on electricity storage potential prior to the implementation of actual storage technologies. However, in Figure 4.5.(b), simulation results for the electricity storage potential of the entire system are presented after the utilization of storage technologies. This allows for a comparison between current storage discharge and storage discharge potential, as well as identification of the utilization of the most optimal size of the selected energy storage technology.



(a) Before storage (b) After storage

Fig. 4.5. Identified electricity storage potential before and after storage integration in the system.

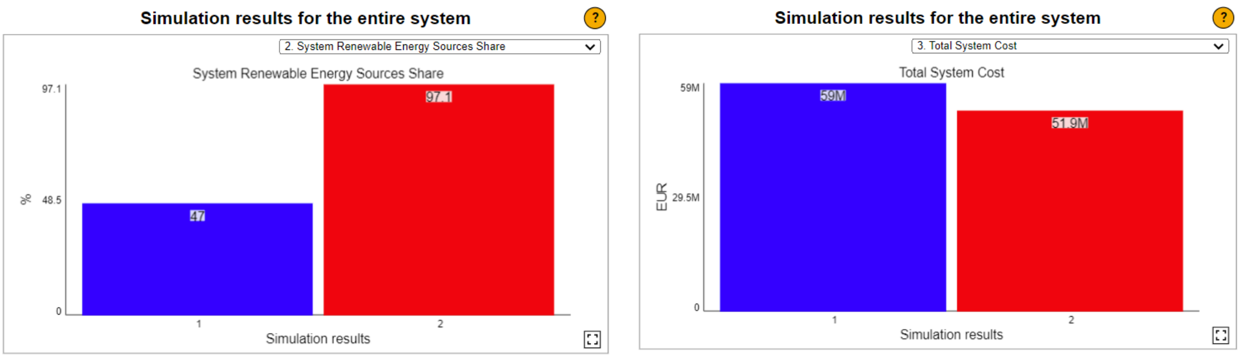
Furthermore, tool also provides simulation results for the entire system to determine the storage heat potential (Fig. 4.6.). The results show the identified heat potential before and after the integration of heat storage technologies. This makes it possible to compare how much heat the system currently stores and how much it could potentially store.



(a) Before storage (b) After storage

Fig. 4.6. Identified heat storage potential before and after storage integration in the system.

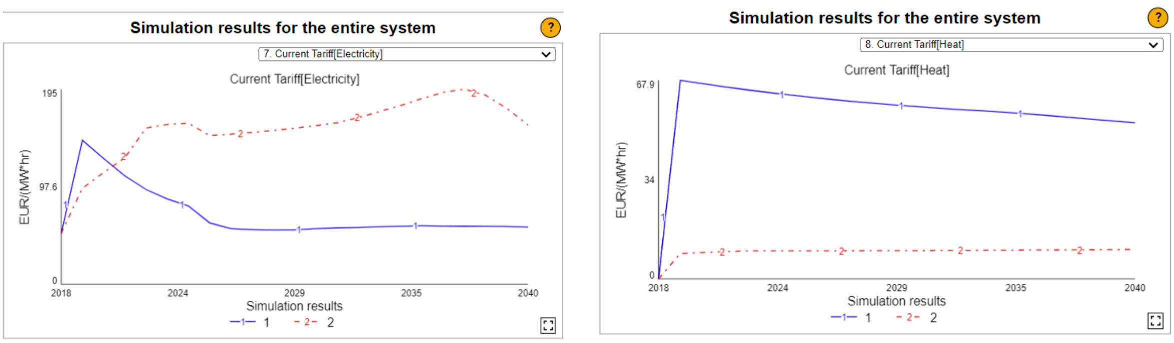
Moreover, Energy Equilibrium Platform modelling tool provides a summary of the share of renewable energy sources for the entire system, both before and after the introduction of energy storage technologies (Fig. 4.7.(a)). Additionally, it presents the total system cost under the specified input indicators (Fig. 4.7.(b)). The results of the example show that the share of renewable energy resources was significantly higher when energy storage technologies were integrated. In addition, the total system costs for the simulation period up to 2040 were also lower when energy storage technologies were integrated into the energy system.



(a) Before storage (b) After storage

Fig. 4.7. Simulation results for the renewable energy share and total system costs of the entire system.

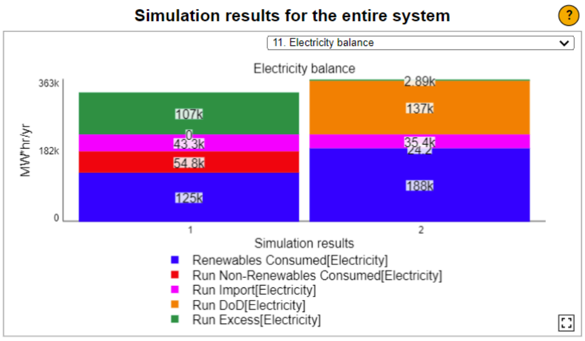
Figure 4.8. shows the simulation results comparing the changes in heat and electricity tariffs following the implementation of energy storage technology. The results allow to project the potential impact on the price of electricity and heat due to the overall changes in total system costs.



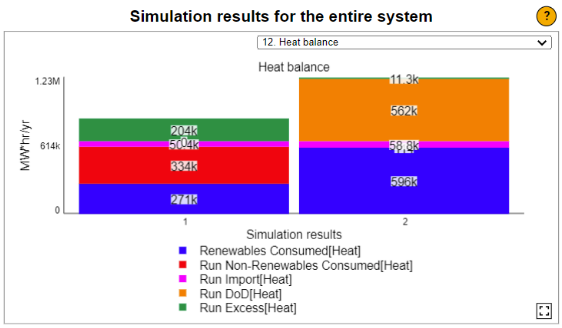
(a) Electricity tariff (b) Heat tariff

Fig. 4.8. Simulation results for the electricity and heat tariffs of the entire system.

The simulation results depicting electricity and heat balances illustrate the overall flows of electricity and heat in the system throughout the entire simulation period. They highlight the quantities of existing excess energy, consumed renewable and non-renewable energy, imported energy, and discharged energy (DoD). In Figure 4.9.(a), the electricity balance is presented for both scenarios: without any energy storage and when energy storage technologies are employed. Similarly, in Figure 4.9.(b), the heat balance is displayed for both scenarios as well.



a) Electricity balance



(b) Heat balance

Fig. 4.9. Simulation results for the electricity and heat balances of the entire system.

Simulation results for the selected technology

The prototype of the Energy Equilibrium Platform also generates simulation results for the specific technologies. In this example, the results for the lithium-ion battery with a capacity of 1 MWh are demonstrated. Simulation results of total cost of production are illustrated in Figure 4.10.

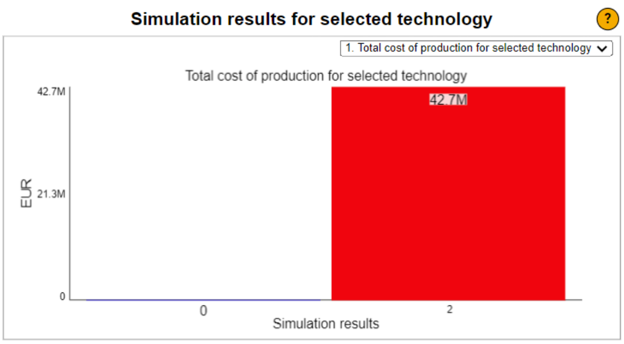


Fig. 4.10. Simulation results for the total cost of production of lithium-ion battery.

Simulation results for the tariff components of the lithium-ion battery are illustrated in Figure 4.11. The results show tariff components distributed by three main cost components – fixed costs (FC), variable operation and maintenance costs (VO&M) and fixed operation and maintenance costs (FO&M).

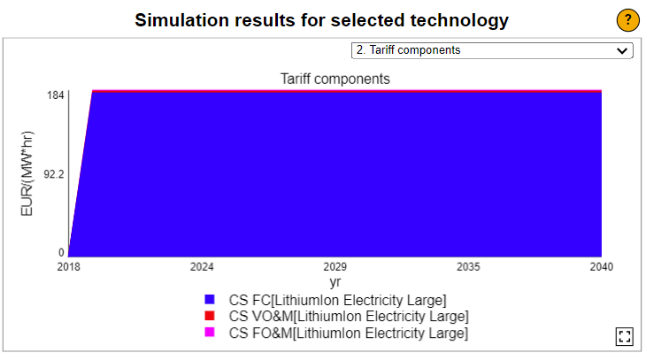


Fig. 4.11. Simulation results for the tarriff components of lithium-ion battery.

The "Current price vs. Market price" chart illustrated in Figure 4.12. contrasts the current costs of the lithium-ion battery with the current market price. The results of the example show that current price and market price of lithium-ion battery is equal.

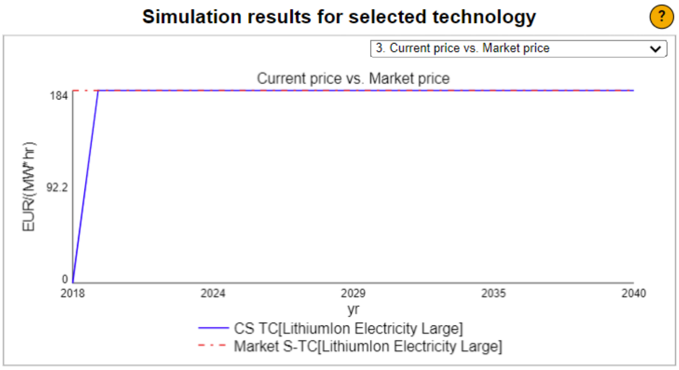


Fig. 4.12. Simulation results for the current price vs. market price of lithium-ion battery.

Technology installations graph (Fig. 4.13.) shows how much of the lithium-ion battery is currently in use and how much is planned for future installations for the entire simulation period. The figure depicts the storage capacity ordered in the specific years and total capacity of storage in operation.

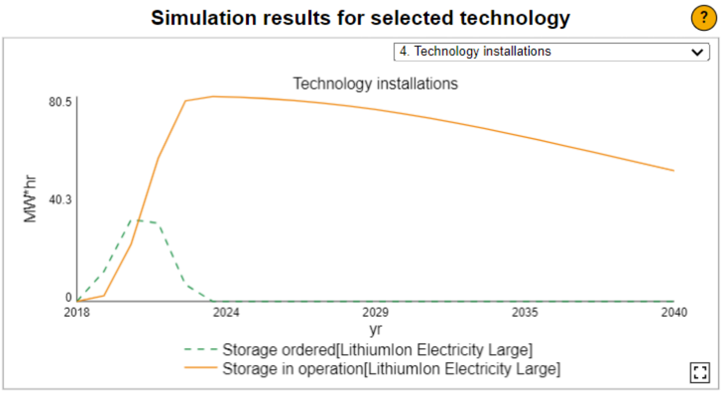


Fig. 4.13. Simulation results for the technology installations of lithium-ion battery.

The tool also furnishes data on the storage share of supply, indicating the proportion of the total energy supply contributed by the selected energy storage technology within the municipality. In the case of electricity storage technologies, it reveals the share derived from the overall electricity supply, exemplified here by lithium-ion batteries (Fig. 4.14).

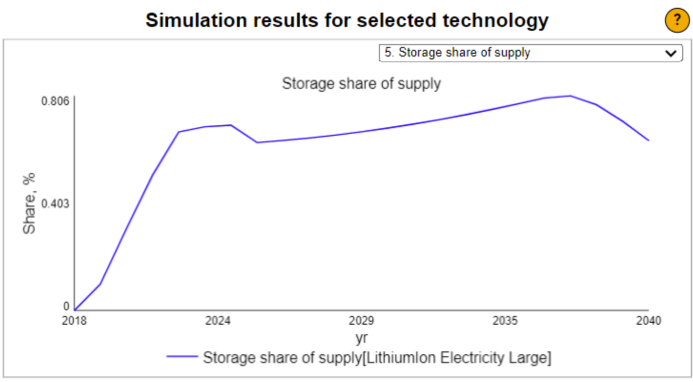


Fig. 4.14. Simulation results for the lithium-ion battery share of supply.

The data on discharge amount in Figure 4.15. displays the overall energy discharged from the chosen energy storage technology, specifically the lithium-ion battery in this instance.

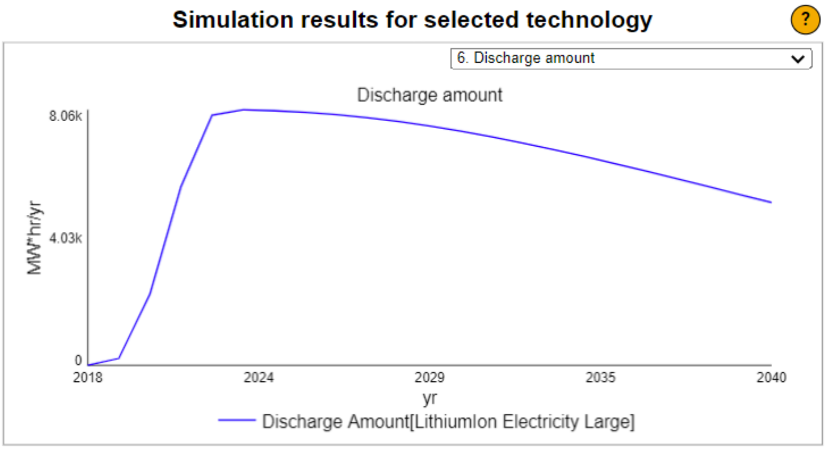


Fig. 4.15. Simulation results for discharge amount of the lithium-ion battery.

4.3 Further steps in the interface improvements

Further activities involve Energy Equilibrium platform improvements in various segments based on the feedback received from the group model building activities (implemented in the scope of GoA 1.4.). and experience that will be gained during the platform pilots in Work Package 2.

This report describes general structure of the system dynamics model used to create Energy Equilibrium platform. The model will be continuously improved and complemented with additional features which will be described in detail in the next deliverables of the project.

5 List of sources

[1] RTU IESE, "Assessment and analysis of energy efficiency policy." [Online]. Available: https://videszinatne.rtu.lv/en/science/project-and-research/aaeep/

[2] Oficiālās statistikas portāls, "Average prices of energy resources for final consumers (excluding VAT) [ENC010]." [Online]. Available: https://data.stat.gov.lv/pxweb/en/OSP_PUB/START__NOZ__EN__ENC/ENC010/

[3] H. Iskov, T. Kvist, and J. Bruun, "Biogas, Biomethane and Electro-methane cost comparison," 2019, [Online]. Available: https://dgc.dk/media/g1bn0xut/electrolyser-and-methanisation-economics_final-1.pdf

[4] Renewable Gas Trade Centre in Europe, "Biogas has the highest reference prices in 2020." [Online]. Available: https://www.regatrace.eu/biogas-has-the-highest-reference-prices-in-2020/

[5] T. Broberg, E. Dijkgraaf, and S. Meens-Eriksson, "Burn or let them bury? The net social cost of producing district heating from imported waste," *Energy Economics*, vol. 105, p. 105713, Jan. 2022, doi: 10.1016/j.eneco.2021.105713.

[6] IPCC, "IPCC Guidelines for National Greenhouse Gas Inventories. Chapter 2. Stationary Combustion." 2006. [Online]. Available: https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/2_Volume2/V2_2_Ch2_Stationary_Combustion.pdf

[7] Danish Energy Agency, "Technology Data for Generation of Electricity and District Heating," 2016. [Online]. Available: https://ens.dk/en/our-services/projections-and-models/technology-data/technology-data-generation-electricity-and

[8] Danish Energy Agency, "Technology Data for Energy Storage," Energistyrelsen. Accessed: Mar. 30, 2023. [Online]. Available: https://ens.dk/en/our-services/projections-and-models/technology-data/technology-data-energy-storage

[9] RTU IESE, "4muLATe. Sustainable and renewable transport policy formulation in Latvia." [Online]. Available: https://videszinatne.rtu.lv/en/science/project-and-research/4mulate/