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Preface

This report documents the MUSE GRIDS Energy Planning tool developed in the MUSE GRIDS project. The process has been a two-stage process split into two work package tasks where Task 3.3 has focused on establishing the MUSE GRIDS Planning specifications based on surveys with MUSE GRIDS demo site partners and Task 3.4 has focused on the actual development of the MUSE GRIDS Energy Planning Tool. The work also links up to Tasks 3.1 and Task 3.2 where mapping of demands and supply options is addressed with a view to providing inputs for the MUSE GRIDS Energy Planning Tool.

The work process is mirrored in this deliverable, which is split into two parts:

Part 1: Assessment framework design characteristics

Part 2: MUSE GRIDS Energy planning tool user guide

The first part establishes the design characteristics and the second part details the model with a focus on user needs, thus it is designed as a reference guide

Part 1: Assessment framework design characteristics

1 Introduction

The main aim of this part of Deliverable 3.2 is to examine the planning practices of local municipalities to identify important specifications and critical design criteria the MUSE GRIDS Energy planning tool intended for energy system analysis and scenario-making. This tool is developed as part of the MUSE grids project and is designed to accommodate to the needs of the municipalities. This part is followed by a second part which details the development of MUSE GRIDS Energy Planning Tool and how it is used for scenario-making and energy systems analysis.

This part of Deliverable 3.2 furthermore addresses important themes relevant to the establishment of critical design criteria for energy system modelling tools and is intended to be of use for city planners and policy-makers involved in planning the transition to renewable, smart and integrated energy systems. Furthermore, the analyses and results are of relevance to researchers and practitioners in energy system modelling, as well as model developers, modelling energy systems on a local-/city-scale with its description of current practice within the field.

The analyses are based on interviews and surveys conducted with representatives from the planning authorities of the local communities functioning as physical and virtual demo-sites in the MUSE GRIDS project in Belgium, Spain, Italy, Israel and India. Planning authorities in this regard include a broad range of stakeholders, including local municipalities, planning offices, or utility companies involved in energy planning activities such as heat, electricity, or gas distribution companies.

Chapter 2 examines the changing role of energy planning in the context of the transition to renewable energy, the prevalent use of energy system modelling tools, and predominant research trends on tool usage in energy planning.

Chapters 3-6 are structured according to the four themes guiding the interviews: a) long-term planning goals, b) energy planning practices, c) delimitation and criteria, and d) capacity and competences. Every chapter first outlines how the theme is relevant and provides insights into the tool design criteria, followed by the essence of what was uncovered from the interviews and surveys. Every chapter ends with an overview of the individual inputs from the involved demo-sites.

This part of Deliverable 3.2 is the result of the combined effort of the MUSE GRIDS project partners with AAU as the main contributor and leading partner and exploiting the local knowledge of the project partners to provide an in-depth assessment of critical inputs for the tool development process.

The following functions as a brief introduction to the six demo-sites from which the qualitative inputs for the tool development, and the quantitative demand and resource data for the tool testing are obtained.

Osimo (Italy, physical demo-site)

The demo-site is the whole town of Osimo with approximately 35,000 inhabitants, located in the Marche Region in Italy. Osimo is a historic city with primarily low-efficiency buildings, and a weak connection to the national electricity grid. A local micro-grid is present with a variety of installed technologies, including a 1.2 MW_e gas CHP engine serving a small district heating area, 30 MW photovoltaics, 400 kW mini-hydro, and two biogas plants with a total power production of 2 MW. Furthermore, the local utility company ASTEA is leading an early stage electric vehicle program. To represent Osimo, inputs were obtained from the municipality’s technical office.

Oud-Heverlee (Belgium, physical demo-site)

Oud-Heverlee is a municipality slightly east of Brussels in Belgium, however, the demo-site is limited to a rural street at the end of a local distribution line. While the total number of inhabitants in Oud-Heverlee municipality is approx. 11,000, the actual demo-site only includes approximately 40 houses. There is already a considerable amount of heat pumps and electric vehicles present, and the distribution line is not fit for an additional load. In 2015 the municipality developed a climate action plan as part of the covenant of mayors, and to contribute to the fulfilment of the European 2020 climate objectives. It has not been possible to locate and engage with energy planners from the local municipality. Instead, to represent Oud-Heverlee, inputs were obtained from the existing Climate Action Plan of Oud-Heverlee, developed as part of the Covenant of Mayors initiative [1,2].

Eilat (Israel, virtual demo-site)

Eilat, a popular touristic city, is the southernmost city in Israel with approx. 50,000 inhabitants. The city is implementing a plan to become energy-independent by 2021. The very substantial tourist sector of Eilat results in large seasonal differences in energy demands during the peak summer and winter tourist season. Further, because of the hot desert climate and year-round high ambient temperatures, the demand for cooling is very high. To represent Eilat, inputs were obtained from the municipality of Eilat.

Balí (India, virtual demo-site)

Balí is an island village located in a rural part of West Bengal, with approximately 32,000 inhabitants. Located in the Sundarbans, there was until recently no electricity connectivity, making the island entirely reliant on solar photovoltaics and diesel generators. The process of grid connection has begun, including the installation of meters. Qualitative inputs were not obtained from Balí.

Bélen (Spain, virtual demo-site)

Bélen is a district with some 1,800 inhabitants located in Valladolid in North-Central Spain. An energy community has been established in Bélen, which has developed a plan to increase renewable energy production. The plan is based primarily on increased deployment of PV and increased utilization and connection with the nearby district heating network. To represent Bélen, inputs were obtained from the Municipality of Valladolid's environmental office.

San Cebrián de Campos (Spain, virtual demo-site)

San Cebrián de Campos is a rural municipality in North-Central Spain with around 445 inhabitants. Due to challenges related to depopulation, a group of people has worked for the recovery of the village, providing basic infrastructures and economic activities. Several other rural areas in Spain are suffering from similar challenges of depopulation and weak grid connection, limiting the incentive for local businesses to promote energy efficiency initiatives. Qualitative inputs have not been obtained from San Cebrián. Due to the small size of the municipality the municipality did not believe they could contribute with information within the scope of the investigation. San Cebrián municipality are however very interested in the MUSE grids project in general and aim to collaborate going forward.

2 The changing role of energy planning and tool usage

Negating the effects of climate change attracts growing attention from both industry, academia, and political decision-makers. The attention to climate change is exemplified through global political agreements such as the Paris agreement from 2016 and the United Nations Sustainable Development Goals. Realizing these wide-encompassing goals requires radical changes, including the transition of the energy sector to 100% renewable energy supply. This will require the co-operation and co-ordination of a multitude of actors, technologies, and industries, on a global, national, and local scale.

Transitioning the energy system to renewable energy supply is a complex challenge, necessitating comprehensive planning of the energy system. However, an exclusive definition of what constitutes energy planning has not yet emerged. While authors approach the subject of defining energy planning differently, it is clear that balancing the technical supply and demand for energy with economic, environmental, and social concerns are fundamental pillars [3–7]. The purpose of energy planning is to improve the decision basis for important policy decisions [3], and thus the importance of good and reliable energy planning should not be underestimated.

Thery and Zarate [6] argue that the complexity of energy planning is enforced by its multi-criteria and multi-scale issues. The wide-ranging issues of energy planning must be incorporated both in short-term (<1 year), medium-term (1-15 years), and long-term (>15 years) plans, with temporal resolutions ranging typically from hours to days, weeks, months, and years.

Energy planning can be considered as the act of developing the energy system with a view to balancing the demands and requirements of multiple energy (sub)-sectors while maintaining a holistic overview of the entire energy system. This typically includes transport, heating, cooling, electricity, and industry, as broad overall energy sectors. The complexity stems from the need to co-ordinate consumers and producers of various energy sources while ensuring the security of supply. Because of the diversity of involved energy sectors, the planning process needs to incorporate not only a variety of technologies, but also energy grids such as district heating grids, district cooling grids, electricity grids, and gas grids, to properly address the energy system development.

The smart energy system approach [8] is in many ways the theoretical epitome of holistic energy planning, in which the integration, combination, and optimization of energy sectors is the focal point. The smart energy systems approach emphasizes the analysis of coherent energy systems as opposed to single sector thinking. Specifically, when planning for and modelling 100% renewable energy systems, the interplay of sectors and technologies is integral, and an approach focusing solely on e.g. the electricity sector will not capture the complexity of reality.

The Choice Awareness Theory [9] conceptualises the presence of choice in the context of designing future energy systems. Existing organisational and institutional interests will however often seek to eliminate alternatives threatening to disrupt the existing system, leading to a perception of no choice. Choice Awareness Theory advocates the design of technical alternatives, feasibility studies, and design of public regulation in the light of conflicting interests, to demonstrate that as a society we do in fact have a choice. Planning procedures should allow for the design of alternatives, and an essential first is the ability to conduct technical analysis for a range of scenarios. Instead of describing only one possible solution, technical analysis should aim at presenting an array of available alternatives. Being aware of the available alternatives and the resulting complications is the first step to an informed decision process and to making better decisions for our future.

2.1 Renewable energy implementation phases

With the on-going transition of the energy system to being supplied by renewable energy sources which largely are fluctuating by nature, energy systems have become increasingly complex. This results in a growing need for long-term strategies and reliable energy systems modelling to manage the transition. Lund [10] describes how the transition to 100% renewable energy system involves three distinct phases, each with increasing complexity and growing requirements to scenario-based energy system modelling tools. The three phases (introduction, large-scale integration, and 100% renewable energy) correlate to the state of the energy system and the share of renewable energy present, with key characteristics described in the following.

The introduction phase is characterized by having no or a very limited share of renewable energy. The introduction phase can further be identified by the minimal introduction of renewable energy. This makes it easy to identify the technical influence of renewable energy production on an annual basis, for example in the form of fuel savings. During the introduction phase, the system behaves very predictably due to the limited impact incurred by fluctuating renewable energy production. Further, there is generally no need for high temporal resolutions in energy system modelling during the introduction phase, since because of the limited presence impact of renewable energy, renewable energy production results in a decreased production from combustion-based technologies. There are no excess productions, and the combustion-based technologies can accommodate any changes in any renewable contributions.

The large-scale integration phase entails a situation where the renewable energy share is high in an energy system. Thus, further increases in renewable energy generation capacity will have energy system implications that are more complex, and the implications will depend on parameters such as available storage capacity, and whether the electricity demand is high or low during the hour of production. This results in a need for more detailed energy system modelling approaches, preferably with hourly time steps as opposed to monthly or annual balances.

The 100% renewable energy phase describes a situation where the energy system is undergoing a transition to 100% renewable energy. Technologies and measures applied become increasingly diversified, and renewable technologies no longer primarily compete against fossil fuel technologies, but instead against other renewable energy technologies. Because of the broad spectrum of technological solutions involved, including increased utilization of conservation, storage and conversion technologies, and use of smart grids, assessing the influence on the energy system becomes correspondingly complex.

The three defined implementation phases clearly outline how the requirements for both modelling tools and modeller increase as energy systems progress towards renewable energy. The three defined implementation phases can thus be used to both to guide the selection and design of tools suitable for simulation of renewable energy systems [10].

2.2 Decentralized municipal energy planning

Energy planning, while increasingly necessary at all scales, has traditionally been conducted at the national level; in part due to a previous emphasis on centralized production of energy from e.g. central power plants [11]. This is however changing, and decentralized authorities and actors such as municipalities and city planners are increasingly incorporating energy planning aspects into their practices.

In a study examining the correlation between decentralized and centralized energy planning, Sperling et al. [12] observe an increasing willingness among Danish municipalities to carry out energy planning. However, the study also found a need to outline the role of municipalities more clearly to enable coordination of central and decentral planning activities. The authors further conclude that navigating the national institutional framework of policies and regulation is challenging to most municipalities; a viewpoint further emphasized by Krog [13]. Municipalities are an important, and even essential, part of implementing national renewable energy strategies, but to enable this, an institutional framework supporting this development and reducing the gap between national and local policy must be formulated at a centralized level beforehand [14]. Basically, local levels must be given appropriate authority to ensure that energy plans are also implemented.

Based on practical experiences modelling four European cities, Simoes et al. [15] argue for the benefits of combining qualitative analysis with quantitative modelling at an urban level to identify an optimal mix of measures. Further, it is concluded, that an approach relying solely on quantitative energy system modelling would result in substantially different scenario recommendations compared to a more holistic methodological approach. This is supported by Morlet and Keirstead [16], concluding that while energy system modelling tools are valuable for cities planning for transitions to renewable energy systems, quantitative assessment should be complemented by a holistic appreciation of the local context. Thus, when conducting energy planning in an urban or municipal setting, it is important to keep in mind how the decentralized setting differs from a centralized setting; such as an increased emphasis on appropriate utilization of local resources and attention to demands [17].

Decentralized, bottom-up planning could be a source of development in the transition to renewable energy, leading to changes to the institutional practice of energy planning. There is however still a need for simultaneous decentralization and centralization of strategies in energy planning [12]. An emerging increased emphasis on decentralized energy planning, strategies and ambitions on a city and municipal scale could prompt the development of the energy system as a whole.

A plethora of models and tools are available for the simulation of energy systems and the design of transition scenarios. These are suitable for a variety of different contexts, and new tools frequently being developed. As new tools are being developed to deal with the increasing complexity of the renewable energy transition, these should be designed or adapted to comply with the needs of the local communities in mind.

2.3 Types of energy system modelling tools

A wide range of tools for energy system analysis and modelling with highly differing purposes exist already. This ever-growing range of tools makes it increasingly difficult to choose what and when to apply each of these. This section will briefly outline how energy system modelling tools differ with regards to key defining characteristics, and how such tool characteristics are pivotal determinants when deciding on an energy system modelling tool.

<u>Targeted scale of planning</u>

The targeted scale of planning can range from assessment of globally interconnected energy systems to local and site-specific assessments, for example of household photovoltaic systems. The requirements to the applied energy system modelling tool are vastly dependant on the scale investigated, and rarely is one tool capable of encompassing both very large and small scale system analyses.

<u>Simulation vs optimization</u>

In a simulation model, the system design will be defined exogenously, or in other words, designed by the user/modeller. A simulation model enables the modeller to simulate the operation of a given energy system given certain assumptions and conditions. In an optimization model, the system design is typically defined endogenously, meaning the model is capable of maximizing (or minimizing) an objective function and determining an optimal system design accordingly. The key difference between simulation and optimisation models is thus whether the model is capable of determining an optimal energy system design or not. However, for comparing scenarios and for long-term decision-making, simulation models provide the distinct advantage of presenting a variety of options which are not optimised solely according to an economic parameter [18].

Temporal resolution

The temporal resolution of a model is the time-step of which simulation (or optimization) is conducted. Short time-steps of a second or less can be suitable for load and frequency balancing of the electricity grid, but very demanding if modelling for long time horizons. Hourly time-steps have become standard practice in integrated energy system analyses conducted using the EnergyPLAN tool [19–21]. Hourly time steps allow the model to take fluctuations of energy demands and renewable energy production into consideration while maintaining a temporal resolution that enables simulation of one or several years. Input data, such as electricity and heat demands or electricity and fuel prices, is also typically readily available in an hourly format. Obtaining such data for time-steps of a second or less can be challenging, rendering short-time steps counterproductive to the simulation regardless. Higher temporal resolutions of a day, week, month, or even full years have also been applied in modelling. Such high temporal resolutions can be used when modelling for very long planning horizons; however, some of the temporal interactions are lost. This approach is thus also mainly relevant where intra-day, intra-week, intra-month or intra-year variations may be considered inconsequential for modelling results. This is e.g. the case with non-sector integrated systems based on storable fuels.

Planning horizon

The planning horizon denotes the period for which the modelling tool will simulate the operation of the energy system. This might only be one day for very detailed models with low temporal resolutions of a second or less, but for hourly or yearly models, the planning horizon can range from one year and upwards of 50 years.

Sector modelling vs integrated modelling

Depending on the purpose of the energy system model, different approaches will be preferable. Some models focus on providing a detailed simulation of a single energy sector such as the electricity sector, whereas other models emphasize an integrated modelling approach where the interplay of sectors and technologies is essential. Both approaches have their advantages and disadvantages, but if the goal is designing future integrated energy systems, a holistic sector-integrated approach appears to be needed.

The following describes examples of existing widely applied energy system modelling tools. The tools described are categorised according to three distinct planning scales: Global/international, National, and Local community/site-specific project. This further includes key characteristics of the tools, as outlined previously. The purpose of this description is not to provide an extensive and all-encompassing review of all existing tools, but merely to provide examples of available tools and their primary application purposes.

Global/international energy system models enable the modelling of energy systems containing several countries, or interconnection and exchange of energy across borders. This is relevant for example when analysing interconnected markets such as the electricity market, in which countries are connected and trade electricity. Models with large geographical scales and long time steps are typically designed as top-down models so that technical details can be omitted [22]. Such international interactions can be analysed in the modelling tool BALMOREL [23] developed in the coding language GAMS. BALMOREL emphasizes the electricity and combined heat and power sectors and allows simulations of varying time-steps, including hourly and daily. Inputs and results can be included for individual areas such as countries, regions, or district heating areas, and has been applied in a variety of different projects internationally. Additional examples of tools applicable to modelling global/international energy systems include MESSAGE, EMPS, LEAP, GEM-E3, EnergyPLAN, TIMES.

For national energy systems analysis, tools such as TIMES [24], EnergyPLAN [25], and LEAP [26], are widely utilized globally. The TIMES tool has been used to simulate goals for the European Commission and is widely used for country models. TIMES is able to represent the entire energy system and its development over long time horizons of 20 to 100 years. The LEAP tool is also capable of modelling a variety of different integrated energy systems and is based on annual time steps. It is designed around the principle of scenarios, which can be compared and the most advantageous scenario can be chosen. LEAP is used in more than 30 countries for the development of energy plans. EnergyPLAN simulates the operation of national energy systems based on the operation for one year with hourly time-steps. EnergyPLAN is based on endogenously defined priorities of all relevant units and what the developers denote “analytical programming” in which the reaction of each unit to given impetuses are pre-programmed. In the model, the energy system is described through aggregated inputs. This implies that e.g. power plants are aggregated and the aggregated capacity correlates to one input value. The hourly simulation approach enables EnergyPLAN to analyse the influence of variable renewable energy generation and integration of sectors.

Tools for local community energy systems or site-specific projects typically allow for more detailed modelling and simulation than tools whose primary purpose are large-scale energy systems. This can involve shorter simulation time-steps, in some cases less than one second, or allow detailed specifications of the included technologies. Such an approach can be useful for load and frequency simulations, for example in household photovoltaic systems, something that can be modelled in detail in TRNSYS. Other applications for the use of site-specific tool includes modelling of district heating systems and related technologies, as it is possible using the EnergyPRO software. The tool HOMER [27] is specialized in modelling, simulating, and optimizing hybrid distributed- and micro-grid energy systems. HOMER is often applied for early-stage design and feasibility studies for distributed energy systems, for example when designing off-grid systems.

Finally, there are also tools available in which the modelling scale can be adjusted, with RETScreen [28] being an example of such a tool that can be applied for both small and large-scale projects.

2.4 Research trends: tool usage in energy planning

The terms “tool” and “model” are often in literature used interchangeably, and for the purpose of this study, either is acceptable. This is however further complicated by the interchanging use of “model” and “framework” in a large body of research not specifically dealing with the use of computer tools, but instead with frameworks or general methodologies for strategic energy planning. The literature of such nature is omitted from the review for this deliverable.

Research on the use of tools and models is conducted both on a holistic/systemic energy planning level (planning emphasizing several energy sectors) and for a sector-based level (e.g. electricity or transport sectors).

For these analyses it is however required that a wider energy system perspective is applied; e.g. papers only dealing with the use of modelling tools in electricity systems are excluded. Finally, the scale of planning varies considerably, ranging from individual building level to international interconnected energy systems. For the initial review, all planning scales are considered, with only the individual building level being excluded. This means that papers on tools for modelling demand or production of individual buildings, e.g. simulation of household solar photovoltaic systems, are excluded.

The existing scientific literature regarding the use of tools in energy system analysis and modelling can generally be categorized according to the following three categories:

A. **Tool classification/categorization**: Classification of tools according to characteristics, field of use, etc. A large number of tools are compared, typically according to many different parameters.
B. **Tool application or comparison**: Examples of use for a limited number of cases and tools, or comparison of tools. A small number of tools are compared with an emphasis on the results produced, e.g. differences in results obtained for one or several cases.
C. **Tool principles (design or use)**: Emphasis on principles for correct usage of tools in energy planning or tool design, including the formalization of "best practice guidelines".

The purpose of this review of research trends is to provide an overview of common approaches and methodologies applied in research on tool usage for energy planning purposes. It is not meant to be an all-encompassing review, but merely an introduction to predominant research trends and potential gaps as indicated by existing research.

Tool classification or categorization

The number of energy system models and tools is increasing rapidly, and alongside it, an extensive amount of literature reviewing tools and models for energy systems has been produced [29,30] with slight variations in the methodology applied for categorization or classification. Some of these categorization studies are very broad, with the aim of encompassing a broad range of energy system modelling tools for differing planning scales and purposes [22,29–31]. Other categorization studies focus on a subset of tools and models, for example, tools applied in a district or urban setting [4,32–34].

Connolly et al. [31] present an extensive review of 37 computer tools for modelling of energy systems, comparing these with regards to their typical application and analytical approach. From this it is concluded that it is not sensible to identify an ideal energy tool; instead, it is imperative to choose a modelling tool keeping in mind the objective and context of the analysis.

In a review of 24 energy system models, Lopion et al. [35] determine a trend towards models focused on renewable energy and decarbonisation – a development which combined with cross-sectoral technologies, energy storage needs, and growing international markets results in increased model complexity. The authors further state how it is essential that future models become open and transparent while focusing on the technological issues of today.

Hiremath et al. [4] argue that energy planning traditionally has been based on centralized models, and goes on to develop a framework for categorizing decentralized energy system models according to key characteristics. The authors conclude that decentralised energy planning models and approaches need to be developed and applied. Further, they argue for the relevance of a bottom-up approach as opposed to a top-down approach, with time horizons preferably being short to medium term, with the purpose of identifying optimal matching of demand and supply.

Despite a large number of available energy system tools, a gap appears to be present for modelling tools for supporting decision-makers at a local or community level, as indicated in several studies [17,32,36].

In a study on methods and tools for urban energy systems, Manfren et al. [34] summarize by describing critical challenges in the transition toward efficient district energy systems. These include the balancing of supply and demand while taking into account local peculiarities related to energy, economic, and environmental resources. To meet these challenges, Manfren et al. [34] argue that there is a need for innovative and smart tools capable of supporting the transition at a community level. Likewise, Huang [37] argues that existing energy planning tools emphasize supply-demand balancing, at the expense of local characteristics. Results further indicate that for the community planning stage it is challenging to apply existing tools such as e.g. EnergyPLAN and RETScreen since a well-defined system or object is required. This selection of technologies and capacities can be challenging to planners, leading to issues in applying such models.

Tool application and comparison

Because of the otherwise near endless amount of examples of applications of tools and models, this review will be limited to cases conducted in the context of decentral or urban and city-level planning.

Thellufsen and Lund [38] utilize the EnergyPLAN tool to investigate how local and national energy systems correlate in the integration of renewable energy. To investigate this problem, the cities of Copenhagen and Sønderborg are included as examples of cities with ambitious local energy plans. This is an interesting approach, and an effort into bridging the gap between local or municipal energy planning and national energy planning. The study concludes that through the integration of the local and national energy systems improved performance can be achieved.

Based on the experiences from energy modelling in Madrid, García-Gusano et al. [39] describe the challenges for energy policy at the subnational or decentralized level. It is found, that there is a need for regional level energy system models for Madrid to support technological pathways and sustainable policies. To support policymaking, the Long-range Energy Alternatives Planning System (LEAP) energy system modelling tool was applied, enabling long-term scenario-making and energy-related projections. Models are developed to illustrate the effect of policy scenarios, to aid the process of planning and decision-making. Argues that it is necessary to further develop the practice of regional energy modelling in the support of policies enabling a transition to renewable energy.

Gardumi et al. [40] describe both the role and benefits of open-source energy system modelling in energy planning, as well as the functioning and application of the open-source tool Open Source energy Modelling System (OSeMOSYS). The OSeMOSYS tool can and has been applied in both national and regional analyses, with the primary benefits being the straightforward comprehension and transparency of results due to the open-source nature – bringing together policymakers and technicians.

While the regional and city level planning is as indicated by researchers so far considered important in the transition to renewable energy supply, there are challenges and limitations to consider. This perspective is outlined in the study by Simoes et al. [17] where energy system modelling has been applied in European cities. It is concluded that radical measures needed for decarbonisation are often beyond the influence or authority of the cities, and there is generally limited room to design and implement greenhouse gas mitigation policies such as taxes and subsidies. Attracting and developing large-scale renewable investments in cities can be challenging as well, due to limited space and financing. Finally, the complexity and time-consuming process of developing models such as the TIMES model applied in the study by Simoes et al. [17] does lead to the consideration that simpler options for city-level energy modelling should be explored.

Tool principles

While the majority of research is closely linked to one or several specific tools, there are studies dealing with the principles, or in other words, best practices of energy system modelling [41,42].

DeCarolis et al. [41] argue that so far little effort has been paid to developing formal, general guidance to energy system optimization models and analysis and that the current need for knowledge and judgment to produce policy-relevant insights is extensive. Thus, as a starting point, DeCarolis et al. formalize best practice guidelines, operationalized in the following principles [41]:

- Critical modelling steps
- Research questions
- Spatio-temporal boundaries
- Model features
- Conduct/refine analysis
- Quantify uncertainty
- Communicate insights

However, with the increasing development and complexity of energy systems, new tools, and modelling approaches will arise, and best practice guidelines should be expected to develop further.

Pfenninger et al. [42] establish a practical guide based on the experiences of the Open Energy Modelling Initiative. In this, the authors argue for more openness and transparency in energy research, with key considerations including providing access to model and code. The study does not review energy system tools as such but instead argues as to why models/tools/code should be made publicly available, and steps on how to, are presented. Further, it is discussed that the past lack of transparency in energy research, modelling, and planning is a hindrance to the continued growth and that all actors are to benefit from increased openness and transparency. Morrison [43] concurs with the suggested transition to openness and transparency in energy modelling, based on arguments such as a need for public transparency and scientific reproducibility.

Keirstead et al. [44] examine the specific practice of urban energy systems modelling by reviewing 219 existing research papers to identify key practice areas. It is found that urban energy systems modelling has the potential to move from single disciplinary approaches towards integrated sophisticated approaches in the future. Key challenges to urban energy system modelling according to Keirstead et al. [44] include model complexity and data uncertainty, as well as model integration and policy relevance.

Typically the formulation of scenarios is closely related to the act of energy system modelling, however, as argued by Braunreiter and Blumer [45] the actual use of scenarios among researchers and energy planning practitioners varies significantly. Two primary distinctive use cases were identified 1) The model inputs which scenarios are based on are the primary relevant object as these are used for further analysis. 2) The scenario as a description of a plausible energy future is of primary interest. A general take-away from the work of Braunreiter and Blumer [45] is that energy system modellers should put greater effort into presentation and communication of their models so that not only experts are capable of utilizing and applying the model and results as intended.

2.5 Summary

The role of energy planning is changing along with the on-going transition to renewable energy systems. The complexity of energy planning increases because of the increased production of variable renewable energy, combined with an increasing need for integration of energy sectors.

Energy planning is increasingly conducted also at a decentralized level because of a growing interest from municipalities. Decentralized energy planning does, however, entail unique challenges compared to centralised national planning, and the particular local context remains important.

Energy system modelling tools have become essential to the energy planning practice, and a vast array of tools with varying purposes are available. The complexity of integrated energy planning places high demands on both modeller and modelling tool, and for aligning modelling tool with planning goals.

An initial screening of the existing research on tool usage in energy planning reveals a focus from researchers on the applicability and capability of the tool itself. This is as opposed to the limited amount of research on tool design and early-stage development of new tools, taking a starting point in the challenges, goals, and requirements of local decentralized planning authorities and decision-makers.

Existing literature recommends future research focus on energy system tools and models for local or district energy systems. Tools should support and enable decision-makers in the early stages of design and planning while being transparent and providing effective communication of both the functioning of models as well as the results.

An increasing emphasis is placed on principles and best practices of energy system modelling, with key issues being communicating model complexity to policymakers and other key stakeholders. Thus, greater emphasis should likely be placed on the communication and presentation of models. Open-source tools and modelling are making significant advances, a likely consequence of the increased call for model transparency and openness.

3 Long-term planning goals

3.1 Relevance to tool development

This chapter investigates the goals and ambitions guiding long-term development plans for the local municipalities of the demo-sites. Typically, on a centralized, national level, long-term energy-related goals will exist, often in the form of a goal of reduced greenhouse gas emissions or increased share of renewable energy consumption. However, on a decentralized, local level, the extent to which energy planning is conducted varies. Therefore, it is important to uncover both the nature of the goals that are considered most important by the local communities, as well as the planning horizon for these goals.

Planning goals can vary greatly in nature, and there is no universal answer to what constitutes a sustainable energy supply for a municipality. Thus, optimization of an energy system is based on a combination of economic and techno-economic criteria. Economic criteria might include total energy system costs or costs to society, whereas techno-economic criteria might include CO_2 emissions, fuel savings, required back-up capacity, or limitation of import/export [46]. What criteria are considered to be most important does however depend on the energy system and context investigated.

Future energy system modelling tools should be able to address the goals considered important by local communities and enable the incorporation of a broader energy system perspective into the existing planning and strategy procedures. The questions to the involved municipalities aim first at uncovering what goals and strategies of relevance to the energy sector are present. This might include actual energy strategies, as well as strategies for mobility and transportation, built-environment, land-use, etc. Secondly, the technological development focus of the cities is of relevance, in other words; do the cities have untargeted potentials for implementing wind power, solar photovoltaics, energy savings, etc., and if so, how can future energy system modelling tools help realize these potentials.

In a review on the use of the EnergyPLAN modelling tool, the most frequently applied criteria were determined to be total primary energy supply, CO_2 emissions, total energy system costs, and production of excess electricity [47]. However, several others were found, and typically a mix of criteria was applied to determine optimal solutions, leading to issues related to the prioritization of criteria. The review emphasises how there is no unequivocal answer to how to design optimal energy systems, instead defining and prioritizing optimisation criteria which align with the long-term goals is essential.

3.2 Long-term planning goals – assessment and feedback from interviews

Perhaps the most apparent observation is the distinct lack of long-term goals among the municipalities. The demo-sites generally have some areas that for the short term are being prioritized, and maybe even some concrete CO_2 or energy reduction goals. However, the time horizon for these goals appears to be limited to the coming one to four-year period. This is, for example, the case in Osimo, in which the municipality has defined a goal of reducing energy consumption and CO_2 emissions, but not decided on a concrete reduction target or an official time horizon. The predominantly short planning horizon could be a result of the way municipalities are organized and function, where typically a new municipal council is elected every four years, or similar.

The goals that are in place in the demo-site municipalities are mostly of sectoral nature, as opposed to holistic or integrated energy plans. As such, the municipalities might mention a number of different focus areas, this could, for example, be increased deployment of electric vehicle charging stations, or information campaigns advocating for increased insulation of residential housing to promote energy savings.

The municipal emphasis on static and technologically oriented goals is verified by Petersen [14], in a study on the application of renewable energy policy in Danish municipalities. Petersen argues that this emphasis is a result of a predominantly top-down planning approach conducted by a few actors, thus leading to limited involvement of the local community in the framing and development of strategies. Focusing on highly technology-oriented goals can lead to reduced attention to genuine sector integration and holistic energy systems.

For Osimo, Oud-Heverlee, and Bélen the European Covenant of Mayors [48] initiative have functioned as encouragement in the formulation of a climate action plan. Energy planning has otherwise not gathered a lot of attention, but the Covenant of Mayors initiative has helped formulate both broad sustainability agendas and specific actions to pursue related to the energy sector. Most central is the 2020 CO_2 emission reduction goal of 20% which has been adopted by the three previously mentioned municipalities. Adoption of the 20% CO_2 reduction goal has provided the municipalities with a long-term target, but since the target is not binding the municipalities have reached the targeted reductions. In Bélen for example, CO_2 emissions have only been reduced by 8.21%. Furthermore, the impending expiration of the 2020 targets also leave the municipalities in a void, where a new target needs to be formulated.

To municipalities such as Eilat located in weak grid areas, energy independence is considered one of the most important priorities of the future energy system. Other municipalities such as Osimo and Oud-Heverlee have not mentioned this as a priority, likely because of the more reliable local electricity grid in these areas. From this, it thus appears that whether the municipalities actually have ambitions for an independent energy system is dependent on the local context. The ability to assess the capability of a system for island mode operation should however not be deemed irrelevant, and could in fact for some municipalities be an important criterion when choosing an energy system modelling tool.

Prioritizing future development areas appear to be another challenge for the demo-sites. The municipalities do generally have an idea of what areas or sectors they want to target but find it difficult to prioritize technological solutions and initiatives. Osimo, for example, wishes to prioritize solutions with the greatest economic and environmental benefits to the local community, but have not identified a methodology to do so.

Municipalities have a broad field of interest and range of responsibilities; something to keep in mind when conducting energy planning. Plans and strategies for the energy sector will need to align with a range of parallel efforts in e.g. water management, spatial planning, or biodiversity, among many others.

3.3 Long-term planning goals - specific case perspectives

Osimo:

- Goal of reducing CO_2 emissions by promoting electric mobility and imposing energy requirements on buildings. No official time horizon or concrete target has been defined yet.
- Estimates that a considerable untargeted potential remains for implementation of photovoltaics, district heating, energy savings, and hydropower.

Oud-Heverlee:

- Short-term goal of 20% CO_2 emission reduction by 2020 compared to 2011. This is to be achieved through energy savings, increasing energy efficiency, and implementing sustainable energy sources. No long-term goal has so far been established.

- Targets holistic sustainable development for the municipality, not only with regards to energy but also housing and buildings, water management, spatial planning, mobility, biodiversity, underprivileged, etc.

Eilat:

- Short-term goal of becoming electricity self-sufficient by 2021; long-term goal of being energy independent and able to disconnect from the national electricity grid for periods.
- Sectoral plans (transportation, environment incl. water and waste-water management, energy and fuels) all include elements of energy planning but are not combined in an integrated energy plan or strategy.
- Emphasizes deployment and development of solar and battery technologies for the near future, in addition to demand-side management through smart city/smart grid initiatives.

Bélen:

- Main goal is to follow the Covenant of Mayors initiative and achieve the targeted 20% CO_2 emission reductions before 2020 - this does however not appear feasible. No long-term goal has so far been established.
- Primarily focuses on the deployment of solar energy due to an expected remaining potential. Potentially to be supplemented by wind power and heat pumps.

4 Energy planning practices

4.1 Relevance to tool development

While the previous chapter focused on whether long-term energy-related goals and strategies were present, the purpose of this chapter is to acquire information about the day-to-day practice of energy planning in municipalities and cities. This is included to obtain knowledge and understanding of whether quantitative and qualitative scenarios are used already in cities to guide future prioritization of technologies and actions, and if so, what type of scenarios are investigated. The insights from this are relevant both to the design of the energy system modelling tool and to the process of delimiting scenarios in the tool-testing phase.

The questions to the municipalities and cities related to their energy planning practices revolve around on how (if at all) scenarios, tools, processes, and energy system modelling, are utilized today for planning purposes of the energy system. This might include the use of computer tools but could just as well include qualitative planning processes such as procedures for the involvement of local stakeholders. For the purpose of identifying tool design criteria, it is relevant both to shed light on what kind of tools and processes are applied presently, as well as the reason for why they are utilized. Furthermore, if the municipalities do not currently use energy system modelling tools in their planning, determining what alternative processes the municipalities then use to prioritize actions or solutions is important. It might also be, that municipalities and cities do not consider such tools relevant to their planning practice. In that case, it is important to uncover why, and how tools should be adjusted in the future, to accommodate to the planning practices of the municipalities.

4.2 Energy planning practices - assessment and feedback from interviews

The current practice for energy planning in the demo-sites appears to primarily revolve around isolated energy-related initiatives, while coordination across sectors is limited. This can be exemplified through some of the initiatives of Oud-Heverlee such as the home thermoscans, CO_2 meters, or facilitation of group PV purchases. All are sensible and sustainable actions, but their individual influence on the attainment of a larger goal of a sustainable energy system is unclear.

From the interaction with the demo-site municipalities, it appears that the extent to which integrated energy planning is conducted as part of the typical planning practice in the municipalities is limited. Instead, the municipalities work towards implementing specific technology-centric measures, for example, electric vehicle charging stations or support for installation of photovoltaic panels. While these concrete initiatives are important and needed in the transition to renewable energy, it also appears that the municipalities might not always have the necessary overview of the effect on the entire energy system. According to Mirakyan and De Guio [33], integrated planning incorporating such holistic effects and synergies is generally mostly performed at a national level, thus aligning well with the findings based on the demo-sites.

In Chapter 2.1 it was outlined how the requirements to energy system modelling increase along with the transition to renewable energy supply [10]. The general idea is that in the early stages of renewable energy implementation relying on simple scenarios such as annual energy balances is unproblematic. However, from the discussions with the demo-sites, such an approach seems to be prevalent still, despite the ongoing transition to integrated and renewable energy systems.

Generally, the municipalities do have experience in applying scenarios based on annual energy balances for their planning practices, however, the municipalities have none or very little experience actually developing and applying energy system models. This leads to an emphasis on the output; scenarios that are used to describe a plausible energy future. This is likely a result of the lack of experience with model development and thus expertise needed to critically assess the inputs and assumptions included in the development of scenarios and models. This leads to a simplistic use of energy system models “as is”, as opposed to tailoring of the models.

Energy system modelling and tool usage is not a well-established part of the energy planning practice of the municipalities, likely due to a combination of reasons. This includes a lack of capacity due to the often highly limited number of people with actual energy planning responsibilities, or because energy planning tasks are divided across a mixture of municipal departments with a resulting lack of expertise. In general, across the demo-site municipalities, it seems that energy planning is not well-defined internally, and instead, energy planning tasks are sought incorporated into other departments. This results in a large variance in the background of the municipal planners working with energy planning and thus a lack of designated energy planners with the associated expertise.

4.3 Energy planning practices - assessment and feedback from interviews

Osimo:

- A general energy balance assessment is included as part of the municipality’s energy planning procedures.
- Energy system modelling tools are not currently used as part of the municipal energy planning. Building internal capacity on the use of energy systems modelling is however considered to be important.
- The municipality commits an engineer to perform energy diagnosis of buildings to identify the improvements (both energy installations and insulation) suitable for reducing the consumption of the building, and for classifying interventions according to an order of priority.

Oud-Heverlee:

- External consultants developed a baseline and business-as-usual energy scenarios, functioning as the foundation of the 2020 CO_2 emission reduction goal included in the Covenant of Mayor climate action plan. Beyond this, energy planning is not a well-established practice in the municipality.
- A range of initiatives to promote sustainability among citizens have been established, including home thermoscans, lendable CO_2 meters, and assistance in group purchase of PV panels, roof or wall insulation, cycling/e-bike working group, and attention to providing information and support for wind turbines to increase local support.

Eilat:

- Experience with the use of quantitative scenarios for transportation, energy, water. Scenarios are mostly used for energy efficiency and water usage. No experiences with energy system modelling, but willing to learn and apply it in the future.
- Considers constant attention to potential opportunities for co-operation, data exchange, and external meeting important to ensure the best available technologies and solutions are pursued.
- A program supporting and encouraging residential investments in photovoltaics is in place.

Bélen:

- The municipality has access to comparative emission models as a tool to assist in decision-making and determination of optimal scenarios. No other practices in place or experiences with the use of computer tools or energy system modelling.

- Energy system modelling is not currently applied in the municipality. A tool for the revision of all municipal electric bills will be implemented, as a first step towards studying energy efficiency pathways and future consumption optimization.

5 Delimitation and criteria

5.1 Relevance to tool development

Energy planning, as discussed in Chapter 2, is a very wide-ranging concept, and as such, boundary parameters must be established before meaningful results can be produced for municipalities. For the purpose of the energy system modelling tool development, this includes determining how the municipalities perceive their own decentralized energy system, and how this energy system is delimited from national energy systems. This could e.g. be through geographical, technological, organizational boundaries, or even a combination of these. This chapter furthermore investigates what criteria municipalities apply when comparing alternatives with the purpose of identifying optimal solutions. Such criteria may include costs to residents, external costs (e.g. from pollution), self-sufficiency, ease of implementation, ability to create a system in balance not relying on import/export, etc. Furthermore, this chapter establishes what sectors municipalities and cities consider present and relevant to energy planning, in addition to their thoughts on geographical boundaries of energy planning.

The delimitations and criteria uncovered are critical inputs to both the tool design and the delimitation of scenarios for the tool testing. The future energy system modelling tool should be capable of generating the assessment criteria deemed relevant and necessary for planning purposes by the municipalities, regardless of whether these are of economic, environmental or technical nature. Uncovering what type of questions the municipality needs, answering is a crucial step towards designing an appropriate energy system modelling tool.

5.2 Delimitation and criteria - assessment and feedback from interviews

The demo-site municipalities are very diverse, leading to different prioritization strategies. A general consideration for energy planning in municipalities is how being aware of local challenges and diversity is pivotal to successful planning. This is a point that was especially stressed by Eilat Municipality, emphasising how all cities have their own unique businesses and diversity. Eilat, in particular, has a very significant service sector as a result of an important tourist sector, which combined with the high ambient temperatures lead to large seasonal variations in energy demands. While this challenge is not present in the other demo-site municipalities, they instead have other local challenges to consider, such as depopulation, or stability of the electricity grid.

Generally, the municipalities consider a range of sectors important to the transition of which the most often mentioned sectors being the residential, industrial, service, and transport sectors. Sectors which are largely beyond the control of the municipalities, such as electricity generation, are in some cases de-emphasised. This is, for example, the case in the European municipalities, where the national electricity grid is predominantly considered stable. On the other hand, municipalities such as Eilat with a desire to become energy independent and even disconnect from the national grid at times, consider the increase of local electricity generation to be a critical part of future energy strategies.

As mentioned, the demo-site municipalities are seemingly aware of how a sustainable development of the energy system requires the continuous development and integration of a multitude of sectors. Some respondents do however describe a narrow focus of their energy planning practices, emphasising initiatives in particular in buildings and mobility sector. One plausible explanation for the increased attention to these sectors specifically, is that the municipalities find that they have the most direct influence on the development here. Therefore, future energy system modelling tools should both enable the planning and prioritization of these sectors that are important to the municipalities, but preferably also provide the tools needed for the municipalities to expand on their area of operation.

Despite how all the demo-site municipalities are connected to the national electricity grid, they all to some extent, at least with regards to their energy system, consider themselves to be separate from the surrounding energy system. This is exemplified through the presence of local energy goals applying the geographical municipality border as a limitation to the energy system. Energy-related goals such as for example CO_2 emissions or energy savings are accounted for on a municipal level, and future energy system modelling tools should enable capturing this reality. The extent to which this "island operation"-thinking is present varies, and is most striking in Eilat where actual ambitions for at least partial island off-grid operation exist. For the tool design process, acknowledging that the demo-site municipalities strictly consider their responsibility area to be within the municipal border is an important realization and something to incorporate in the tool design.

A number of important assessment criteria has been mentioned by the demo-site municipalities, of which the four most important are outlined below.

Assessment criteria:

- **Costs** are naturally, and without exceptions, considered to be an important criterion to the demo-site municipalities when assessing energy initiatives or alternatives. Incurred costs do however constantly need to be assessed in accordance with the obtained benefits to society.
- **CO_2 emissions** are included as a goal in the European municipalities Osimo, Oud-Heverlee, and Bélen, but is among the remaining municipalities not considered to be a critical criterion in the municipal energy planning. This appears to be the case because the development of the energy system is not solely motivated by environmental concerns but to improve the livelihood of the local community.
- **Energy savings** are generally considered an important target in energy planning strategies due to a combination of economic and environmental concerns.
- **Energy independence** relates to the ambition of having an energy system capable of operating partially in an off-grid operation mode. Ambitions for energy independence are most prevalent in weak-grid areas, and relate to the goal of having high security of supply and energy resiliency, regardless of the status of the national electricity grid.

5.3 Delimitation and criteria - specific case perspectives

Osimo:

- The municipality has not yet identified which initiatives will maximize the benefits for the community, but aim to do so based on profitability in terms of energy and economic savings, with margins calculated as a result of an energy audit.
- Primarily considers the residential, industrial, service, and transport sector important to municipal energy planning. Key targets being improving energy performance of buildings, exploitation of renewable energy sources and sustainable mobility.

Oud-Heverlee:

- Climate measures are prioritized in the following sectors:
    - Buildings and facilities: 20% CO_2 reduction from existing homes, 20% new-build zero-energy homes, 20% energy savings in municipal buildings, 20% energy savings in public lighting.

- Mobility and transport: Realizing fewer car kilometres, charging points for electric vehicles, public transport and car-sharing, increased bicycle use.
- Renewable energy: 10% electricity consumption within the municipality should be from renewable energy, 20% of households should have PV or solar water heaters.

- Other sectors such as agriculture and industry, while considered important to sustainable development have little presence in Oud-Heverlee.

Eilat:

- Energy independence, energy resiliency, and economic costs are the most important criteria in the assessment of future energy systems.
- Geographically energy planning is limited to include Eilat city and nearby surrounding rural communities, despite these being part of a different municipality.
- The substantial seasonal differences in energy demands due to the tourist seasons are difficult to incorporate in planning.

Bélen:

- Primarily consider electricity and heating in the residential, industrial, service, and transport sectors for energy planning in the municipality.
- Energy planning is geographically limited to the municipal border.

6 Capacity and competence

6.1 Relevance to tool development

Capacity and competences relate to the competences and resources available to the municipalities and cities. In the context of energy planning, that correlates to several parameters. Firstly, this relates to the number of people actively involved in energy planning, and to what extent they are involved. It might be that someone whose primary focus is spatial planning, traffic planning, or environmental planning also have secondary tasks related to energy planning. Secondly, this chapter aims at determining the level of technical knowledge and skill of the people involved in planning. Finally, the internal and external resources available to the demo-sites are outlined. Internal resources include factors such as the educational background of the planners and level of experience with energy on a technical and a planning/implementation level. Internal resources also include the availability of in-house experience with using computer tools such as Excel, GIS, MatLab, and Python, etc. External resources include the level of access to experts with knowledge and experiences not present within the city/municipal planning authority.

Being aware of the capacity and competences of the local city planners is essential to the design of the energy system modelling tool. The goal of the tool is for it to be of use for the cities without them relying overly on external experts. Thus, the complexity of the tool should be adjusted to the competences available internally, while maintaining a level of detail that enables the tool to produce the desired reliable results.

6.2 Capacity and competences - assessment and feedback from interviews

Few people are working specifically with energy planning. Energy planning is often conducted by associated departments such as environmental offices or transport offices, and similar. The people who do work exclusively (or almost exclusively) with energy planning often emphasise the implementation of specific projects or tasks. This might include PV incentive and support schemes, mobility strategies, etc. as opposed to integrated energy planning.

Municipal planners generally seem to have technical educations and thus knowledge, however, the level of expertise needed to conduct energy system modelling and -analysis is rarely present within the municipalities. Instead, municipalities rely on external consultancies and experts to supply these analyses. This finding aligns well with the findings in Petersen [14], depicting the nature and application of strategic energy planning in municipalities. Petersen states how often small- and medium-sized municipalities rely on external consultants for the development of municipal energy plans and strategies. A significant drawback to such an approach includes the typical top-down methodology applied by external actors, a methodology that might not capture the local differences between municipalities.

In three Danish cases, a consultancy was involved to develop three separate plans for three municipalities, and despite the spatial differences, the technological solutions identified were nearly identical [14]. Furthermore, relying on external consultancy requires significant financial resources, and is not always an option for smaller municipalities with tighter budgets. If instead, the municipalities were capable of developing the necessary models and scenarios themselves, their understanding and ownership of the plans would likely be much greater, and make it easier to include local differences through a bottom-up approach. Ownership of the model and plan would likely also be greater, and making future alternations to the model or testing alternative scenarios would be easier.

Tool usage for energy planning and –modelling within the municipalities is limited to basic office applications including Excel, and in some instances GIS-based applications. This does pose a challenge for the tool development since preferably both the inputs for the tool as well as the results would be in a format that is simple and intuitive for the municipalities to use. This could, for example, be in the form of Excel inputs and outputs, or some other form of intuitive interface guiding the user through the process of including the required input data. Likewise, important model outputs providing a general overview of system operation should be easily available, and not hidden in a mess of complex data points that the user will first need to sort through and analyse.

6.3 Capacity and competences - specific case perspectives

Osimo:

- Only one person works with topics from the field of energy planning. A climate action plan was developed as a collaboration from different departments, with the Technical Office as primary contributors.
- Use of computer tools is limited to standard MS Office applications. Access to external consultants is highly limited because of limited financial resources.

Oud-Heverlee:

- The municipality relies on external experts for the development of energy scenarios.
- Holistic energy planning is not conducted. Instead, energy planning is limited to isolated initiatives such as implementing low-energy street lighting.

Eilat:

- In total, 20-25 people across different sectors within the municipality have a position that touches upon aspects of energy planning. However, only 1-3 work solely on energy planning.
- Use of computer tools within the municipality is limited to Excel and GIS-based applications. When necessary external consultants are included for complex technical problems or programming.

Bélen:

- The city council relies on the Municipal Energy Agency consisting of two persons for the energy advice of municipal and citizen services. Energy planning activities are incorporated into the procedures of other areas such as spatial planning, traffic planning, and environmental.
- The municipality has access to external consultants for scenario development or technical analyses. Scenarios developed by external consultants have formed the foundation of the most recent Sustainable Energy Action Plan.
- Internal use of computer tools is limited to standard MS Office and GIS applications.

7 Conclusion regarding tool design characteristics

Energy planning is no longer solely a centralised, national task. This is underlined by the growing body of research and literature on decentralised energy planning, stressing the important role of municipalities in the transition to renewable energy systems. The interactions with the MUSE GRIDS demo-site sites further validate this development, apparent through the consistent presence of goals related to renewable energy.

The demo-site municipalities generally have a positive attitude towards energy system modelling, recognise the value of having internal modelling capacity, and consider energy system scenario making and -analysis to be important in the development of future renewable energy strategies. However, most do not possess the internal resources to conduct such energy system modelling. The municipal planners generally have some sort of technical or engineering background, but still do not possess the energy-specific expertise needed, likely a by-product of the diverse area of responsibility for the planners.

The demo-site municipalities generally only have a few people working explicitly with energy planning, and in some cases, there are no dedicated energy planners available. A future energy system modelling tool should preferably be able to provide meaningful results for the municipal planners despite the limited time available for the actual modelling process. An option could be to have a tool that functions at different complexity levels; a "basic" level requiring fewer input parameters, and an "advanced" level requiring a larger range of inputs, but also providing a more detailed output.

Established goals are predominantly technology-focused and static, with an emphasis on short-term objectives, an approach which may not result in the development of the most efficient and least-cost energy system. This effect potentially correlates to the limited available personnel employed solely with an energy planning purpose. From the demo-site municipalities, it appears that energy planning tasks are conducted almost entirely by zero to three people, severely hindering the complexity of the analyses undertaken.

The emphasis on technology-focused goals could be a result of the municipalities close connection to the development and implementation phase of projects. This is as opposed to planning conducted at a centralized national level and might be the reason as to why concrete technology-based goals are prioritized. The planning process is less complicated compared to holistic energy planning across different sectors, and the results are immediate and apparent to the local community.

Awareness of the local context is important to energy system analysis and –modelling at a municipal level, where local differences can impact the analysis significantly. The municipalities are typically knowledgeable of their local system, and having a tool that could be used internally would enable the incorporation of details and local particularities external partners would not otherwise capture.

Municipalities in areas with a weak national electricity grid value energy independence highly. Elsewhere the primary motivation for energy system development appears to be economic savings and environmental sustainability, thus the greatest value is put on reducing energy consumption and CO_2 emissions.

Emphasis on buildings and energy savings appears to be among the most common measures initiated. Likely because this is an area the municipalities are able to directly influence. A takeaway from this is, that an energy system modelling tool should be capable of providing the municipalities with concrete inputs for attainable action plans for areas where the municipalities can reasonably be expected to have actual influence. Often this will include the residential housing and transportation sectors, which also generally have the largest contribution to CO_2 emissions.

In Section 2.3 the main differences of simulation models relative to optimisation models were introduced, and for the tool design, this is an important distinction, with no inherently right or wrong direction. An argument for a simulation-based tool is that the municipalities generally have experience in applying scenarios for decision-making and development of strategies. Designing these alternative scenarios, with the aid of an energy system modelling tool, is not drastically different from their current practices. The process of testing different scenarios arguably also supports the build-up of choice awareness better than an optimization model, where outputs can appear irrefutable since it is the result of optimization. In simulation models, it is more apparent that model outputs are a result of the input data, restriction criteria, and choice of evaluation criteria. A simulation model might thus better enable the build-up of local energy system knowledge and awareness of the range of alternatives available and more active use of energy system modelling, as opposed to an optimization-based approach emphasising one optimal solution.

7.1 Main takeaways by theme

Long-term planning goals:

- A distinct lack of long-term goals results in predominantly short planning time-horizons.
- Concrete objectives such as CO_2 emission reductions or energy consumption reductions are generally present, but defining manageable pathways and prioritizing technologies is a challenge.

Energy planning practices:

- The municipalities have experience in applying scenarios for strategy formulation or technology prioritisation, but generally apply scenarios as simplistic representations of an energy future, as opposed to tailoring and as a basis for scenario comparison.
- No established practice for energy system modelling exists within the municipalities.
- Manageable, isolated energy initiatives are typically preferred - potentially a by-product of the lack of long-term strategies.

Delimitation and criteria:

- The municipalities to some extent consider themselves as isolated from the national energy system, and therefore evaluate initiatives based on their immediate influence on the municipal energy system and -energy balance.
- Main assessment criteria: cost, CO_2 emission reductions, energy savings potential, energy independence.

Capacity and competences:

- The municipalities generally have a positive attitude towards increasing their energy system modelling knowledge and tool usage.
- Limited internal capacity for energy planning; often there are no dedicated energy planners present. Energy planning activities are instead incorporated into other planning areas such as spatial planning, environmental planning, or traffic planning.
- No experiences with energy system modelling or tool usage. When needed these tasks are conducted by external consultants.

Part 2: MUSE GRIDS Energy planning tool user guide

8 Introduction to MUSE GRIDS Energy planning tool

This part of Deliverable 3.2 introduces the user guide for the MUSE GRIDS Energy planning tool that is designed for creating and developing scenarios for municipal-sized energy systems with different energy grids and technology mixes. The purpose of the tool is to assist local energy planning efforts by providing an interface for energy system modelling as well as help tools that can be used for providing inputs and assessments for local-scale energy planning efforts. The tool includes the electricity, heating, cooling, transport, and industrial energy demands.

The MUSE GRIDS Energy Planning tool is designed based on the findings from the survey of the energy planning practices as presented in Part 12 of the deliverable which established the purpose and relevance of energy system modelling and tool use in a municipal context. In those analyses, it was found that several challenges exist that energy system modelling tools should consider if they are to be applicable in a municipal context.

Municipalities generally have a positive attitude towards energy system modelling and using energy system scenarios for energy planning purposes. However, doing so is difficult due to limited internal capacity for energy planning and energy system modelling; often there are no dedicated energy planners present, and energy planning activities are instead incorporated into other planning areas such as spatial planning, environmental planning, or traffic planning.

Typically, municipal planners have limited experience with energy system modelling or tool usage, and when required, such tasks are often undertaken by external consultants. This comes with a risk of having more generalized scenarios, as such external consultants do not have the same local knowledge and expertise as the local energy planners.

A general lack of long-term goals for the municipal energy systems was found in Part 1, and even when long-term goals are present, defining manageable pathways and prioritizing technologies is a challenge. Instead, short planning time-horizons are generally preferred, with specific and isolated objectives. Established goals are predominantly technology-focused, emphasising short-term objectives, such as energy-efficient street lighting or electric vehicle charging stations. While such initiatives are important, a broader and cross-sectorial energy system perspective also needs to be considered in the planning for renewable energy systems.

Tools for municipal planning purposes therefore must combine the need for cross-sectoral analyses with concrete and implementable initiatives, while striving to balance analytical complexity and operational simplicity.

It was also found in Part 1 of this deliverable that municipal planners have experience in working with Excel, which therefore could be a useful interface for providing easier access to more complex energy system modelling tools. Therefore, the interface of the MUSE GRIDS Energy planning tool is created in Excel using Visual Basic for Applications (VBA) to create connections with an established energy system simulation tool as well as external databases and help tools used for assessments of demands, etc.

8.1 The process of analysing transition pathways using MUSE GRIDS Energy planning tool

The MUSE GRIDS Energy planning tool is a tool for the analyses of different energy transition pathways. It is based on what is referred to in the energy modelling community as “exogenous system optimisation”. This means, that the MUSE GRIDS Energy planning tool leaves it to the user to define the scenarios that are to be analysed thereby engaging the user directly in the choice of technologies and more.

The MUSE GRIDS Energy planning tool is based on defining a reference system and designing and analysing alternative pathways towards a desired goal. Such pathways are designated as scenarios. A scenario is thus a combined set of changes to the energy system – usually something that can be combined under a common header for instance "High wind and electricity savings". Furthermore, the MUSE GRIDS Energy planning tool works with "variations". In this example, this could for instance be different combinations of wind expansion and electricity savings. Another scenario example could be "District heating expansion" where variations could be different technology options for supplying district heating.

Due to its nature with user-defined scenarios, scenario development is a recursive activity as indicated in Figure 1.

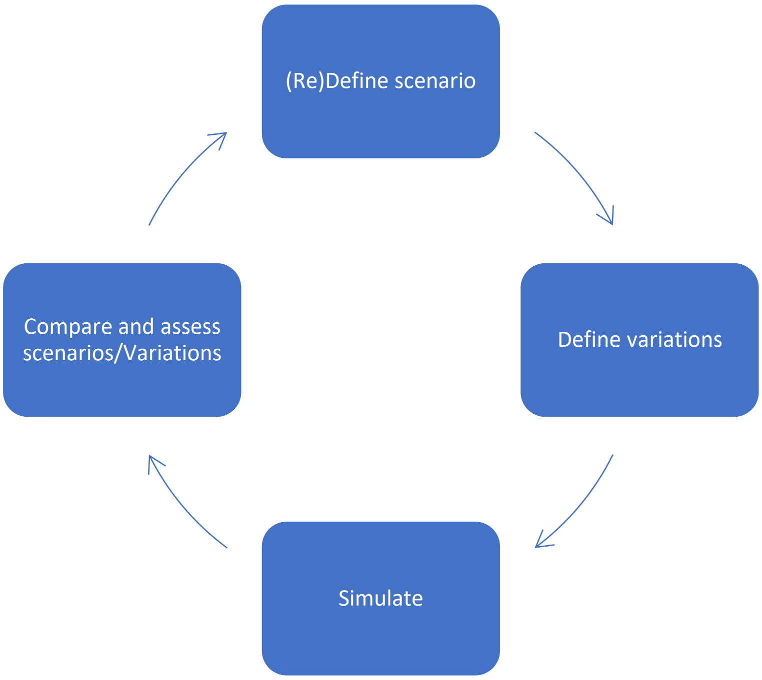


Figure 1 Recursive scenario development process using the MUSE GRIDS Energy planning

The MUSE GRIDS Energy planning allows the user to compare and assess scenarios based on a number of criteria – economic, CO_2 emissions, fuel usage, and electricity exchange (See Section 10.6) and depending on the specific objective of the energy transition process, the user will use one of more of these to modify the scenario/variation.

Typically, CO_2 emissions end costs could be main parameters for a closer inspection, however, if for instance the location is an island, in an area with a weak grid, or if self-sufficiency is of the essence, then a more technical parameter like electricity exchange is relevant to observe. This indicates to what extent the modelled system relies on the surrounding world to maintain the balance between electricity production and demand.

Thus, through the recursive definition of scenarios and variations and the analysis of the simulation results, the planner will identify appropriate transition strategies that meet the local objectives.

9 The energy system simulation tool EnergyPLAN

To analyse future energy system scenarios, it is important to have temporal evaluations of the operation of the different energy system scenarios. This is e.g. to include effects of peak demands, variable electricity production of renewable technologies, and energy storage technologies. For this purpose, an existing energy system modelling tool is implemented as part of the MUSE GRIDS Energy planning tool. The tool is EnergyPLAN. This version of the MUSE GRIDS Energy planning tool uses EnergyPLAN v15.1.

EnergyPLAN simulates hourly energy balances in all the sectors in an energy system, including the heating, power, gas, transportation, and water desalination sectors. In EnergyPLAN, the energy system is represented as a copper-plate model in terms of the electricity and gas system with no spatial specification of the location of demands and supply within the modelled system. An overview of technologies and sectors present in EnergyPLAN is shown in Figure 2.

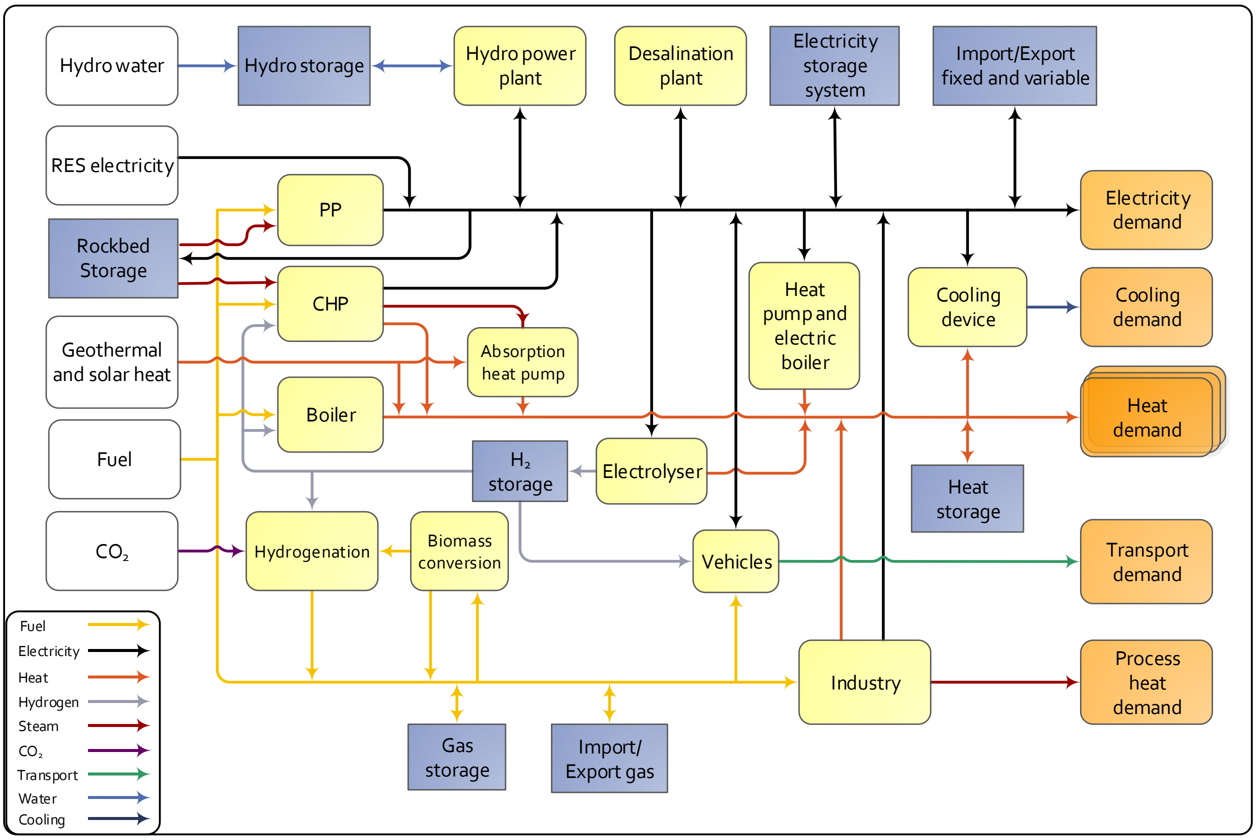


Figure 2 Overview of EnergyPLAN technologies and cross-sector integration

The MUSE GRIDS Energy planning tool does not utilise all aspects of EnergyPLAN but only those that are most relevant for municipal energy planning. E.g., the tool does not include hydro storage, desalination plants, electrolysers, hydrogenation, biomass conversion, micro-CHP units, and gas storage. Some of the included parts have also been simplified to accommodate easier access for non-experts. In EnergyPLAN, district heating is e.g. divided into three groups according to technology, but the MUSE GRIDS Energy planning tool does not include district heating Groups 1 and 2 but only use Group 3.

Overall data structure and system requirements

Microsoft Windows and **Microsoft Excel (2016 or newer)** are required to use the MUSE GRIDS Energy planning tool.

The MUSE GRIDS Energy planning tool is downloaded as a zip file that should be extracted to a folder on a local drive (C:\, D:\, etc.). The tool is not designed to work on network drives. The newest version can be found at www.energyplan.eu

When the zip folder is extracted the main folder contains two files and two folders:

- "**MUSEGRIDS-tool.xlsm**" - The user interface of the tool. **Open this to start the tool**.
- "UserGuide.pdf" – The user guide for the MUSE GRIDS Energy planning tool.
- "Help tools" folder – Contains the different assessment tools that are not part of the VBA code within Excel.
- "ZipEnergyPLAN151" folder – Contains the energy system modelling tool EnergyPLAN that is used for simulations of the defined energy system. In the subfolder "energyPlan Help" you can find documentations related to EnergyPLAN.

This folder structure should not be altered, as this might result in issues related to the automatizations of the tool.

Figure 3 shows a general overview of the data structure utilised by the MUSE GRIDS Energy planning tool.

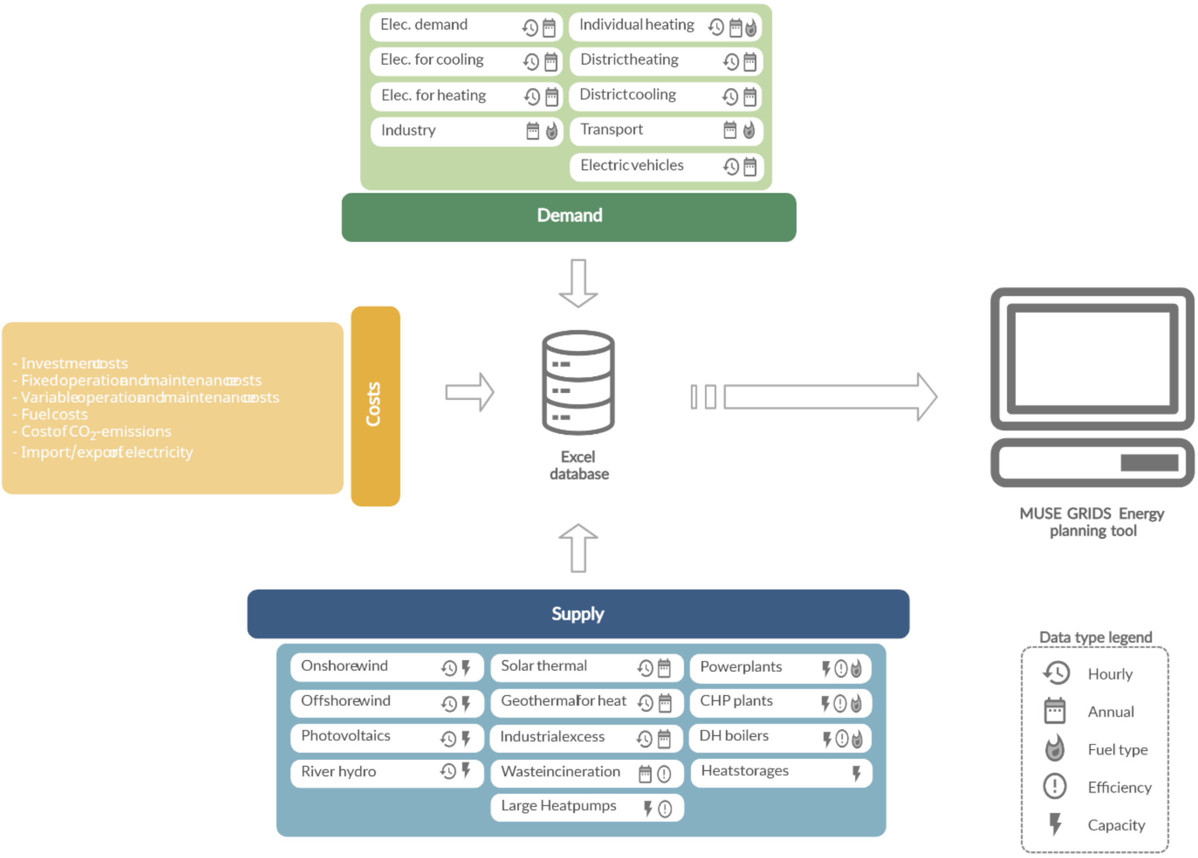


Figure 3 General overview of the data structure utilised by the MUSE GRIDS Energy planning tool. DH is short for district heating.

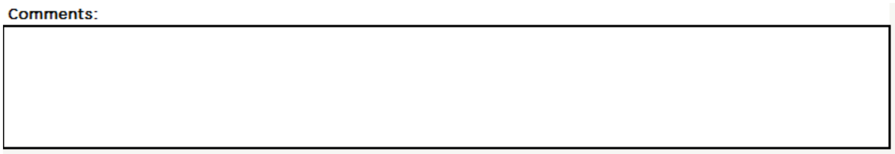
More information about the different inputs and methods as well as how to collect data on these can be found in Deliverable D3.1 – *Mapping tool (Sources and demands) prototype*, that has been developed as part of WP3 of the MUSE GRIDS project. The aim of D3.1 is to provide methodologies that can be applied in any country, each of these chapters have a generic approach, that typically uses general national statistics as input data. However, as the MUSE GRIDS Energy planning tool is created with the purpose of modelling local municipality energy systems, a more detailed approach is also provided for the most relevant demands and resources. As to easier find the relevant information in Deliverable D3.1, throughout the detailed explanation of the user interface in chapter 10, references for where to find more information in Deliverable D3.1 are provided.

10 The MUSE Grids tool user interface and standard values

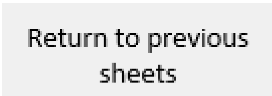
This section introduces the MUSE Grids tool user interface and where applicable describes the standard values included with the tool. These standard values can be considered as general recommended inputs in the event that no local data inputs can be located. The standard values included are described in the following sub-sections 10.2, 10.3, and 10.4.

Generally, the following principles are used throughout the MUSE GRIDS Energy planning tool:

- All grey cells highlight a possible input. Marking a grey cell shows a short description of the input needed.
- If something is not part of your energy system you can leave that cell blank.
- Some demands and technologies require an hourly distribution for being able to simulate the energy system on an hourly basis, as is done in EnergyPLAN. If no hourly distribution is chosen then the tool is set to use a constant distribution, meaning the demand or production would be the same in all hours of the year.
- All distributions need to contain <u>exactly</u> 8,784 hours of data.
- The method for selecting distributions are drop-down menus, where several options are available. To the right of each, an option to show a graph of the distribution is available.
- For some inputs, additional assessment tools are available. This can either be in form of a button or as part of the options in a drop-down menu. These tools are not part of EnergyPLAN and are described in Chapter 11.
- A comment field is available at the bottom of each input sheet. This gives the user the option to describe and document the inputs.



- Some places in the tool a button for "Return to previous sheet" will appear. This button returns the user to the former sheet opened.



- Costs are stated throughout the tool and are generally located in the same input sheets as where the technical data of a given technology is stated. In the tool costs are divided into:
    - **Investment costs:** The cost of investing in the technology at the time of investment. Investment costs are annualised using an interest rate and the technical lifetime. Investments are defined where the technology is defined. (Note, if no lifetime is stated by the user, the lifetime is assumed to be 1 year)
    - **Fixed operation and maintenance costs:** Operation and maintenance costs that do not change with production or consumption, such as maintenance of buildings. This is expressed in % of the investment cost (e.g., if the investment is 1,000 EUR and fixed operation and maintenance is 10 EUR/year this should be inserted as 1 % of investment). Fixed operation and maintenance costs are defined where the technology is defined.
    - **Variable operation and maintenance costs:** Operation and maintenance costs that do change with production or consumption, such as wear and tear caused by operation. This is expressed

as a cost per unit. Variable operation and maintenance costs are defined where the technology is defined.

- **Fuel costs:** Cost of coal, fuel oil, diesel and gasoil, petrol, gas, waste, and biomass. Handling costs for different places of consumption can be set as Handling costs. Fuel costs are set in "Supply-Fuel costs".
- **Cost of CO_2-emissions:** Cost of emitting CO_2 in CO_2-equivalents. This can both be the CO_2-emissions in the modelled area, but also the CO_2-emission effects of import and export of electricity. CO_2-emissions and CO_2-costs are set in "Supply-Fuel costs".
- **Import/export of electricity:** The cost of importing electricity and income from exporting electricity. Costs for import and export of electricity are set in "Supply-Electricity connections".

Cost data for a range of different technologies in a format that is directly useable by the MUSE GRIDS Energy planning tool can be found at: https://www.energyplan.eu/useful_resources/costdatabase/

The overall interface has a menu to the left and the data input or output is seen on the right. This is shown in the following screenshot.

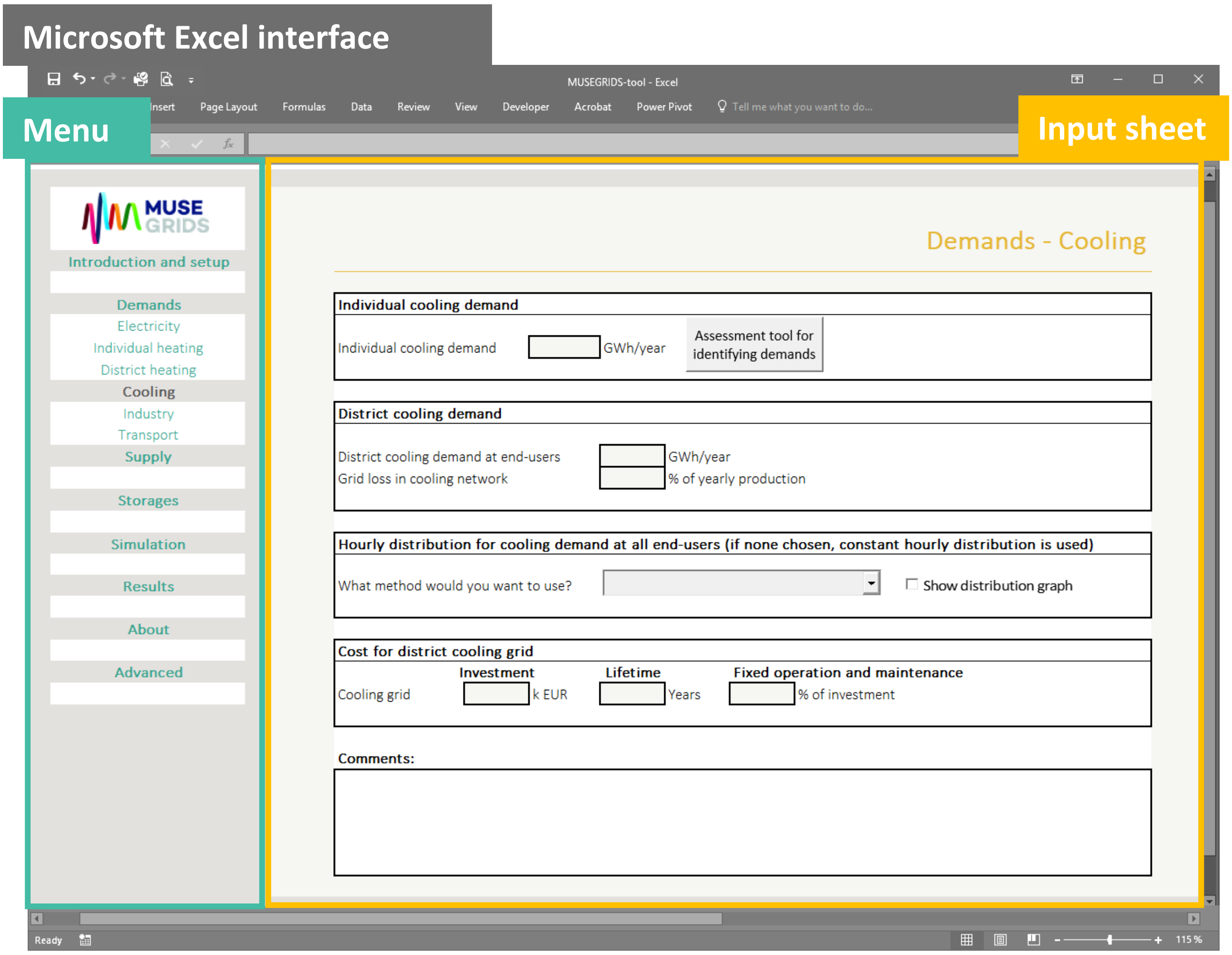


Figure 4 Screenshot of the MUSE GRIDS Energy planning tool overall interface

The main menu consists of "Introduction and Setup", "Demands", "Supply", "Storages", "Simulation", "Results", "About", and "Advanced". Clicking on most of these shows the submenus available for that item and opens the first input sheet in the submenu. “Introduction and Setup” and “About” have no submenu items. As seen in the screenshot, once a menu is open and a submenu is chosen, the enabled sheet name text turns dark grey. In the picture, the user would be navigating through the Cooling subcategory’s input sheet, in the Demands menu category, in the MUSE GRIDS Energy planning tool.

In the following sections, each of the input sheets of the Excel file “MUSEGRIDS-tool.xlsm” are described in more detail. Each input sheet is presented first with a short description of the purpose, then a screenshot and lastly bullet points describing each of the inputs or input categories of the input sheet. The short descriptions are also found in the tool by marking/clicking on any of the input cells. The screenshots in the following sections exclude the Excel interface, as it is irrelevant in the context of understanding the MUSE GRIDS Energy planning tool. In the actual tool the Excel interface is present. Lastly in the input sheets descriptions, a reference to where in the Deliverable D3.1 – *Mapping tool (Sources and demands) prototype*” more information can be found. The deliverable is referred to as D3.1 in the descriptions.

10.1 Introduction and setup

Here some short introduction and some general setup options are found.

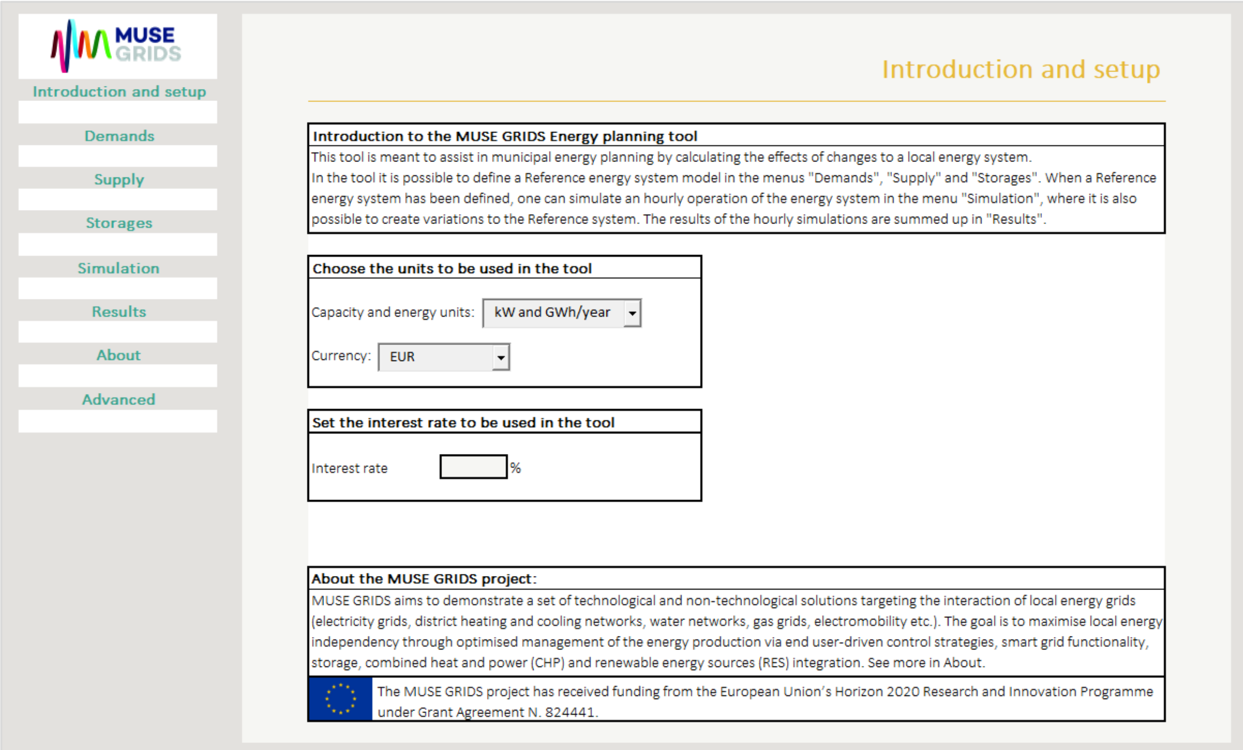


Figure 5 Screenshot of the "Introduction and setup" interface

- **Capacity and energy units**: Choose the pair of capacity and energy units to be used in the tool. Three options are available: "kW and GWh/year", "MW and TWh/year", and "GW and PWh/year". Typically, "kW and GWh/year" should be used for municipal-sized energy systems. "MW and TWh/year" is typically used for country scale energy systems and "GW and PWh/year" for large countries or continental energy systems.
- **Currency**: Set the currency unit to be used. Note, the tool does not convert costs if the currency is changed, only the currency label is changed.
- **Interest rate**: Set the interest rate to be used for all investments made. All investments are transformed into equivalent annual costs using the interest rate and the stated lifetime of the technology.

10.2 Demands

Here the inputs for the different energy demands are defined. The energy demands are divided into electricity, individual heating, district heating, cooling, industry, and transport.

10.2.1 Electricity

In this input sheet, the electricity demand in the modelled energy system is set. The electricity demand defined here should not include electricity for district heating producing units and transport, such as electric cars.

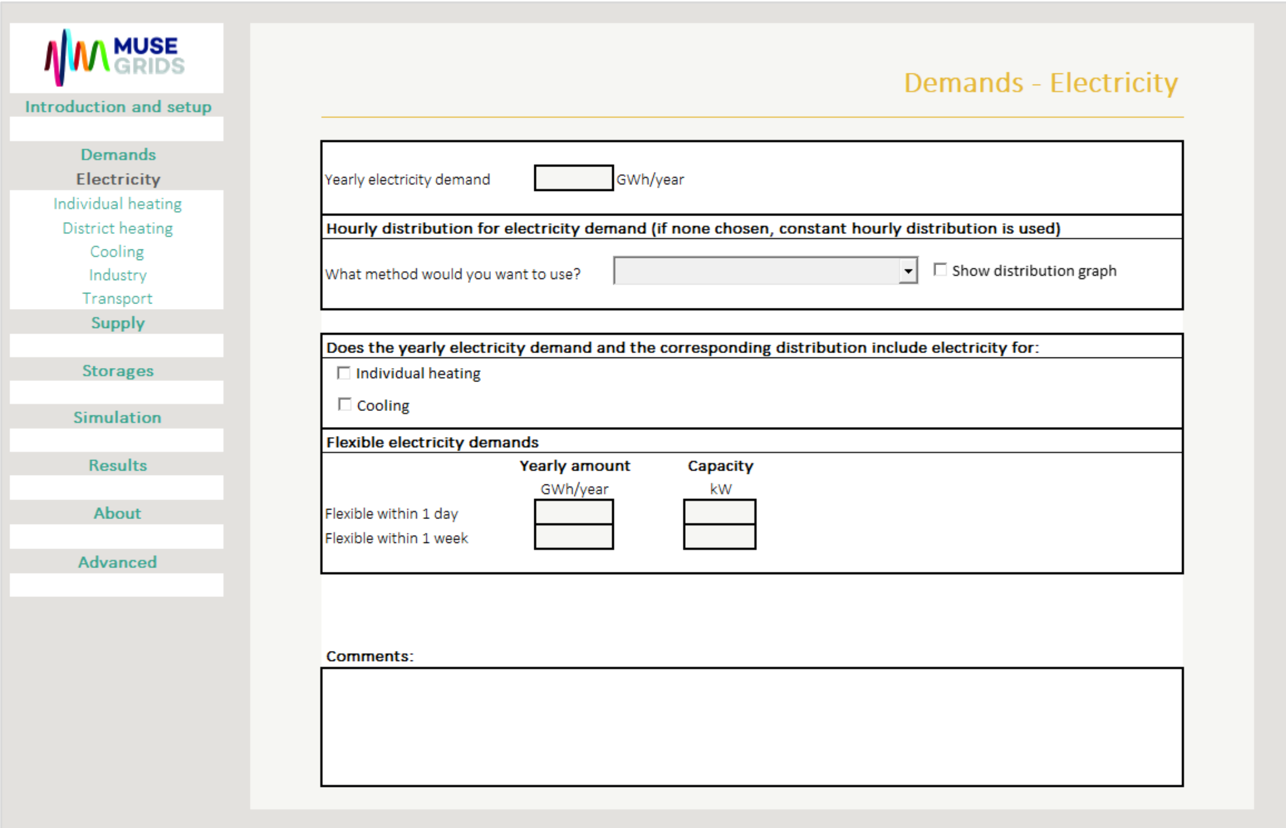


Figure 6 Screenshot of the "Electricity" in Demands interface

- **Yearly electricity demand**: The yearly electricity demand is inserted here. In case this electricity demand includes electricity for individual heating or cooling, use the check boxes below.
- **Hourly distribution for electricity demand**: The hourly distribution that is needed for dividing the yearly electricity demand into each hour. The distribution does not need to be absolute demand values in each hour, but can be relative values for each hour, as the distribution is used alongside the yearly demand to calculate demands in each hour.
- **Does the yearly electricity demand and the corresponding distribution include electricity for**: Check either of these boxes if the electricity used for Individual heating (e.g. heat pumps) or Cooling is part of the electricity demand and the corresponding distribution above. If these boxes are checked, then the tool will estimate the electricity demand for these depending on the inputs given for Individual heating in the "Demands-Individual heating" and for Cooling in the "Demands-Cooling". Often measured electricity demands for an area will include these values.

- **Flexible electricity demands**: Here an amount of the yearly electricity demand can be designated as being flexible within 1 day or 1 week. These are the demands where the time-of-use can be shifted in time if appropriate from a system perspective. The demand needs to be stated as the yearly amount and the corresponding capacity that can be moved. Note, the flexible demand should be included in the "Yearly electricity demand" number. Also, do not include electricity demands for Individual heating, District heating, Cooling, or Transport, as there are introduced in their respective windows.

Check methodologies for this input in D3.1, Section 2.

10.2.2 Individual heating

In this input sheet the energy demands for heating supplied by individual heat sources (e.g. household gas boilers) is defined.

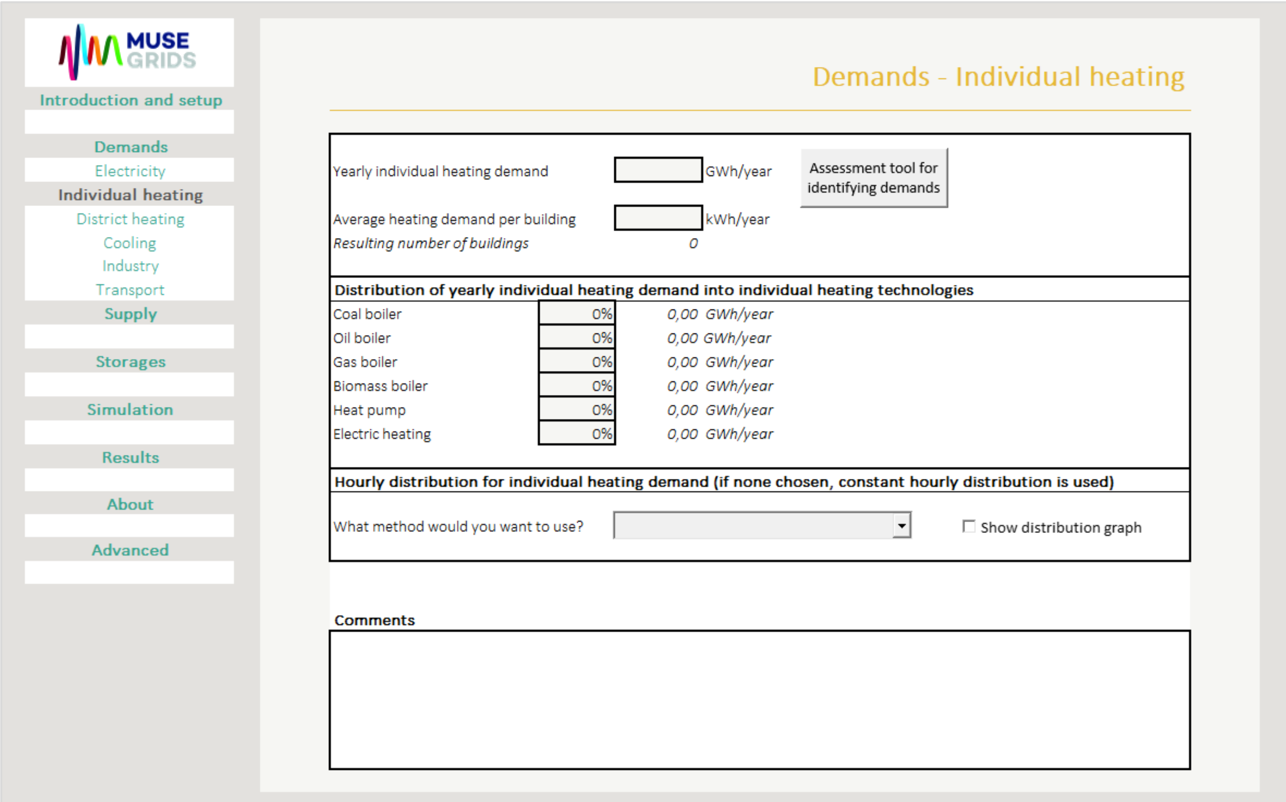


Figure 7 Screenshot of the "Individual heating" in Demands interface

- **Yearly individual heating demand**: Here the total heating demand supplied by individual heat sources (e.g. household gas boilers) is inserted. The heat demand is after the conversion loss in the energy conversion technologies.
- **Average heating demand per building**: Here the average heating demand per building is inserted. This is used to calculate the amount of installed individual heating sources to calculate total investment costs of the individual heating solutions.
- **Assessment tool for identifying demands**: Goes to the Assessment tool for identifying demands. That is described in Section 11.4. Can be used for assessment of the Yearly individual heating demand, Average

heating demand per building, and Distribution of yearly individual heating demand into individual heating technologies.

- **Distribution of yearly individual heating demand into individual heating technologies**: Share of the individual heating demand supplied by the different types of individual heating technologies that the tool allows. The share is relative, so the total is not required to be 100%.
- **Hourly distribution for individual heating demand**: The hourly distribution that is needed for dividing the yearly individual heating demand into each hour. The distribution does not need to be absolute demand values in each hour, but can be relative values for each hour, as the distribution is used alongside the yearly demand to calculate demands in each hour. Assessment tool selection in the drop-down menu accesses the "Assessment tool for identifying heating and cooling distributions" that is described in Section 11.5.

Check methodologies for this input in D3.1, Section 3.

10.2.3 District heating

In this input sheet, the energy demands for heating supplied by district heating systems are defined. District heating systems are systems for distributing heat generated in centralized locations through a system of pipes for residential and commercial heating requirements, such as space heating and water heating.

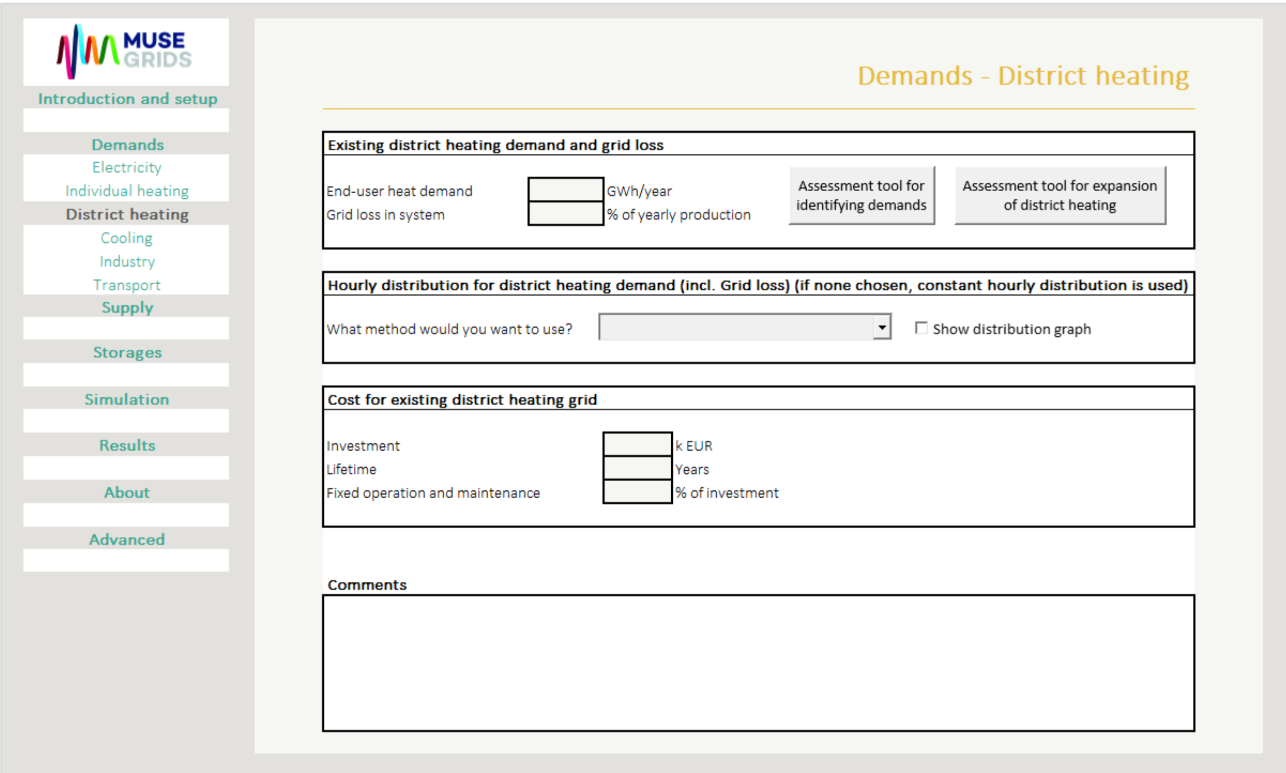


Figure 8 Screenshot of the "District heating" in Demands interface

- **End-user heat demand**: Here the district heating demand at the end-users (excl. heat losses in the grid) is inserted.
- **Grid loss in system**: Here the grid loss of the district heating network is inserted. The grid loss needs to be inserted as a percentage of the total district heating production. Typically, district heating systems

have a grid loss somewhere in the range of 10-30% depending on several factors. Especially the heat density of the area supplied is important for the grid loss with a higher heat density resulting in lower grid loss, but other factors such as the temperature in the grid and insulation of the pipes also factors into the grid loss. The tool “Assessment tool for expansion of district heating” can provide an estimate for the grid loss at different levels of district heating in an area.

- **Assessment tool for identifying demands**: Goes to the “Assessment tool for identifying demands”, that is described in 11.4. Can be used for assessment of the End-user heat demand.
- **Assessment tool for expansion of district heating**: Goes to the “Assessment tool for identifying the potentials for expansion of district heating”, that is described in Section 11.4. This tool does not know the existing district heating demands in the current system but can be used for assessment of the grid loss if this is not known.
- **Hourly distribution for district heating demand**: The hourly distribution that is needed for dividing the yearly district heating production into each hour. The distribution does not need to be absolute demand values in each hour, but can be relative values for each hour, as the distribution is used alongside the yearly demand to calculate demands in each hour. This distribution should include the grid loss in the district heating grid.
- **Cost for existing district heating grid**: Here the total investment costs, technical lifetime (from the time of installation) and fixed operation and maintenance costs are inserted for any existing district heating grid.

Check methodologies for this input in D3.1, Section 3.

10.2.4 Cooling

In this input sheet, the demands for cooling are set. Cooling demands can be defined for individual cooling solutions (i.e. electric chillers installed at households) and demands supplied by district cooling systems.

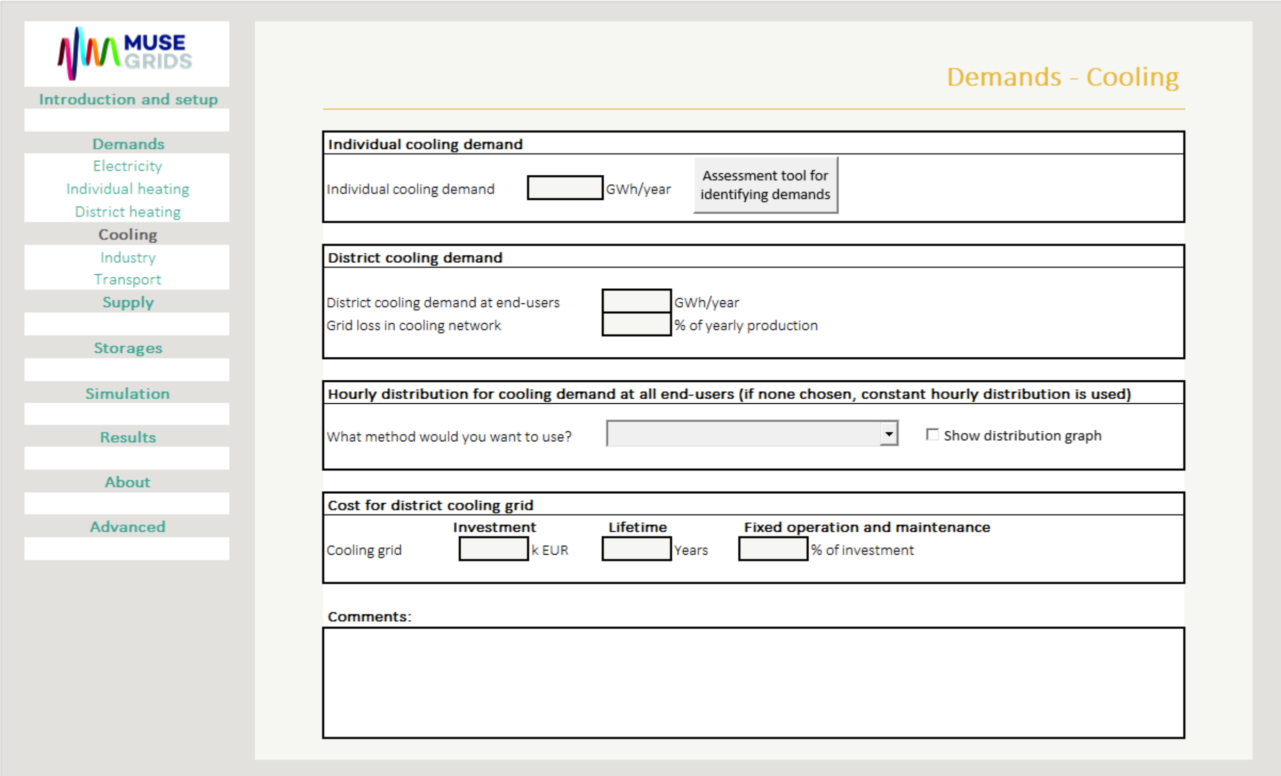


Figure 9 Screenshot of the "Cooling" in Demands interface

- **Individual cooling demand**: Here the cooling demand that is met by individual cooling units should be inserted.
- **Assessment tool for identifying demands**: Goes to the "Assessment tool for identifying demands", that is described in Section 11.4. Can be used for assessment of the End-user heat demand.
- **District cooling demand at end-users**: Here the cooling demand at end-users (excl. grid loss) that is delivered by a district cooling system should be inserted.
- **Grid loss in cooling network**: Here the grid loss of the cooling network is inserted. The grid loss needs to be inserted as a percentage of the total district cooling production. The loss is assumed to be constant in absolute terms throughout the year.
- **Hourly distribution for cooling demand**: The hourly distribution that is needed for dividing the yearly cooling demand into each hour. The distribution does not need to be absolute demand values in each hour, but can be relative values for each hour, as the distribution is used alongside the yearly demand to calculate demands in each hour. This distribution should not include the grid loss in the district cooling grid. The distribution is used for both individual and district cooling end-user demands.
- **Cost for district cooling grid**: Here the total investment costs, technical lifetime (from the time of installation) and fixed operation and maintenance costs are inserted for any existing district cooling grid.

Check methodologies for this input in D3.1, Section 3.

10.2.5 Industry

In this input sheet, the fuel demands for the industrial sectors' energy demands can be set.

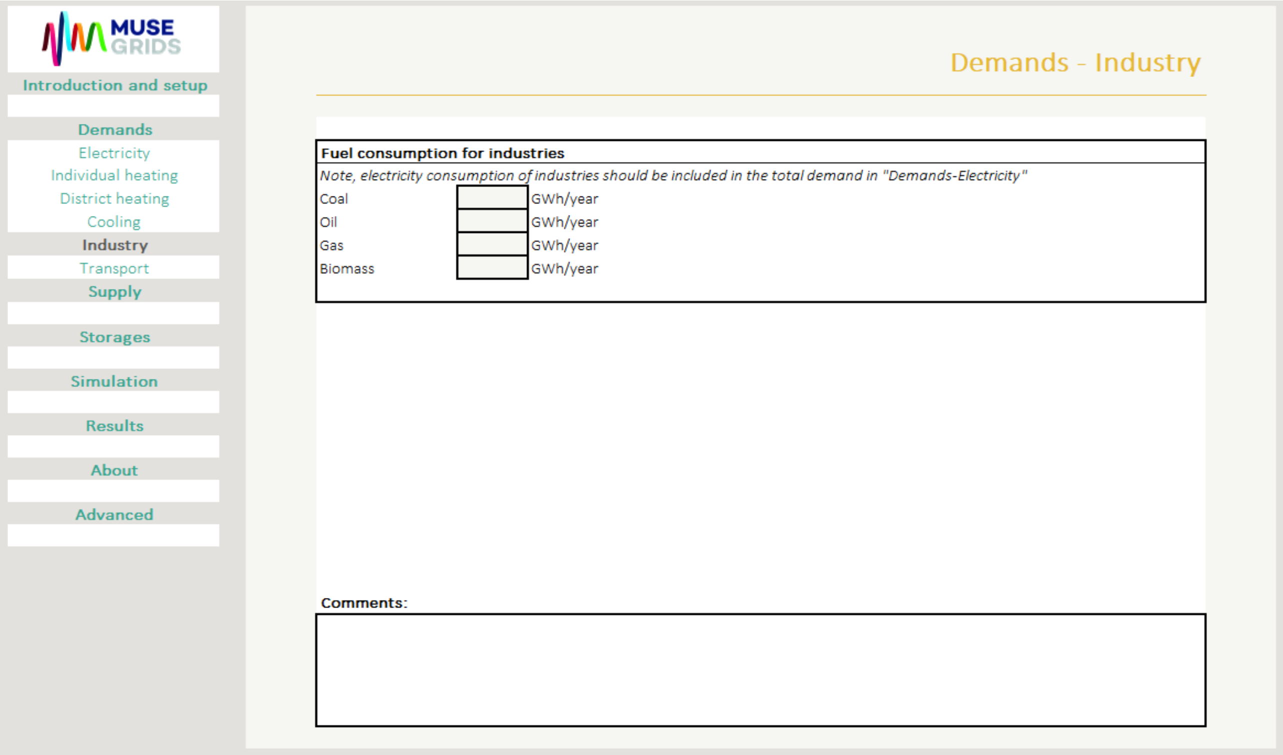


Figure 10 Screenshot of the “Industry” in Demands interface

- **Fuel consumption**: The industrial energy demands are only represented as yearly fuel usage in the tool. Some of the industrial demands might also be part of the Yearly electricity demand set in the “Demands-Electricity”, End-user heat demand in “Demands-District heating” if supplied by district heating, or in “Demands-Cooling” if either of these cooling technologies are used for industrial demands.

Check methodologies for this input in D3.1, Section 8.

10.2.6 Transport

In this input sheet, the energy demands for the transport sector can be stated. This input sheet also includes a link to an assessment tool for transport demands, assisting the user in establishing reasonable input data in the event that no local data is available. The assessment tool is described further in Section

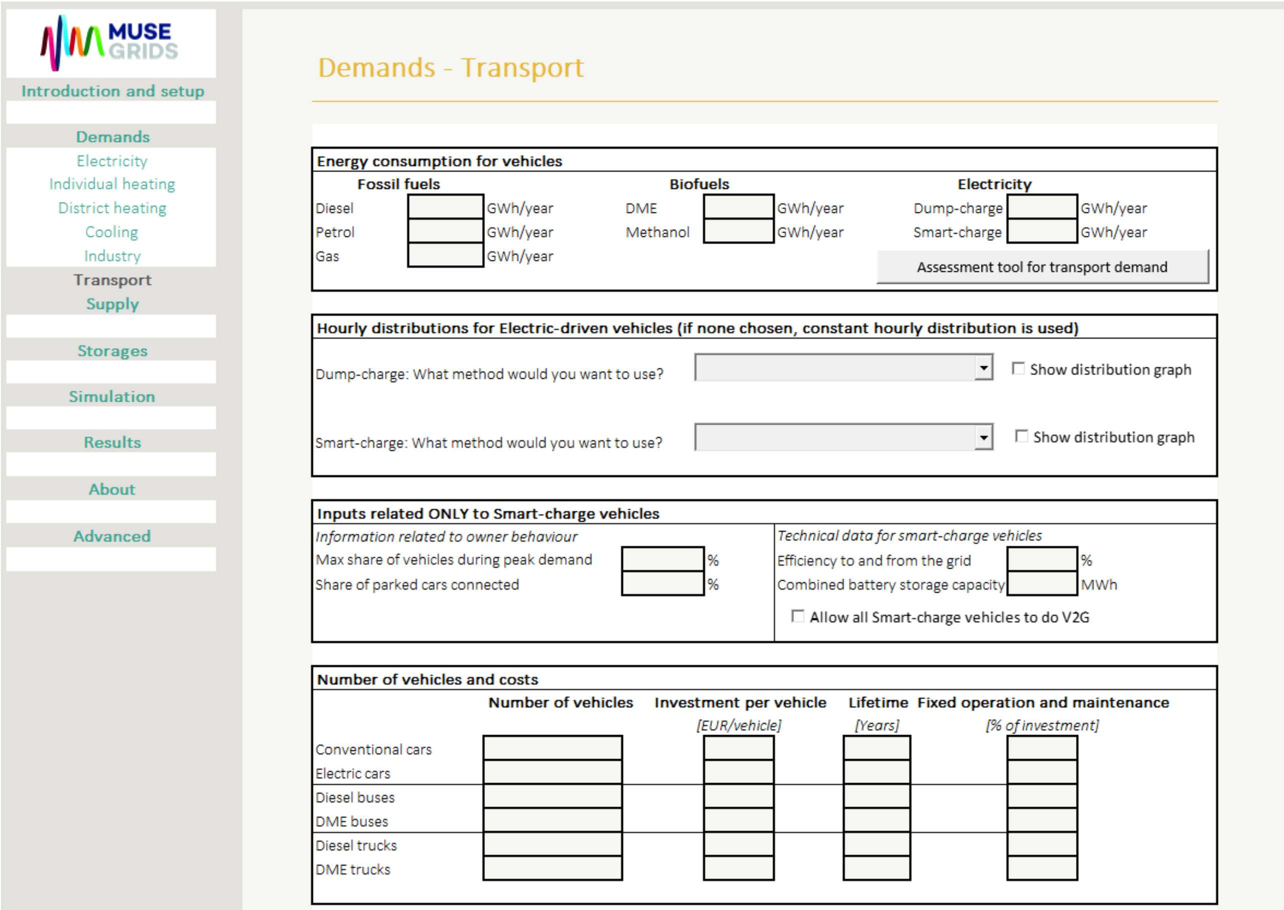


Figure 11 Screenshot of the "Transport" in Demands interface

- **Energy consumption for vehicles**: Here the yearly energy consumption is inserted. The yearly energy consumption is separated into different fuel types incl. electricity. For electricity two demands are defined, being: Dump-charge and Smart-charge. Dump-charge is defined as electricity demands for transportation that is inflexible, e.g. non-battery electric-driven trains or vehicles that charge only based on the consumer demands. Smart-charge is battery electric vehicles where some flexibility in the time of charging is possible, depending on the users' needs and the needs of the energy system.
- **Hourly distribution for Electric-driven vehicles**: If electric vehicles are added to the energy system, information about hourly charging profiles are required. In the tool, the user can add a profile both for dump and smart-charge vehicles. The tool uses the dump charge profile to estimate the electricity consumption for charging electric vehicles, while the smart-charge profile must represent when the electric vehicles use their batteries (i.e. when they drive). As such, the tool uses the smart charge profile to estimate when the vehicles can be charged, rather than fixing the charging pattern, like the dump charge electric vehicles. The distributions do not need to be absolute demand values in each hour, but can be relative values for each hour, as the distributions are used alongside the yearly demand to calculate demands in each hour.
- **Inputs related ONLY to Smart-charge vehicles**: Inputs that are only related to smart-charge vehicles.
    - *Max share of vehicles during peak demand*: Insert the maximum share of cars which are driving during peak demand hour. Peak demand being the peak of the smart-charge distribution. At 100% all smart-charge cars are driving during peak-demand hours. A standard value of 70% is included with the tool.

- *Share of parked cars connected*: The share of parked cars that is available to the electricity system. Keep below 100% if parking does not mean that the unit is connected to the electric grid. A standard value of 20% is included with the tool.
- *Efficiency to and from the grid*: Efficiency of charging, and potentially discharging, the vehicles (from electricity in the grid to the battery, and potentially from the battery back to the grid with V2G). A standard value of 90% is include with the tool.
- *Combined battery storage capacity*: The total battery capacity of all smart-charge (and V2G) vehicles.
- *Allow all smart-charge vehicles to do V2G*: Checking this box allows all the smart-charge vehicles to send back electricity stored in their batteries to the grid, using the same conversion efficiency as is used for charging.

- **Number of vehicles and costs**: Here the number of vehicles, investment costs per vehicle, technical lifetime and fixed operation and maintenance costs are inserted for different types of vehicles. This section is only used for identifying the annual investment and fixed operation and maintenance costs, and as such, is independent of the energy inputs. If the cost of charging infrastructure for electric vehicles is to be included, these can be included as an extra investment per vehicle.

Check methodologies for this input in D3.1, Section 7.

10.3 Supply

Here the inputs for the different energy supply technologies are defined. The energy supply technologies are divided into power plants, renewable electricity, CHP (Combined heat and power) units, waste incineration, district heating, individual heating, cooling, electricity connections, and fuel costs.

10.3.1 Power plants

In this input sheet, power plants installed in the modelled energy system can be defined.

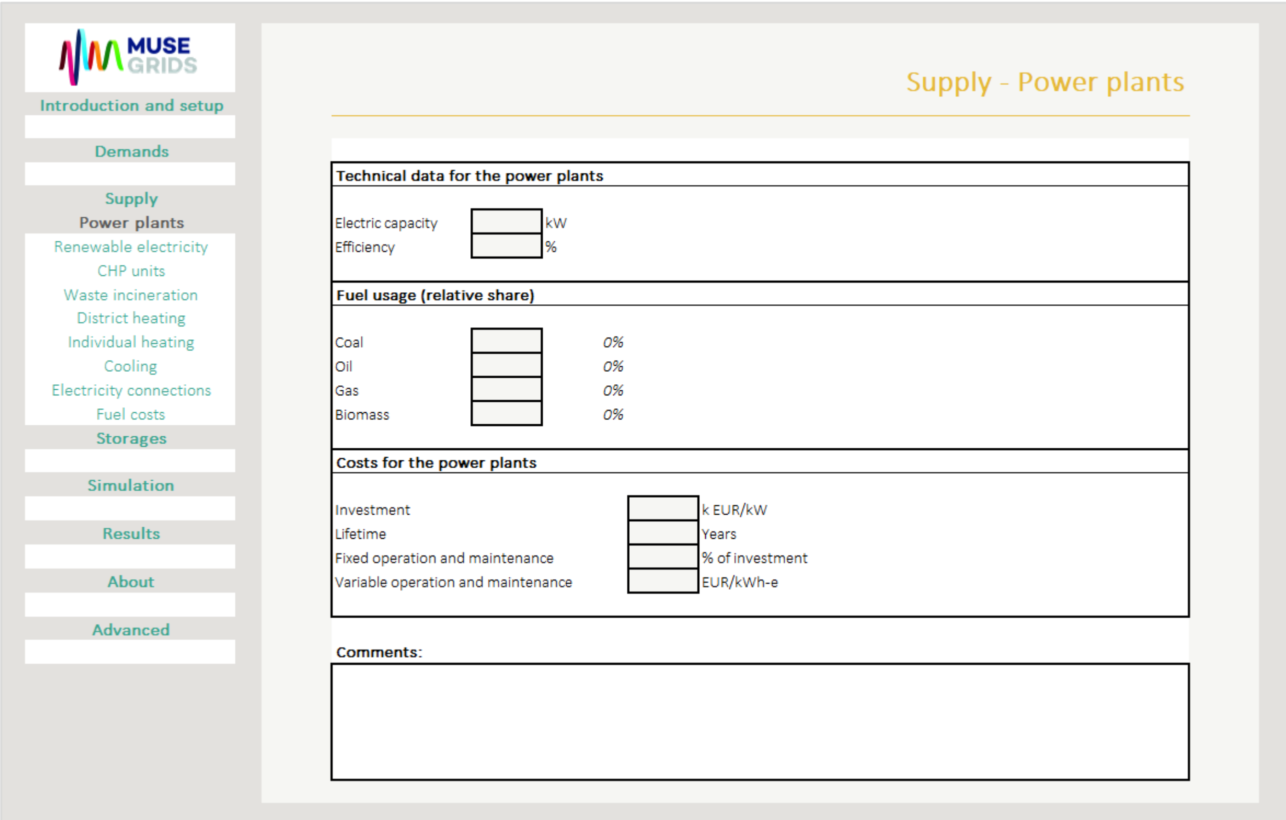


Figure 12 Screenshot of the "Power plants" in Supply interface

- **Electric capacity**: Here the total electric capacity of all power plants (non-CHP) in the energy system should be inserted. If no power plant is in the modelled system, keep this empty or at zero.
- **Efficiency**: Here the yearly average efficiency of all power plants (non-CHP) should be inserted.
- **Fuel usage**: Share of fuel usage in the yearly fuel input to the power plants. The share is relative, so the total does not need to be 100%.
- **Costs for the power plants**: Here the total investment costs, technical lifetime (from the time of installation) as well as the variable and fixed operation and maintenance costs are inserted for the power plants.

Check methodologies for this input in D3.1, Section 5.

10.3.2 Renewable electricity

In this input sheet, variable renewable electricity sources installed in the modelled energy system, can be defined. The variable renewable electricity sources included in the tool are: Onshore wind power, Photovoltaics (PV) and Run-of-river hydroelectric. The production of these units is variable by nature, and as such, additionally to a capacity, an hourly production profile is needed to define their operation. Biomass-based technologies are defined by the fuel usage in different sheets based on the conversion technology.

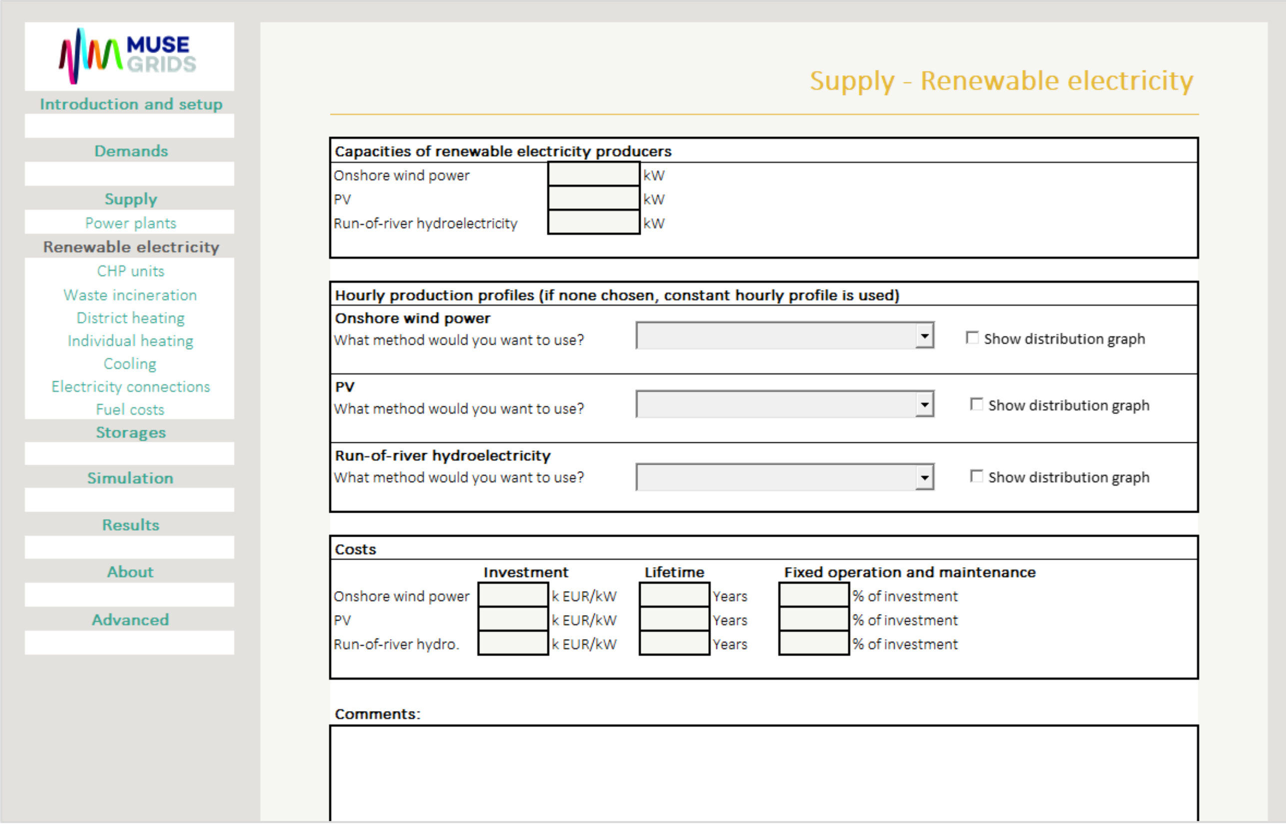


Figure 13 Screenshot of the “Renewable electricity” in Supply interface

- **Capacities of renewable electricity producers**: Here the capacities for the included variable renewable electricity sources can be inserted.
- **Hourly production profiles**: The hourly production profiles for each of the renewable electricity technologies. These hourly production profiles are used alongside the installed capacities to calculate the hourly production of each technology. The distributions do not need to be absolute production values in each hour, but can be relative values for each hour, as the distributions are used alongside the capacities to calculate production in each hour. If a distribution only contains values between 0 and 1, then the values in the distribution will be considered as production in percentage of the installed capacity. For the Onshore wind power and PV, it is possible to import data from Renewables.ninja as described in Section 11.2.
- **Costs:** Here the total investment costs, technical lifetime (from the time of installation) and fixed operation and maintenance costs are inserted for each of the variable renewable electricity producing sources.

Check methodologies for this input in D3.1, Section 6.

10.3.3 CHP units

In this input sheet, combined heat and power (CHP) units in connection with district heating systems can be defined. Waste incineration CHP units are defined in “Supply-Waste incineration”.

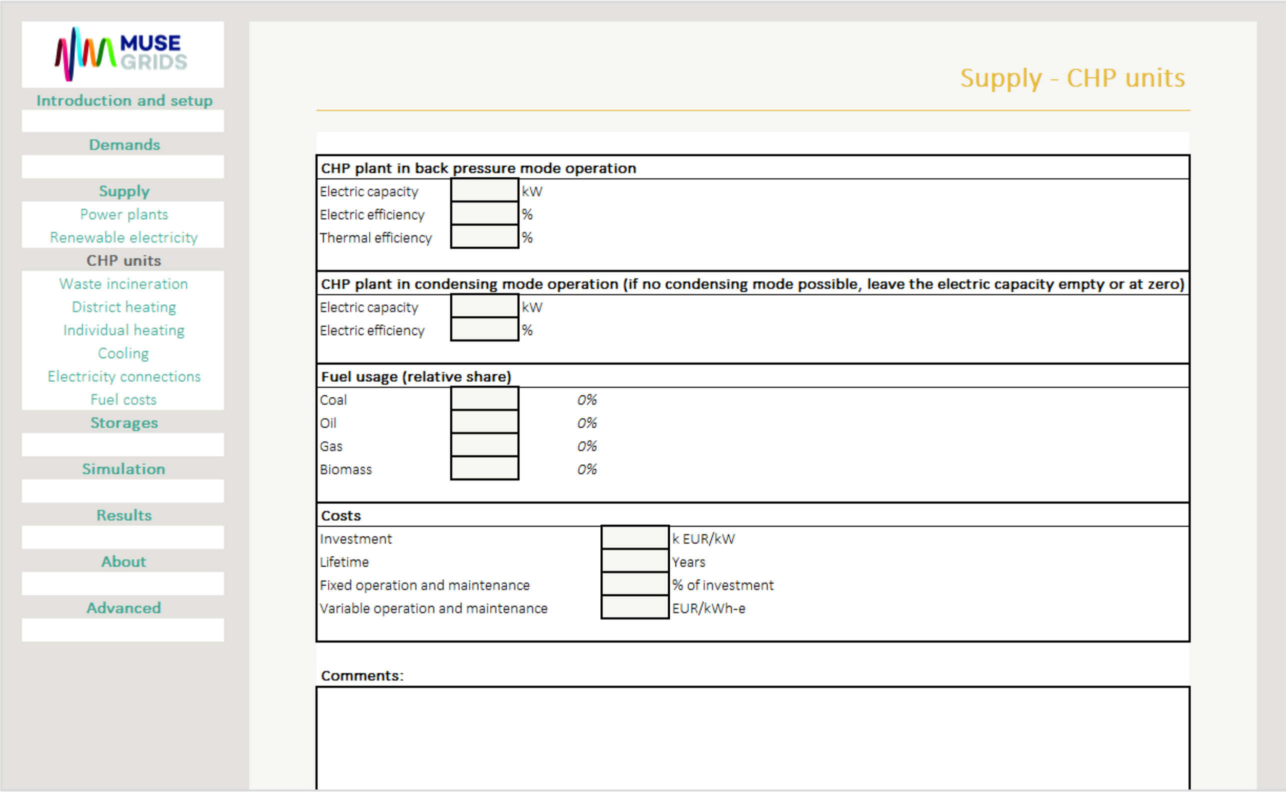


Figure 14 Screenshot of the "CHP units" in Supply interface

- **CHP plant in back pressure mode operation**: Here the total electric capacity, average electricity efficiency and average thermal efficiency of the CHP units can be inserted for when these are operating in back pressure mode, meaning when the CHP units are producing both useable heat and electricity. The CHP units defined here are only used for district heating.
- **CHP plant in condensing mode operation**: Here the total electric capacity and average electricity efficiency of the CHP units can be inserted for when these are operating in condensing mode, meaning that they are operating only for producing electricity and discarding the heat produced. Not all CHP units are able to carry out such operations, and if not possible for the installed CHP units leave empty.
- **Fuel usage**: Share of fuel usage in the yearly fuel input to the CHP units. The share is relative, so the total does not need to be 100%.
- **Costs**: Here the total investment costs, technical lifetime (from the time of installation) as well as the variable and fixed operation and maintenance costs are inserted for the CHP units.

Check methodologies for this input in D3.1, Section 4.

10.3.4 Waste incineration

In this input sheet, waste incineration units are defined. In case of a useable heat output from these units, the heat is used for district heating systems. The electricity and heat production of waste incineration units is assumed constant throughout the year.

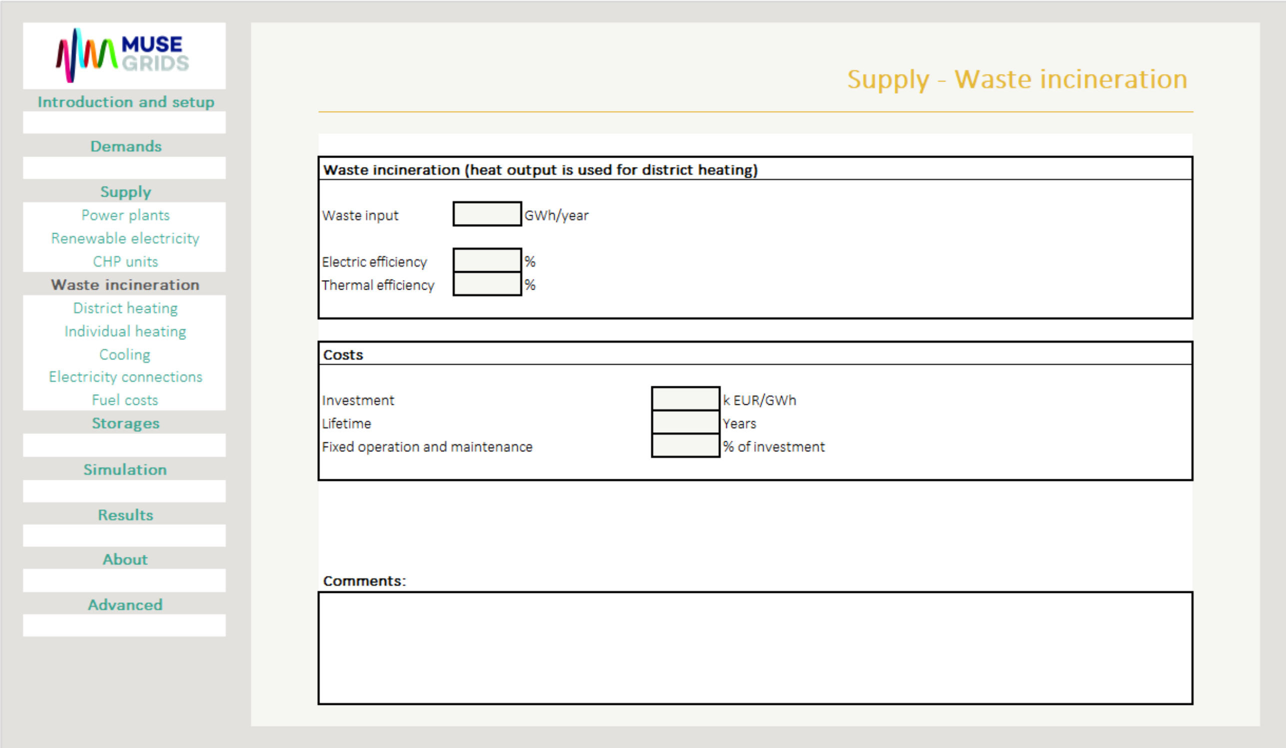


Figure 15 Screenshot of the "Waste incineration" in Supply interface

- **Waste input**: Total yearly input of waste to the incinerator in energy.
- **Electric efficiency**: Yearly average electric efficiency of the waste incinerator. Can be left at zero or empty if no electric output.
- **Thermal efficiency**: Yearly average district heating production efficiency of the waste incinerator. Can be left at zero or empty if there is no thermal energy output to district heating systems.
- **Costs**: Here the total investment costs, technical lifetime (from the time of installation) and fixed operation and maintenance costs are inserted for the waste incineration plants.

Check methodologies for this input in D3.1, Section 4.2.

10.3.5 District heating

In this input sheet, the heating technologies only for supplying heat to district heating systems can be defined. CHP units and Waste incineration can also provide heat for district heating, though these are defined in their separate sheets.

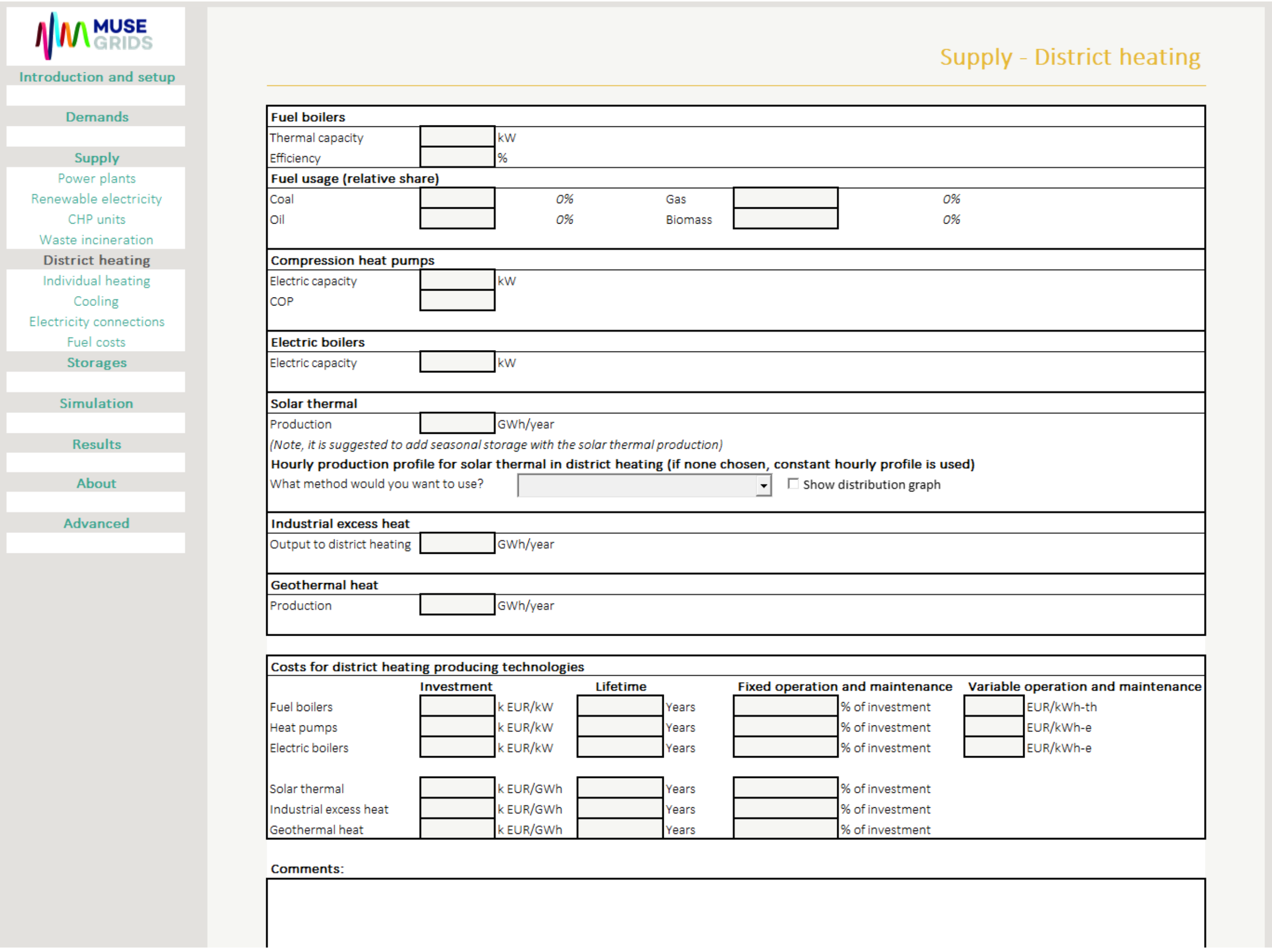


Figure 16 Screenshot of the "District heating" in Supply interface

- **Fuel boilers**: Here the total Thermal capacity and yearly average Efficiency of all fuel boilers installed to produce district heating is inserted. If a demand for district heating is inserted in "Demands-District heating" then a tool tip recommending a minimum capacity of these units is shown to the right of the Thermal capacity input. The assumption in the tool tip's suggestion is that fuel boilers are expected to be the units used for peak load and backup in the district heating system.
- **Fuel usage**: Share of fuel usage in the yearly fuel input to the district heating-based fuel boilers. The share is relative, so the total does not need to be 100%.
- **Compression heat pumps**: Here the total Electricity capacity and yearly average coefficient of performance (COP) of the compression heat pumps for district heating production should be inserted.
- **Electric boilers**: Here the total electric capacity of electric boilers for production of district heating should be inserted. The efficiency is assumed to be 100% in the tool and is thereby not an input.
- **Solar thermal**: Here the solar thermal production for district heating can be specified. Two inputs are needed: The total yearly production of solar thermal and an hourly production profile. The hourly production profile is used alongside the yearly production to calculate the hourly production of solar thermal to district heating. The distribution does not need to be absolute production values in each hour, but can be relative values for each hour, as the distribution is used alongside the yearly demand to calculate production in each hour.

- **Industrial excess heat**: Here any industrial excess heat for district heating can be added as a yearly amount of energy. The industrial excess heat is assumed to be delivered to the district heating systems with a constant hourly profile.
- **Geothermal heat**: Here production of geothermal heat for district heating can be added as a yearly amount of energy. The geothermal heat is assumed to be delivered to the district heating systems with a constant hourly profile.
- **Costs**: Here the investment costs, technical lifetime (from the time of installation), as well as variable and fixed operation and maintenance costs are inserted for the technologies defined in this input window for units specific for production of district heating.

Check methodologies for this input in D3.1, Section 4.

10.3.6 Individual heating

In this input sheet, the heat production technologies for individual heating (e.g. household gas boilers) are defined.

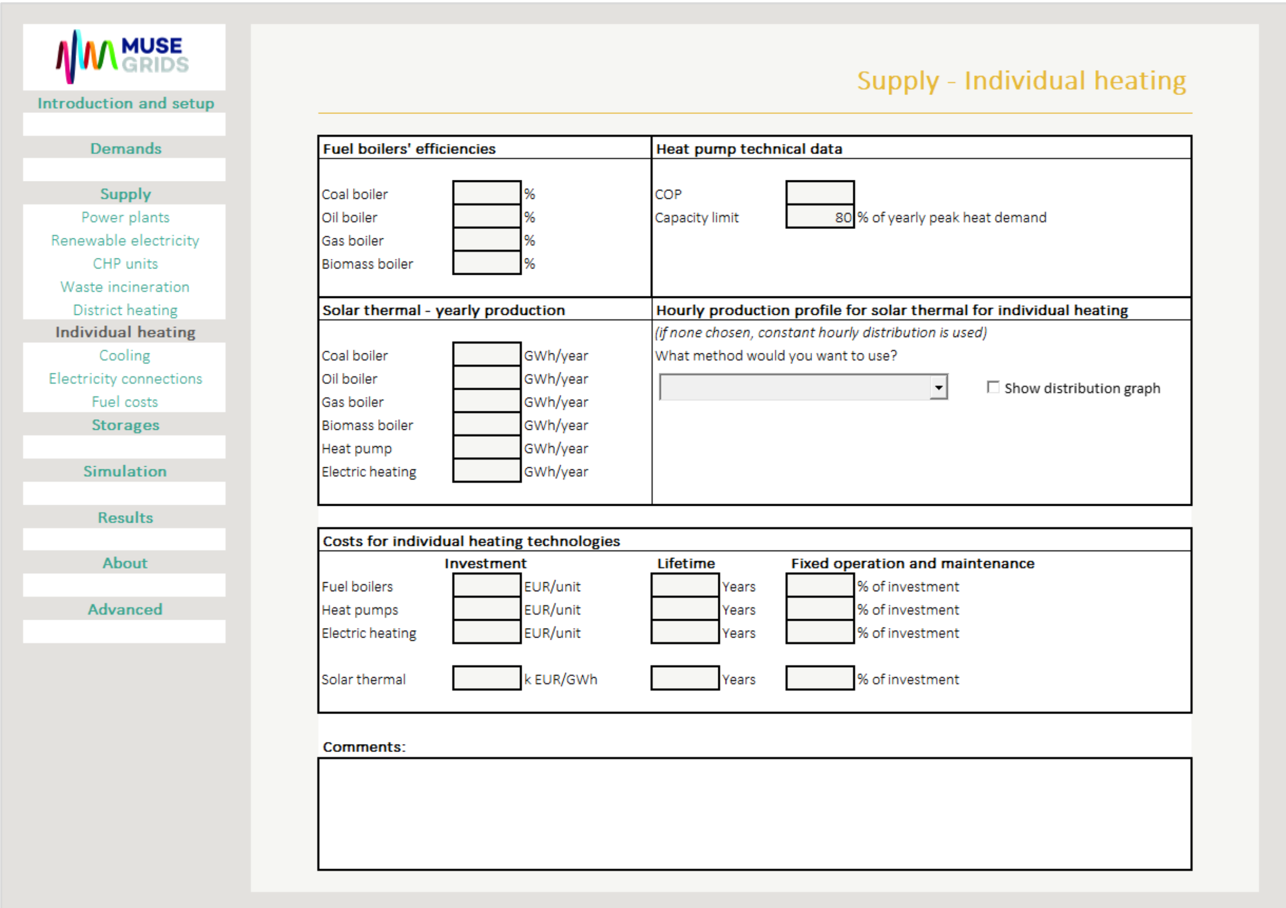


Figure 17 Screenshot of the "Individual heating" in Supply interface

- **Fuel boilers' efficiencies**: Here the different efficiencies of the fuel boilers for individual heating should be inserted.

- **Heat pump technical data**: Here the heat pumps for individual heating are defined based on their yearly average coefficient of performance (COP) and capacity limit. The capacity limit is used to define at what level of the peak demand that the heat pump change to pure electric heating. If a limit below 100% is defined, any hourly demand above this % of the peak demand is instead produced with a COP of 1. The default value is set to 80%, meaning in the peak demand hour of the year 80% of the heat is produced with the stated COP value and the remaining 20% is produced with a COP of 1.
- **Solar thermal – yearly production**: Here the solar thermal for individual production of heating can be specified. Two inputs are needed: The total yearly production of solar thermal and an hourly production profile. The yearly production should be stated for each of the used main heating supply technology. The hourly production profile is used alongside the yearly production to calculate the hourly production of solar thermal for individual production of heating. The distribution is the same for all buildings. The distribution does not need to be absolute production values in each hour, but can be relative values for each hour, as the distribution is used alongside the yearly demand to calculate production in each hour.
- **Costs**: Here the investment costs, technical lifetime (from the time of installation), and fixed operation and maintenance costs are inserted for the technologies defined in this input window for units specific for individual production of heating.

Check methodologies for this input in D3.1, Section 4.

10.3.7 Cooling

In this input sheet, the production technologies for cooling are defined. Cooling is separated into individual cooling solutions (electric chillers installed at households) and district cooling systems.

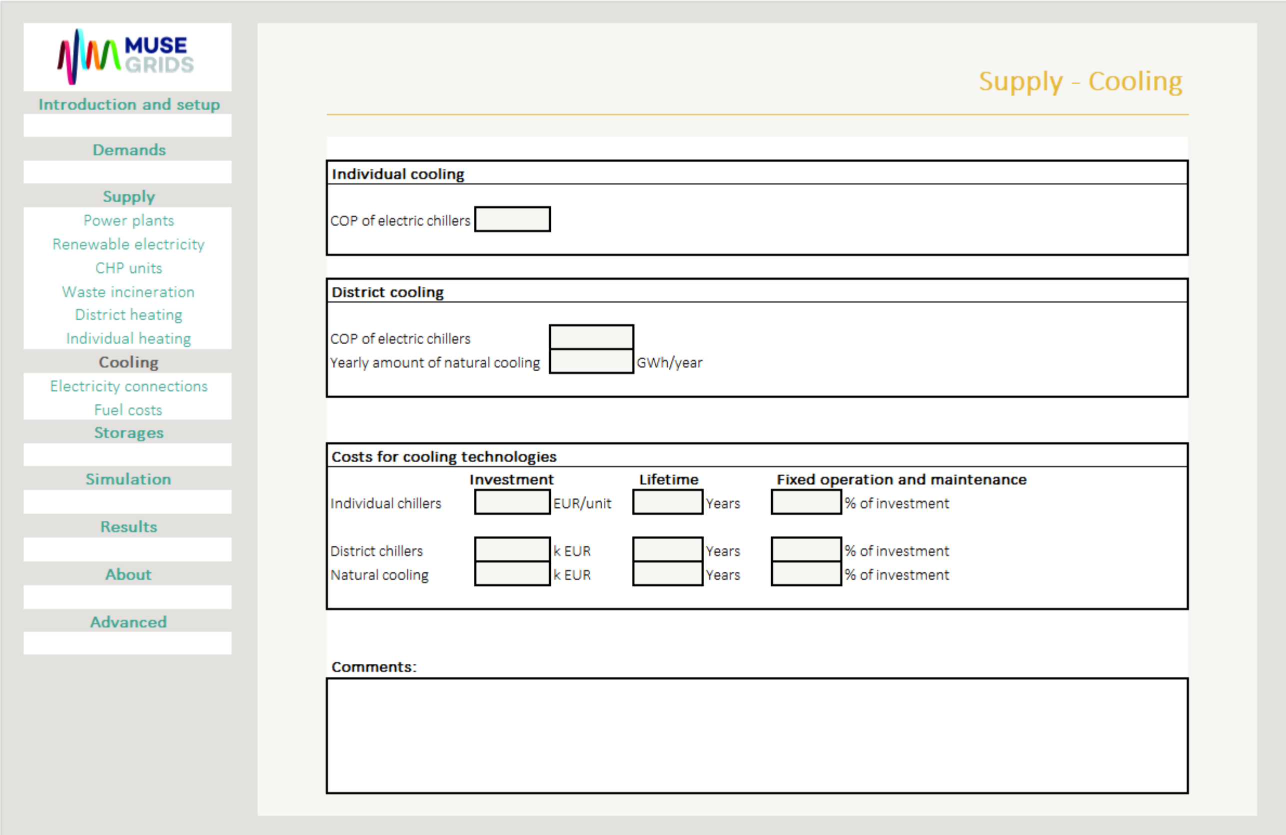


Figure 18 Screenshot of the "Cooling" in Supply interface

- **Individual cooling**: Here the yearly average coefficient of performance (COP) of the electric chillers used for individually produced cooling is inserted.
- **District cooling**: Here the yearly average coefficient of performance (COP) of the electric chillers used for district cooling and the yearly amount of natural cooling are inserted. Natural cooling is cooling from e.g. rivers or sea waters, where no chiller is needed. Natural cooling is assumed to be delivered evenly throughout the year.
- **Costs**: Here the investment costs, technical lifetime (from the time of installation), and fixed operation and maintenance costs are inserted for the technologies defined in this input window for units specific for production of cooling.

10.3.8 Electricity connections

In this input sheet, different aspects for electricity connections to other areas are defined. These are related to the import and export of electricity to and from the modelled energy system.

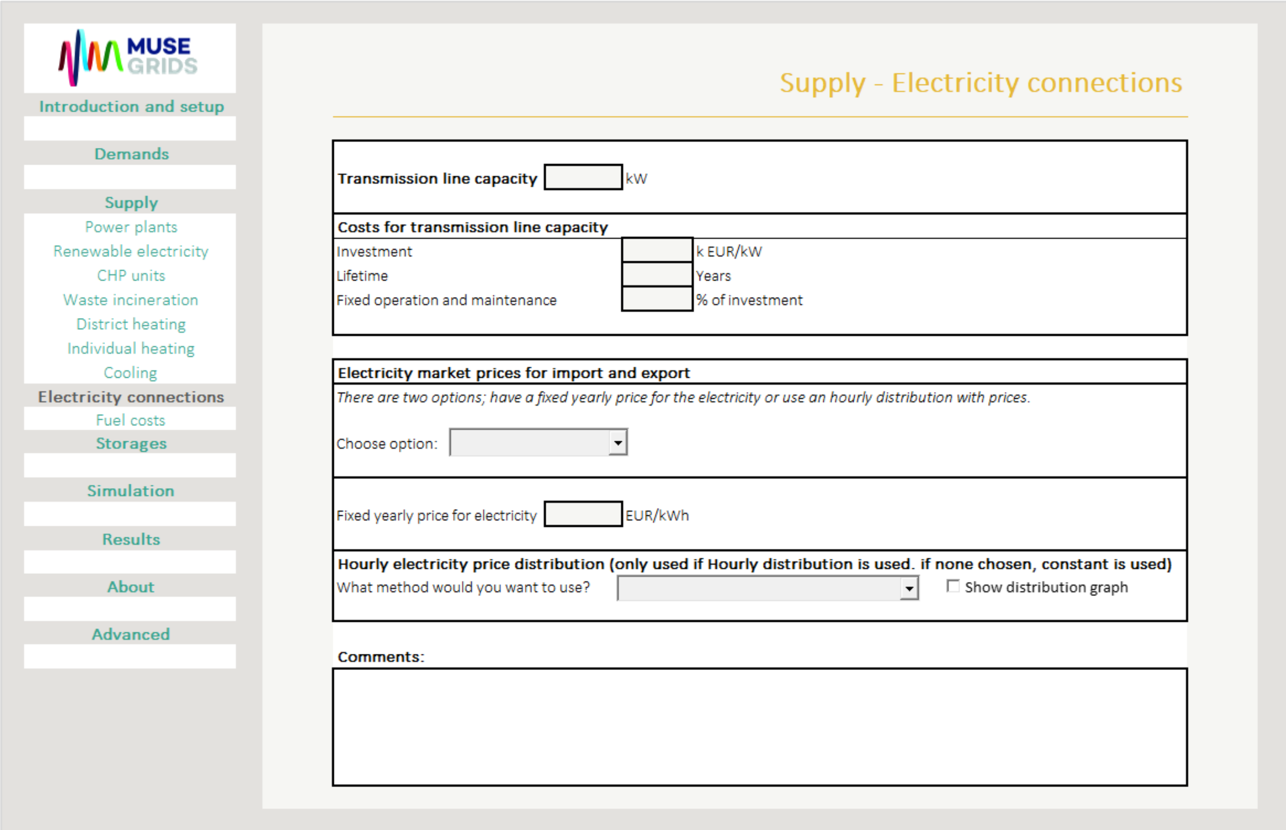


Figure 19 Screenshot of the "Electricity connections" in Supply interface

- **Transmission line capacity**: Electric transmission capacity to and from the modelled area. In case of no capacity limit this can be left empty.
- **Costs for transmission line capacity**: Here the investment costs, technical lifetime (from the time of installation), and fixed operation and maintenance costs are inserted for the transmission line capacity, if this cost is relevant for analysing the costs of the energy system.
- **Electricity market prices for import and export**: Here income from export and costs for import of electricity from and to the modelled area can be defined. There are two options; have a fixed yearly price for the electricity or use an hourly distribution with prices. Use the "Choose option" to choose one of these methods. If no method is chosen, a yearly fixed price of electricity of zero is used, meaning that the export and import of electricity do not provide any change to the costs of the energy system. *Fixed yearly price for electricity* is only used if *Yearly fixed* is chosen and the hourly distribution is only used if *Hourly distribution* is chosen. The price of electricity is the same for export and import. The distribution for electricity prices should contain the exact electricity price in each hour using the same currency as is chosen in "Introduction and setup".

10.3.9 Fuel costs

In this CO_2-costs, CO_2-emissions in CO_2-equivalents for each fuel, and fuel costs are defined.

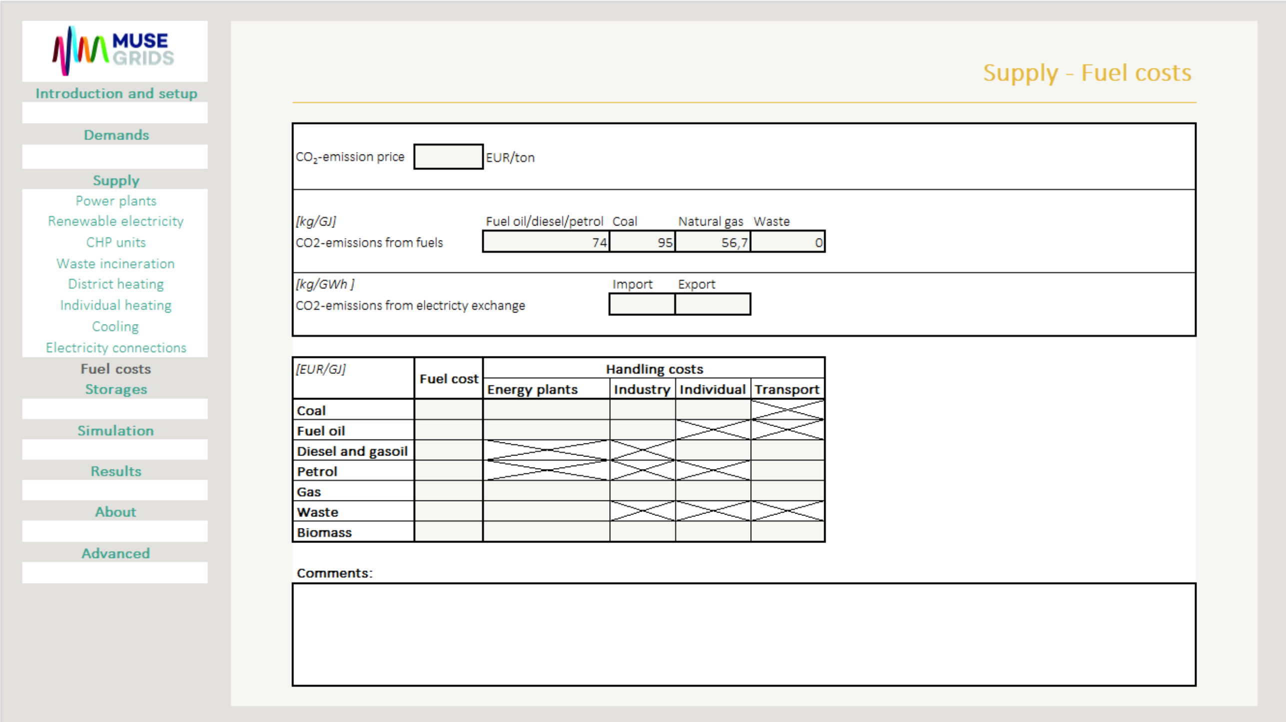


Figure 20 Screenshot of the "Fuel costs" in Supply interface

- **CO_2-emission price**: Here the cost of greenhouse gas emissions in CO_2-equivalents is inserted.
- **CO_2-emissions from fuels**: Here the greenhouse gas emissions from fuel oil, diesel and petrol in CO_2-equivalents are inserted.
- **CO_2-emissions from electricity exchange**: Here one can define values for the yearly average greenhouse gas emissions in CO_2-equivalents for the imported and exported electricity. If these are left empty, import of electricity is not counted as having a CO_2-emission related to it, and exporting electricity is not counted as reducing CO_2-emissions outside of the modelled area.
- **Fuel costs and handling costs table**: Here the Fuel costs and Handling costs of fuels should be inserted. The Fuel costs is the cost of the fuel itself, and Handling costs is the average cost of transporting the fuel to the place of consumption. Handling costs is defined into Energy plants (e.g. CHP, power plants and district heating producing plants), Industry, Individual (individual heating) and Transport.

10.4 Storages

Here any energy storage technologies are defined. The storage technologies are divided into electricity, district heating and individual heating.

10.4.1 Electricity

Here electricity storages can be defined. The technology inputs are set so that they allow a wide range of electricity storage options to be defined.

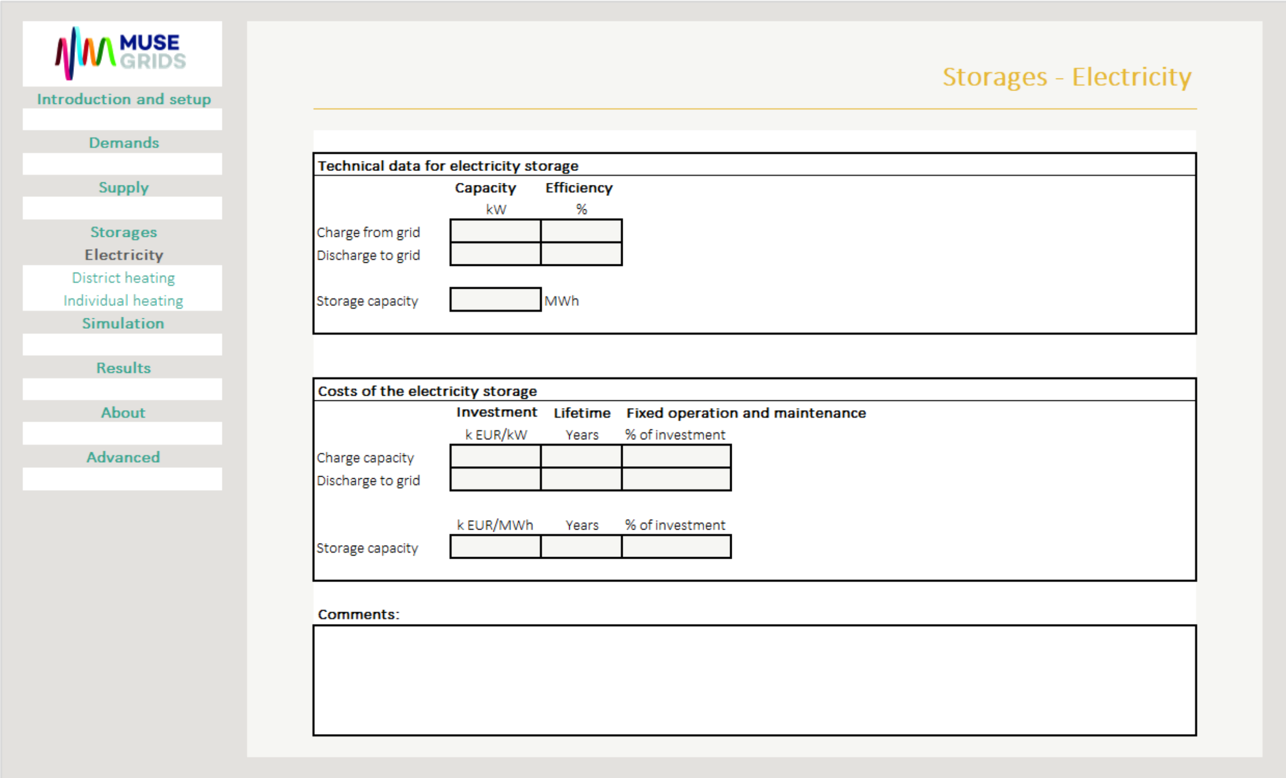


Figure 21 Screenshot of the "Electricity" in Storages interface

- **Technical data for electricity storage**: Here capacities and efficiencies for charge and discharge as well as energy storage capacity can be stated for electricity storage technologies.
- **Costs**: Here the investment costs, technical lifetime (from the time of installation), and fixed operation and maintenance costs are inserted for the electricity storage technologies.

10.4.2 District heating

Here district heating storages can be defined. District heating storages are defined as two distinct types: short-term storages and seasonal storages. Short-term storage is considered as storages that are used to store heat at the most for a couple of weeks. Seasonal storages are used for storing heat for months. The technology inputs are set, so that they allow a wide range of district heating storage options to be defined regardless of whether steel cylinders, pit storage, borehole storage or something else.

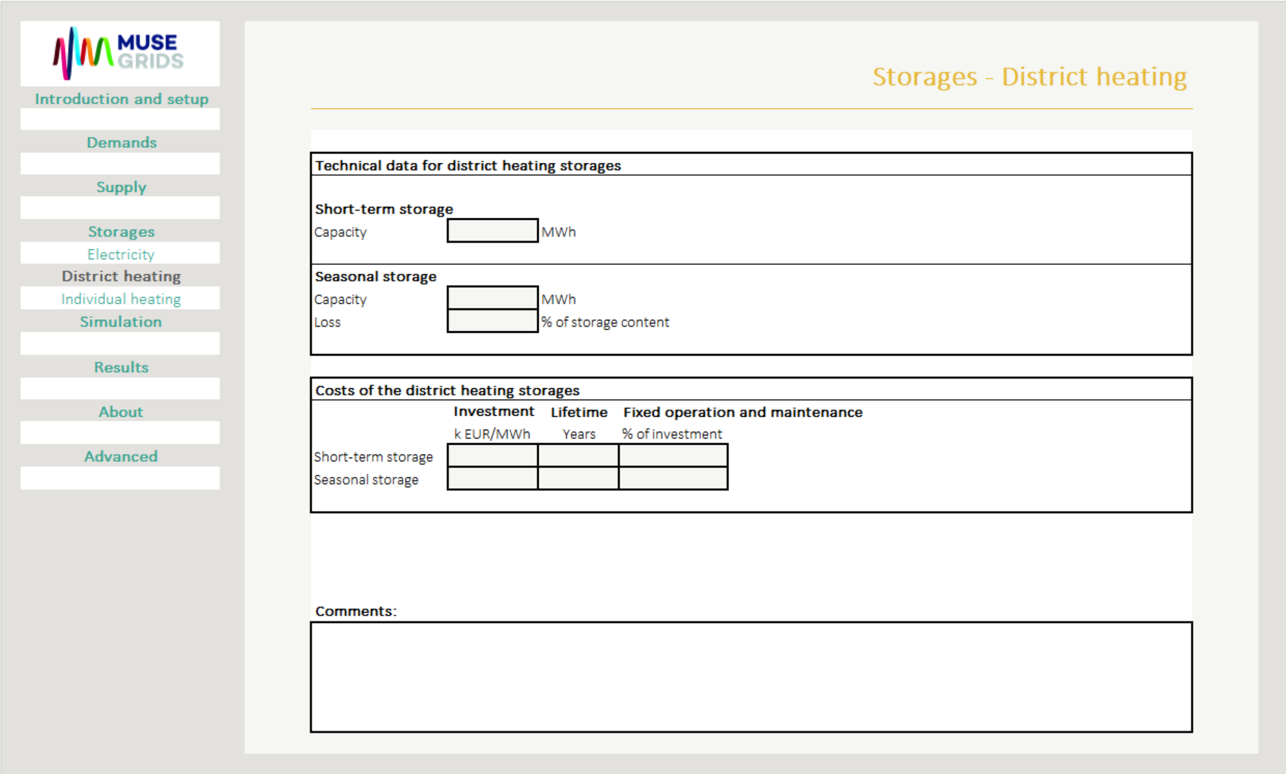


Figure 22 Screenshot of the "District heating" in Storages interface

- **Short-term storage**: Here the total capacity of short-term district heating storages is set.
- **Seasonal storage**: Seasonal storages are defined by their total capacity and energy loss in percentage of the storage content at any given hour.
- **Costs**: Here the investment costs, technical lifetime (from the time of installation), and fixed operation and maintenance costs are inserted for the district heating storage technologies.

10.4.3 Individual heating

Here individual heating storages can be defined. The individual heating storages can be used for both the boiler/heat pump/electric heating and potential installed solar thermal. The technology inputs are set so that they allow a wide range of district heating storage options to be defined.

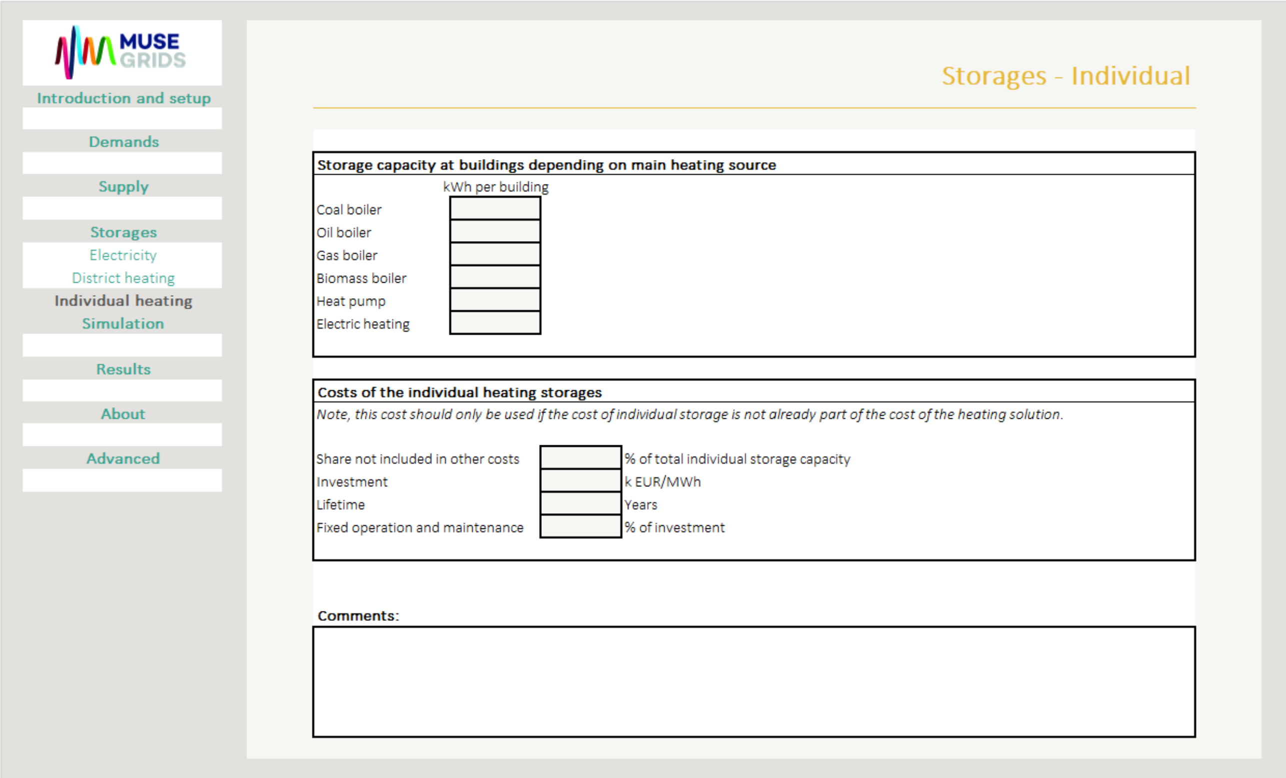


Figure 23 Screenshot of the "Individual heating" in Storages interface

- **Storage capacity at buildings depending on main heating source**: Here the average energy capacity of heat storages per building in buildings is set depending on the main heating unit.
- **Costs**: Here the investment costs, technical lifetime (from the time of installation), and fixed operation and maintenance costs are inserted for the individual heating storage technologies. This section should only be used if the cost of individual storage is not already part of the cost of the heating supply solution. *Share not included in other costs* is used if part of the individual storage costs is already included in other costs.

10.5 Simulation

This section includes starting simulation of the reference scenario, an overview of the assessment tools, and setting and simulating scenarios as variations of the reference.

10.5.1 Simulate reference

In this sheet the simulation of the reference model in EnergyPLAN can be started. The reference model is the inputs given in the "Demands", "Supply", and "Storages" sheets. The sheet also holds some options for error identification in relation to the workings of the MUSE GRIDS Energy planning tool.

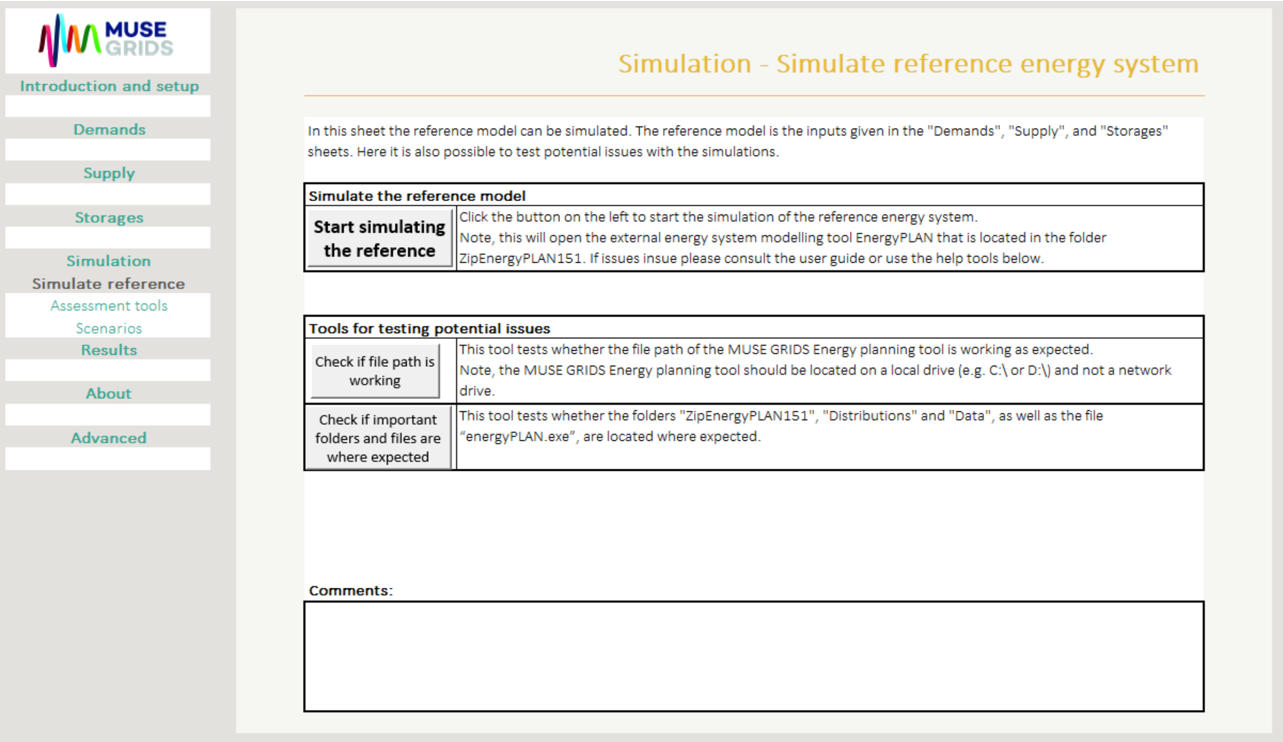


Figure 24 Screenshot of the "Simulate reference" in Simulation interface

- **Start simulating the reference**: Starts the simulation of the reference scenario in EnergyPLAN. Note, EnergyPLAN will popup once. After the simulation is done the user will be send to the sheet "Results-Overview". Note, starting this also removes any existing results of scenarios and resets the scenario matrix in "Simulation-Scenarios".
- **Check if file path is working**: This tool tests whether the file path of the MUSE GRIDS Energy planning tool is working as expected. Note, the MUSE GRIDS Energy planning tool should be located on a local drive (e.g. C:\ or D:\) and <u>not</u> a network drive.
- **Check if important folders and files are where expected**: This tool tests whether the folders "ZipEnergyPLAN151", "Distributions" and "Data", as well as the file "energyPLAN.exe", are located where expected.

10.5.2 Assessment tools

Here an overview of the different assessment tools integrated into the MUSE GRIDS Energy planning tool can be found. A button for each of the tools is available to the left that can be clicked to access the input sheet of the tool. The tools' input sheets can also be access from other places in the tool. Each of these tools are described in more detail in Chapter 11.

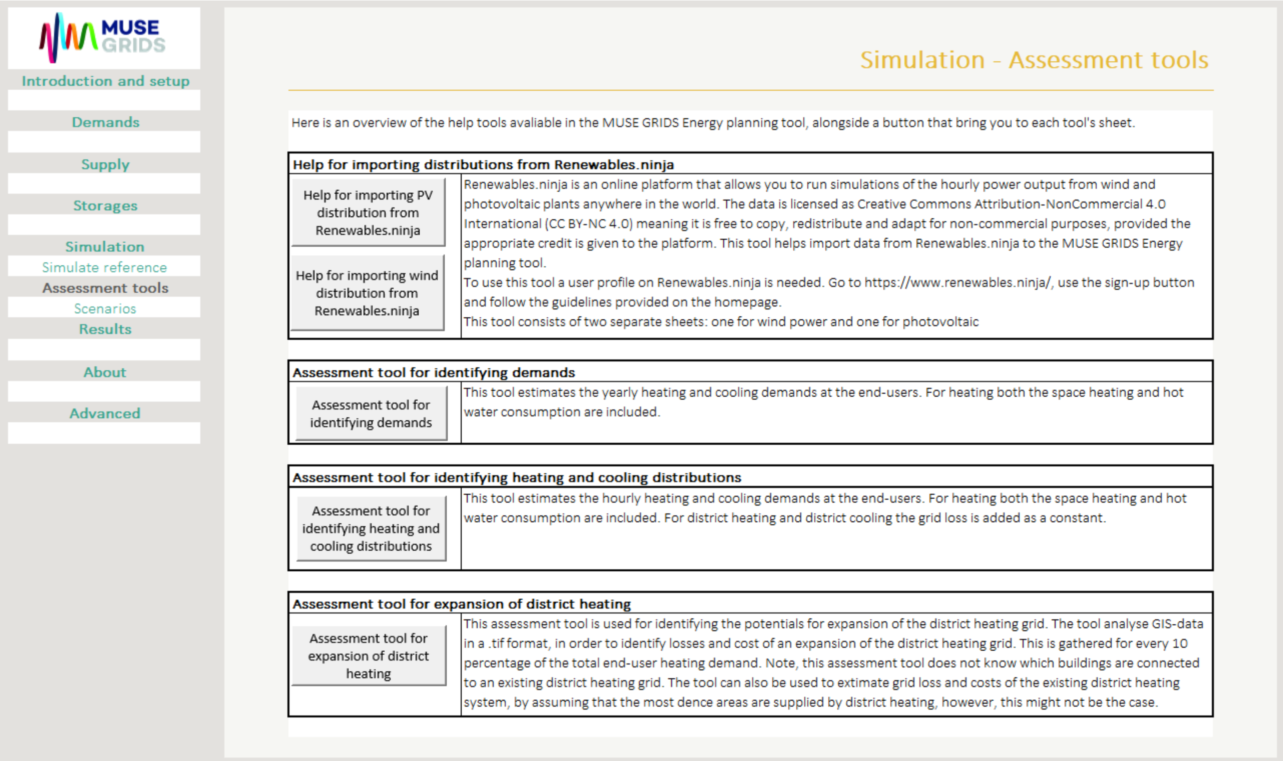


Figure 25 Screenshot of the "Assessment tools" in Simulation interface

10.5.3 Scenarios

Here different scenarios can be designed. The scenarios are defined by their variations to the reference scenario that has been defined in the Demands, Supply, Storages and Introduction and setup parts. You can choose how many scenarios you want to make, as well as how many variations should be made in each scenario.

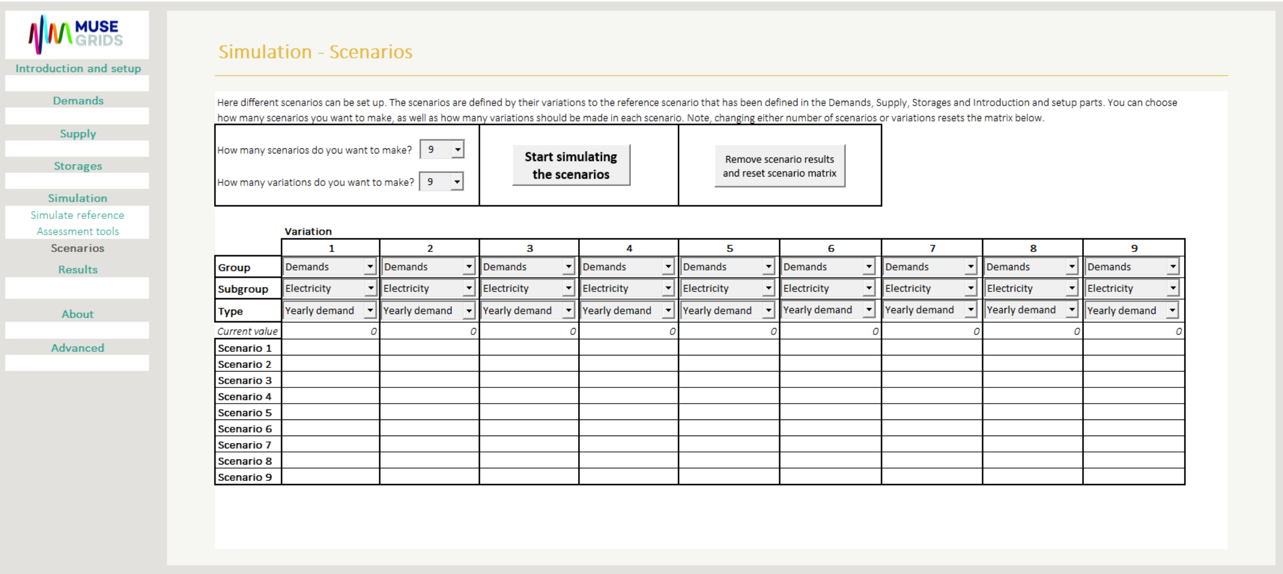


Figure 26 Screenshot of the "Scenarios" in Simulation interface

- **How many scenarios do you want to make?**: Set how many scenarios you want to make. The matrix below will adjust accordingly. Note, changing either number of scenarios or variations resets the matrix below.
- **How many variations do you want to make?**: Set how many variations you want to make on the reference in each scenario. The matrix below will adjust accordingly. It is important to remember that some technologies are defined by more than one input, such as electricity storage, and it is important to include all relevant inputs of a technology that one wants to change. Note, changing either number of scenarios or variations resets the matrix below.
- **Group**: The three overall groups shown in the main menu: Demands, Supply, and Storages, as well as a category called General costs that only contains the interest rate set in "Introduction and setup".
- **Subgroup**: The submenus in each of the overall groups. The content of the dropdown menu depends on the chosen Group above.
- **Type**: The input cells in each of the submenu sheets. The content of the dropdown menu depends on the chosen Subgroup above.
- **Start simulating the scenarios**: Starts the simulation of the scenarios defined below in EnergyPLAN. Note, EnergyPLAN will pop up several time, once for each scenario. After the simulation is done the user will be send to the sheet "Results-Overview".
- **Remove scenario results and reset scenario matrix**: Removes the results of the scenarios and resets the scenario matrix below. This operation is also done when a new reference scenario is calculated.

10.6 Results

Here the results of the simulations are found. The results are presented both in an overview form and in a more detailed form. The tool also provides help to visualise the yearly flows of energy in the energy system by providing help for creating Sankey diagrams. If different scenarios are simulated the overview form is also used for a comparison of the different scenarios.

10.6.1 Overview

Here an overview of the simulation results can be found.

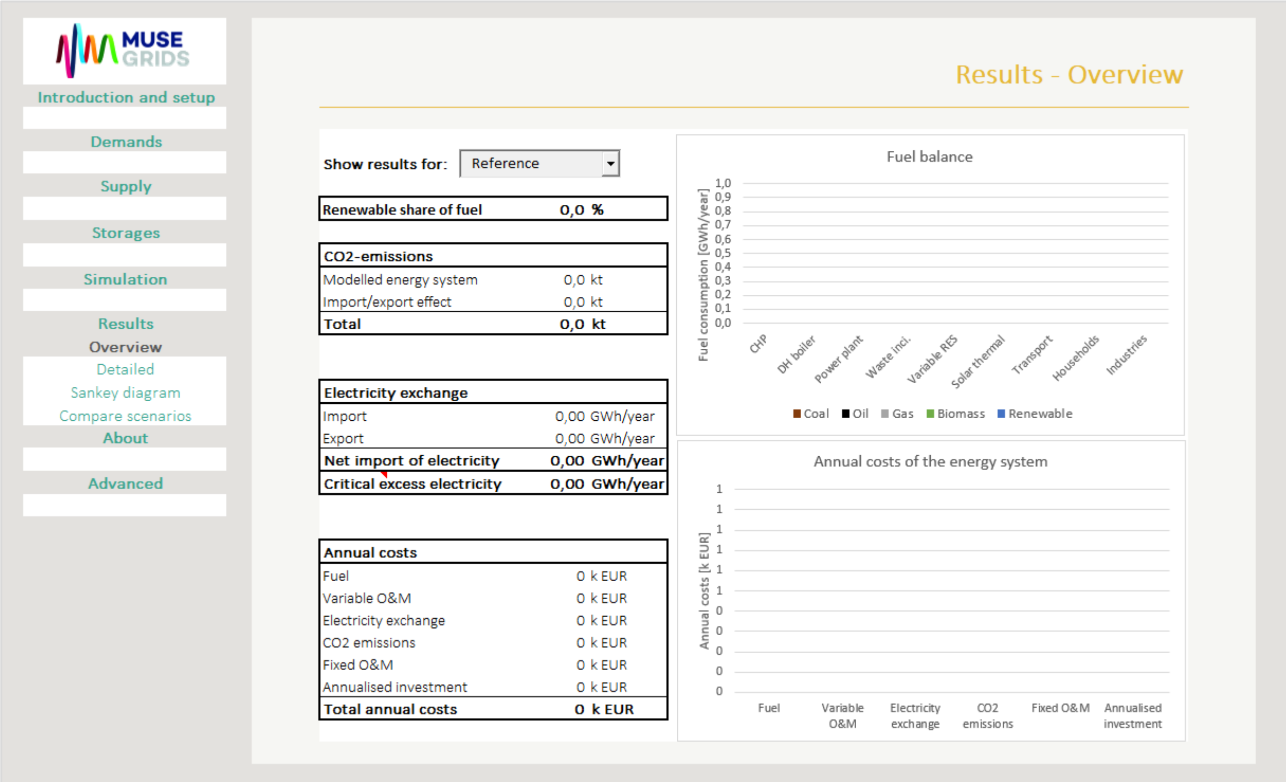


Figure 27 Screenshot of the "Overview" in Results interface

- **Show results for**: Here it is possible to choose what scenario results should be shown. By default, and in case of no scenarios, only the Reference situation is shown. The Reference is the results of the inputs defined in Demands, Supply and Storages. Other scenarios are defined in "Simulation-Scenarios".
- **Renewable share of fuel**: The renewable share of fuel is calculated as a percentage of the primary energy supply. The renewable resources are identified as Wind power, PV, River hydro, and solar thermal productions plus biomass and waste fuels. The total primary energy supply is identified as the same figure added all fossil fuels.
- **CO_2-emissions**: Resulting CO_2-emission based on the simulated operation of the energy system and the CO_2-equvelents defined in "Supply-Fuel costs".
- **Electricity exchange**: The import and export of electricity from the modelled energy system in total annual amounts. Critical excess electricity is electricity that is produced but cannot be used, stored, or exported.
- **Annual costs**: The annual costs of the energy system divided into different types of costs.

10.6.2 Detailed

Here more detailed results are found for district heating, individual heating, electricity production, electricity consumption, transport sector, cooling sector, industry sector, total annual costs, and fuel balance of the energy system's operation. Only district heating and individual heating is shown in the screen shot due to the large amount of content in this sheet.

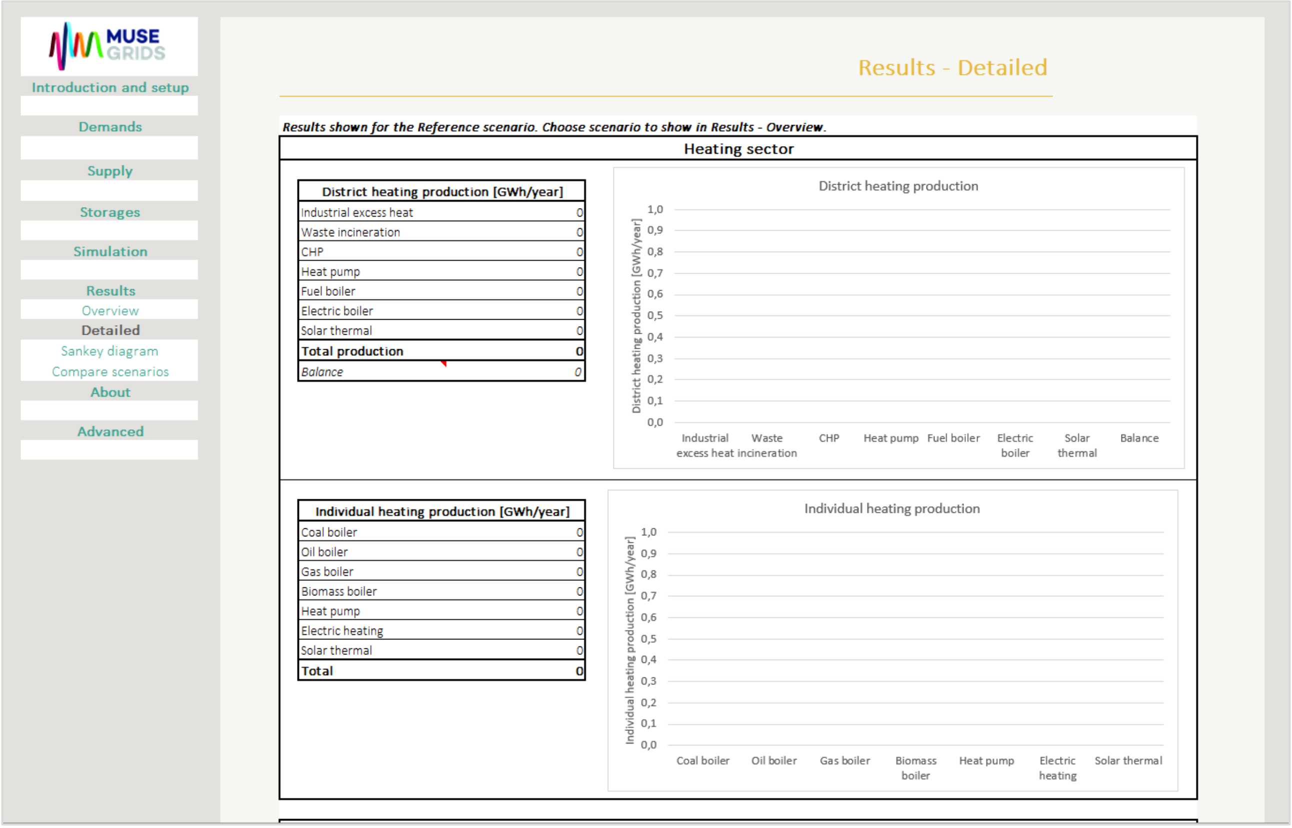


Figure 28 Screenshot of the "Detailed" in Results interface

10.6.3 Sankey diagram

Sankey diagrams are used to show flows of any kind where the width of the flows depict the amount of a flow. Sankey diagrams are useful for showing how energy is flowing through an energy system from the fuels to the end-user demands. In this sheet two options are available for creating a Sankey diagram: the add-in Advanced Data Flow Chart (shown below) and using the homepage SankeyMATIC (http://sankeymatic.com).

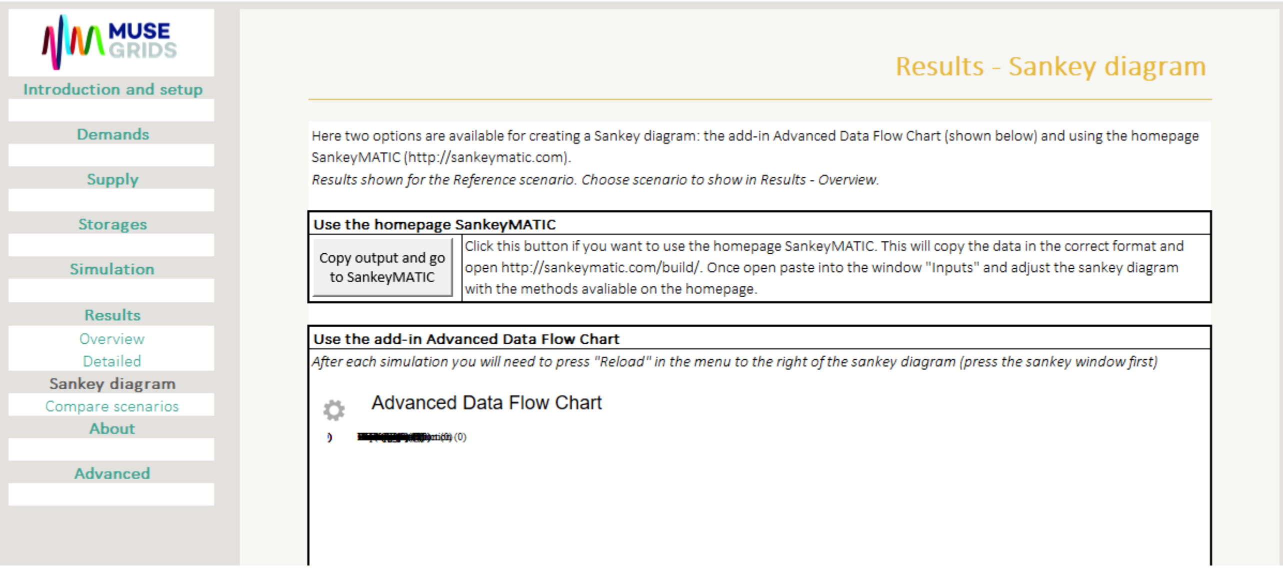


Figure 29 Screenshot of the "Sankey Diagram" in Results interface

Use the homepage SankeyMATIC:

By pressing the button "Copy output and go to SankeyMATIC" the tool will arrange the results in a format that is readable by SankeyMATIC and copy this to the clipboard. Then the tool will open the homepage http://sankeymatic.com/build/, where the copied data can be pasted into the "Inputs" section of the homepage shown in Figure 30. After the data has been pasted into the "Inputs" section the Sankey diagram can be adjusted using the options available on the homepage.

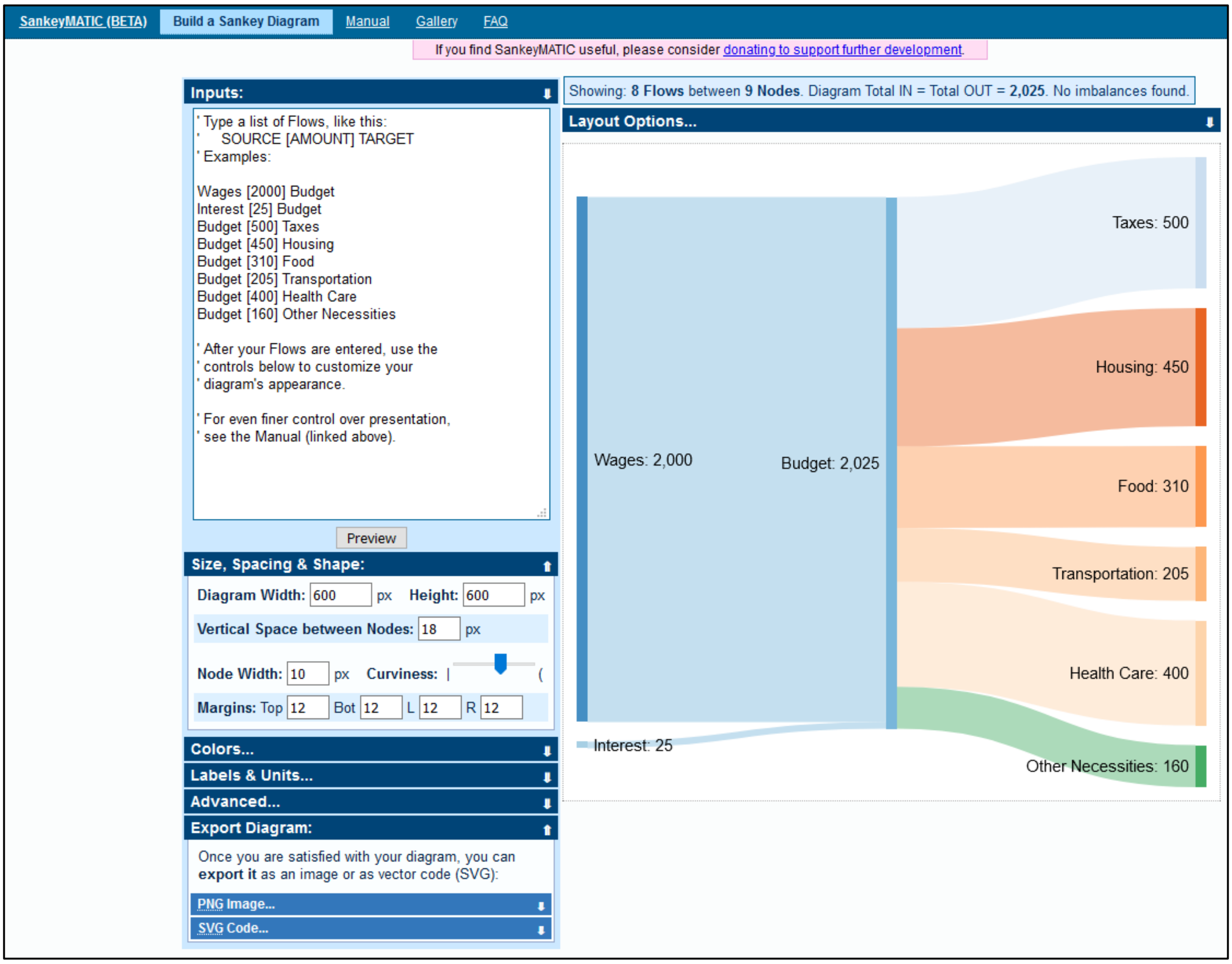


Figure 30 - Screenshot of the http://sankeymatic.com/build/ homepage.

Use the add-in Advanced Data Flow Chart:

Advanced Data Flow Chart is an add-in for Excel developed by a third party. The add-in is described in more detail here: https://gccoai.azurewebsites.net/Support/AdvDataFlowChart.html

To use the add-in the user needs to click the "Reload" button in the menu to the right of the Sankey diagram (press the add-in window first), as shown in the screenshot below. This needs to be done after each simulation or change in “Show results for:” in “Results-Overview”.

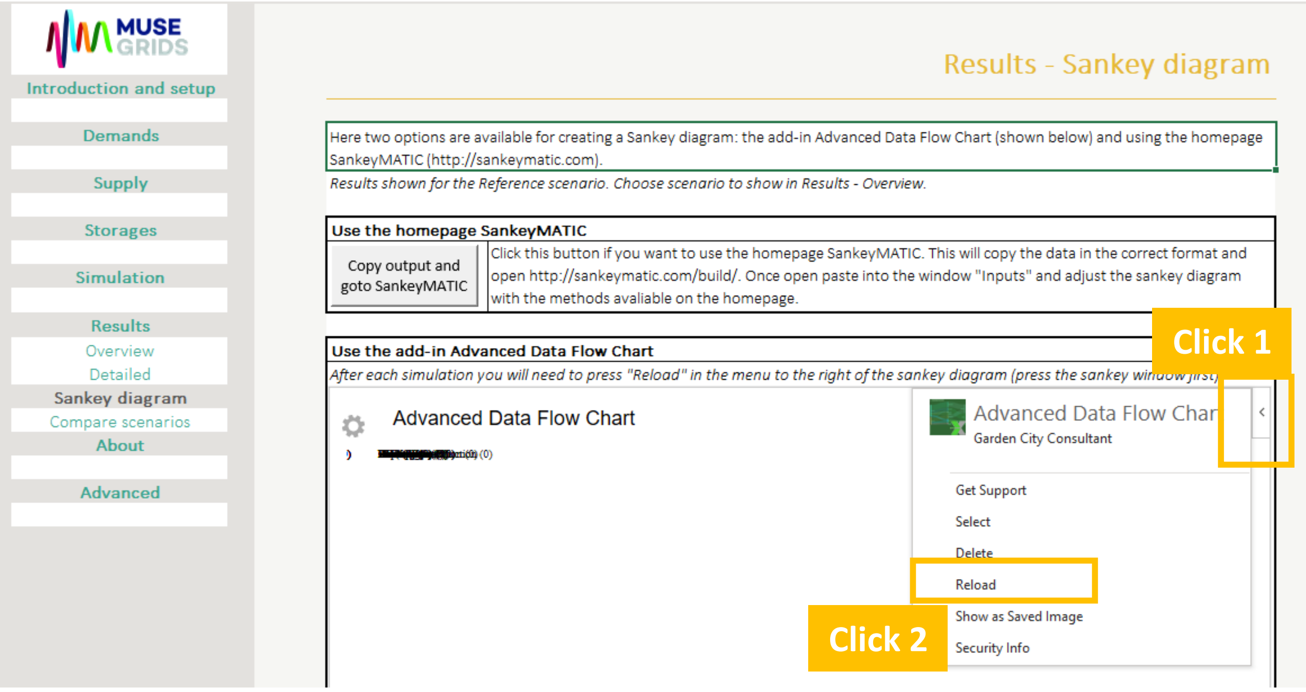
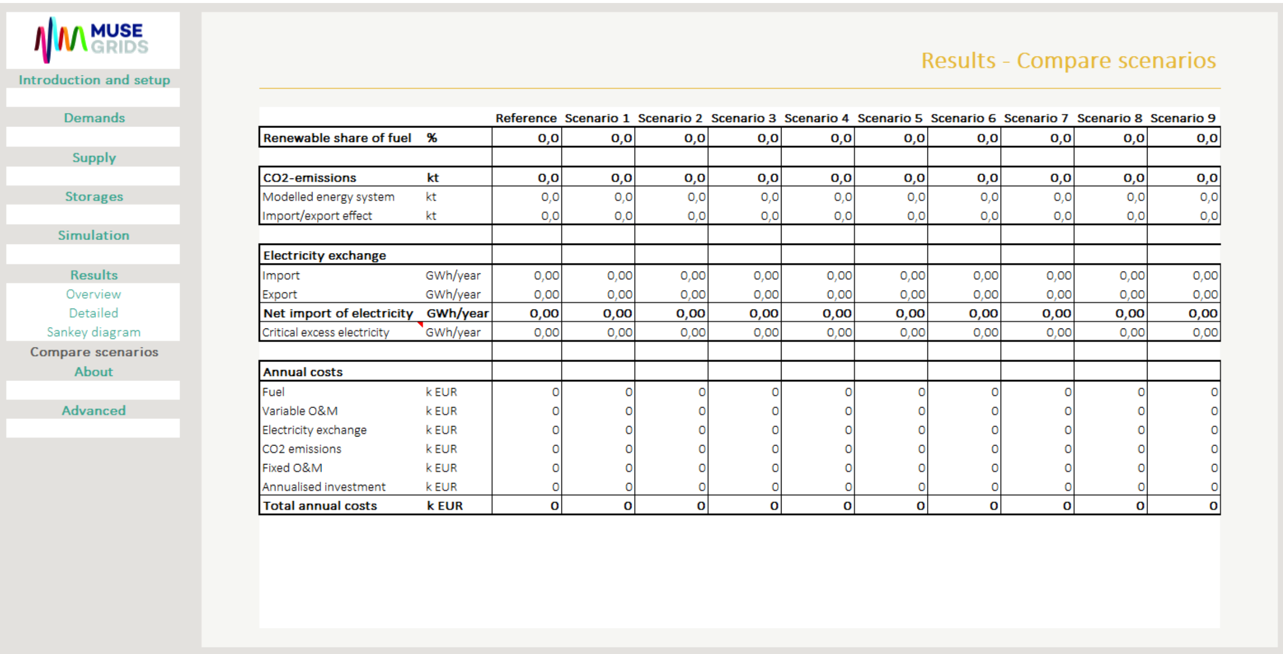


Figure 31 Screenshot of the "Sankey Diagram" in Results interface, in particular of the Advanced Data Flow Chart

10.6.4 Compare scenarios

In this sheet a comparison of the results of the simulated scenarios as well as the reference scenario is shown. The results shown are the same as is shown in "Results-Overview".



		Reference	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Scenario 8	Scenario 9
Renewable share of fuel	**%**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**
CO2-emissions	**kt**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**
Modelled energy system	kt	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Import/export effect	kt	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Electricity exchange											
Import	GWh/year	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Export	GWh/year	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Net import of electricity	**GWh/year**	**0,00**	**0,00**	**0,00**	**0,00**	**0,00**	**0,00**	**0,00**	**0,00**	**0,00**	**0,00**
Critical excess electricity	GWh/year	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Annual costs											
Fuel	k EUR	0	0	0	0	0	0	0	0	0	0
Variable O&M	k EUR	0	0	0	0	0	0	0	0	0	0
Electricity exchange	k EUR	0	0	0	0	0	0	0	0	0	0
CO2 emissions	k EUR	0	0	0	0	0	0	0	0	0	0
Fixed O&M	k EUR	0	0	0	0	0	0	0	0	0	0
Annualised investment	k EUR	0	0	0	0	0	0	0	0	0	0
Total annual costs	**k EUR**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**

Figure 32 Screenshot of the "Compared scenarios" in Results interface

10.7 About

The About sheet describes the MUSE GRIDS project in which this tool has been developed.

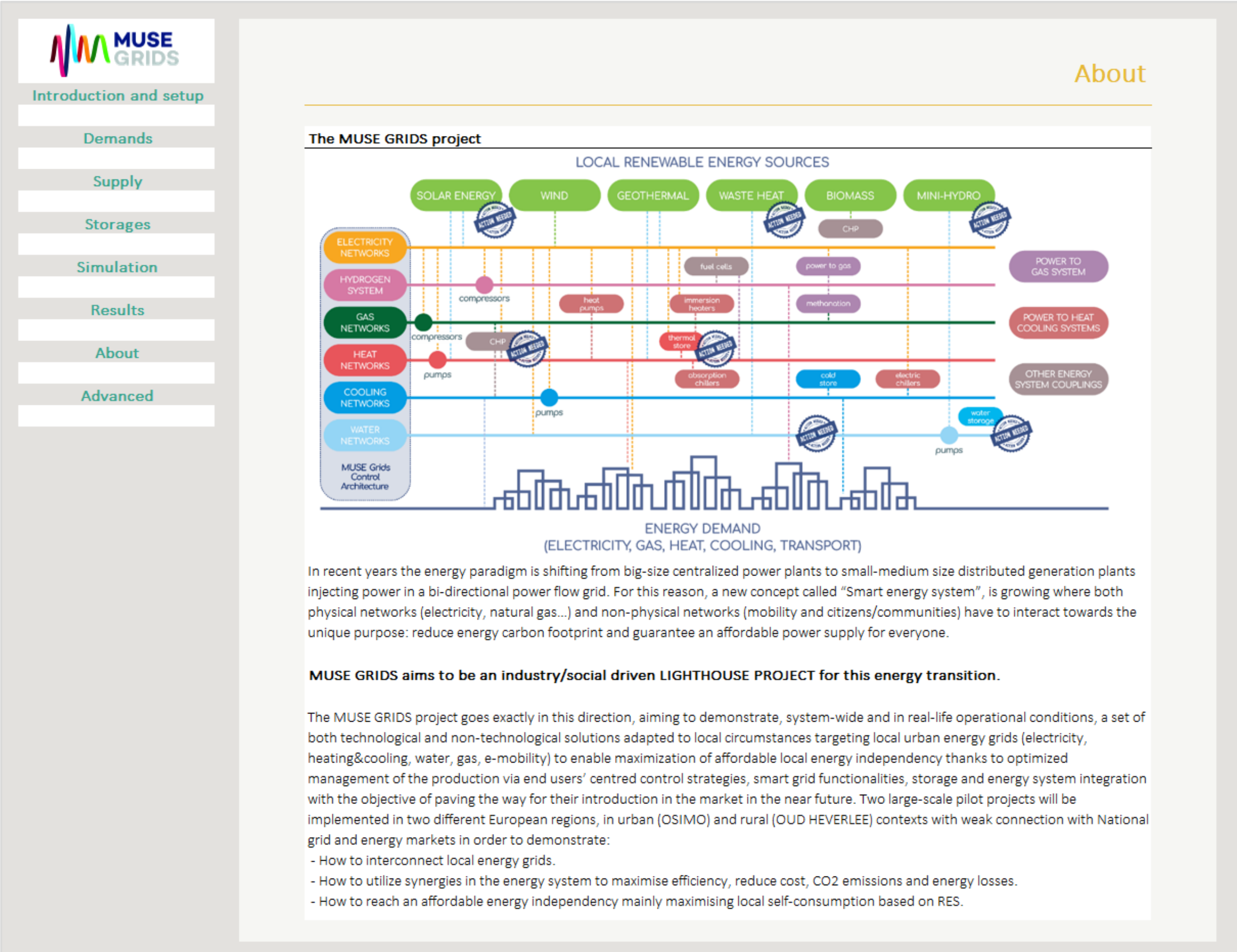


Figure 33 Screenshot of the About interface

10.8 Advanced

Here some more advanced parts of the tool can be found.

10.8.1 Distributions

Here the distributions used for the simulations are stored. It is possible to import and edit the distributions here if need be. Also, when *Insert own* in the drop-down menus for the distributions the user is send to this sheet to insert the data directly. When adding a distribution, **make sure it has numbers in all the 8,784 hours** shown in the input sheet.

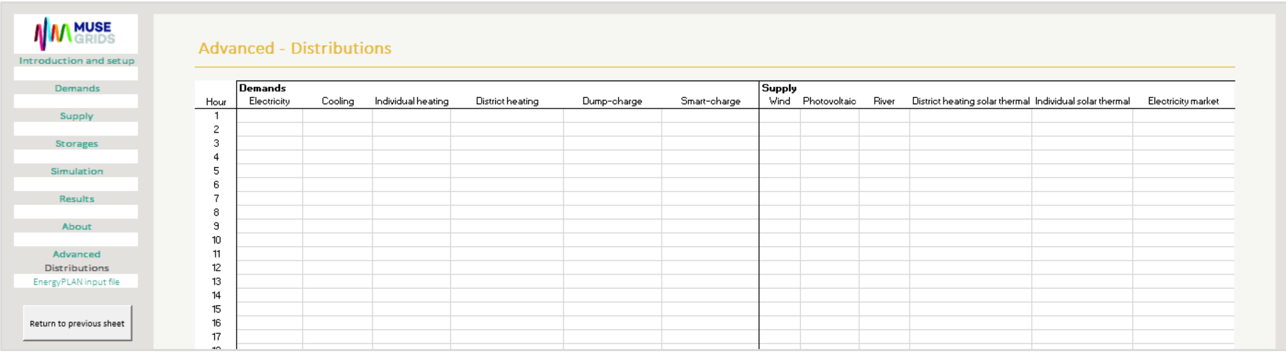


Figure 34 Screenshot of the "Distributions" in Advanced interface

10.8.2 EnergyPLAN input file

Shows the input file generated for EnergyPLAN. This is only relevant for advanced users.

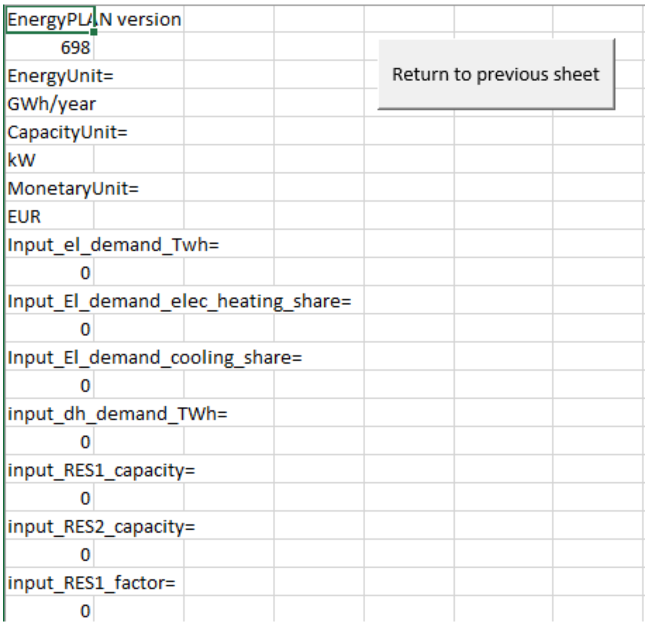


Figure 35 Screenshot of the "EnergyPLAN input file" in Advanced interface

11 Assessment tools

In this chapter, the different assessment tools are described. These tools can assist in the development of the reference energy system or in relation to identifying relevant scenarios. The methods utilised for these are more described in deliverable D3.1 – *Mapping tool (Sources and demands) prototype* Section 3 and further documentation is available in D3.1 Annexes I and II Section 11.

11.1 Assessment tool overview

The assessment tools included can be seen in Figure 36. These will be further described in the following sections.

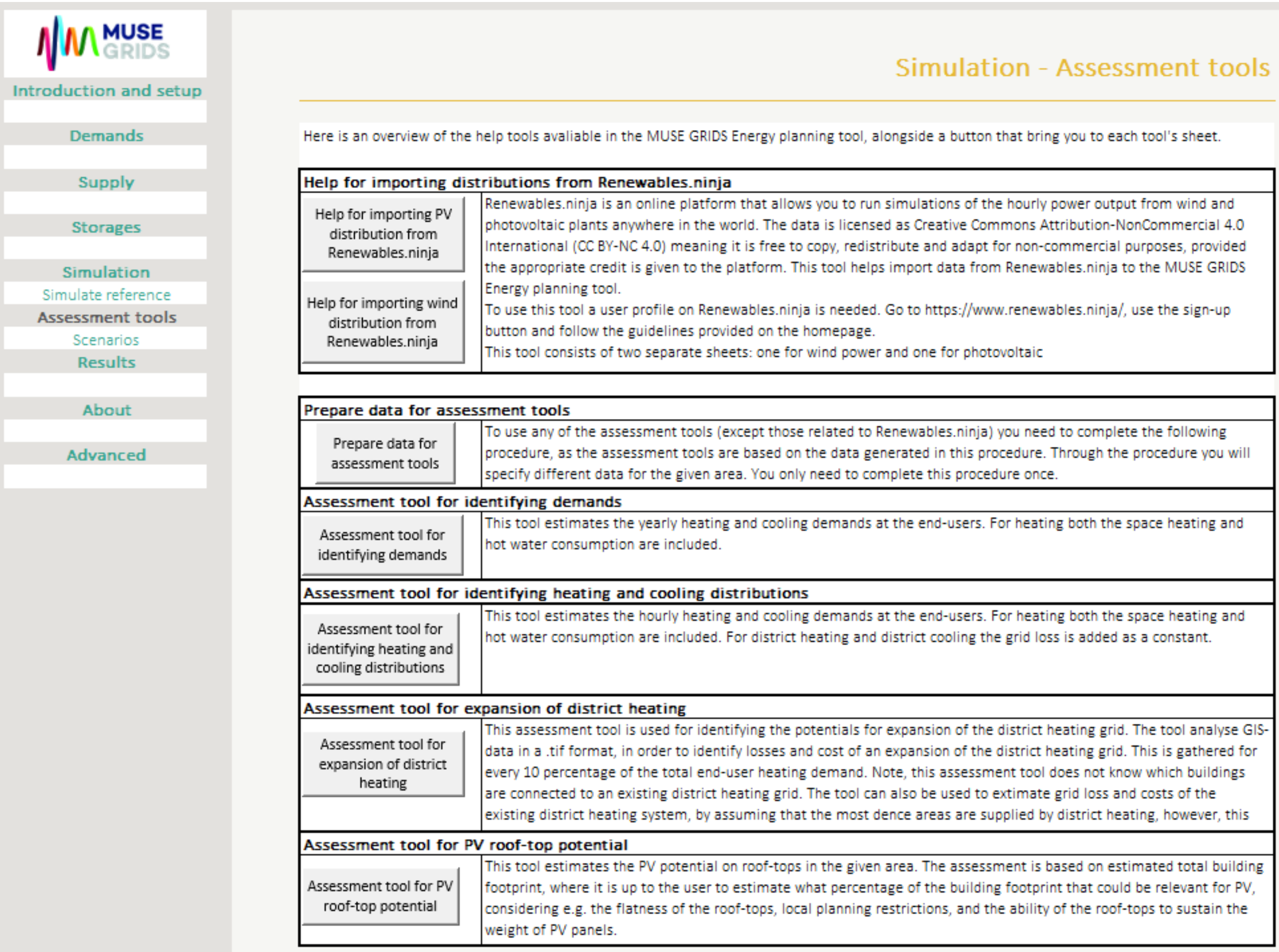


Figure 36 Screenshot with an overview of included assessment tools.

11.2 Help for importing distributions from Renewables.ninja

Renewables.ninja is an online platform that allows you to run simulations of the hourly power output from wind and photovoltaic plants anywhere in the world. The data is licensed as Creative Commons Attribution-NonCommercial 4.0 International (CC BY-NC 4.0) meaning it is free to copy, redistribute and adapt for non-commercial purposes, provided the appropriate credit is given to the platform.

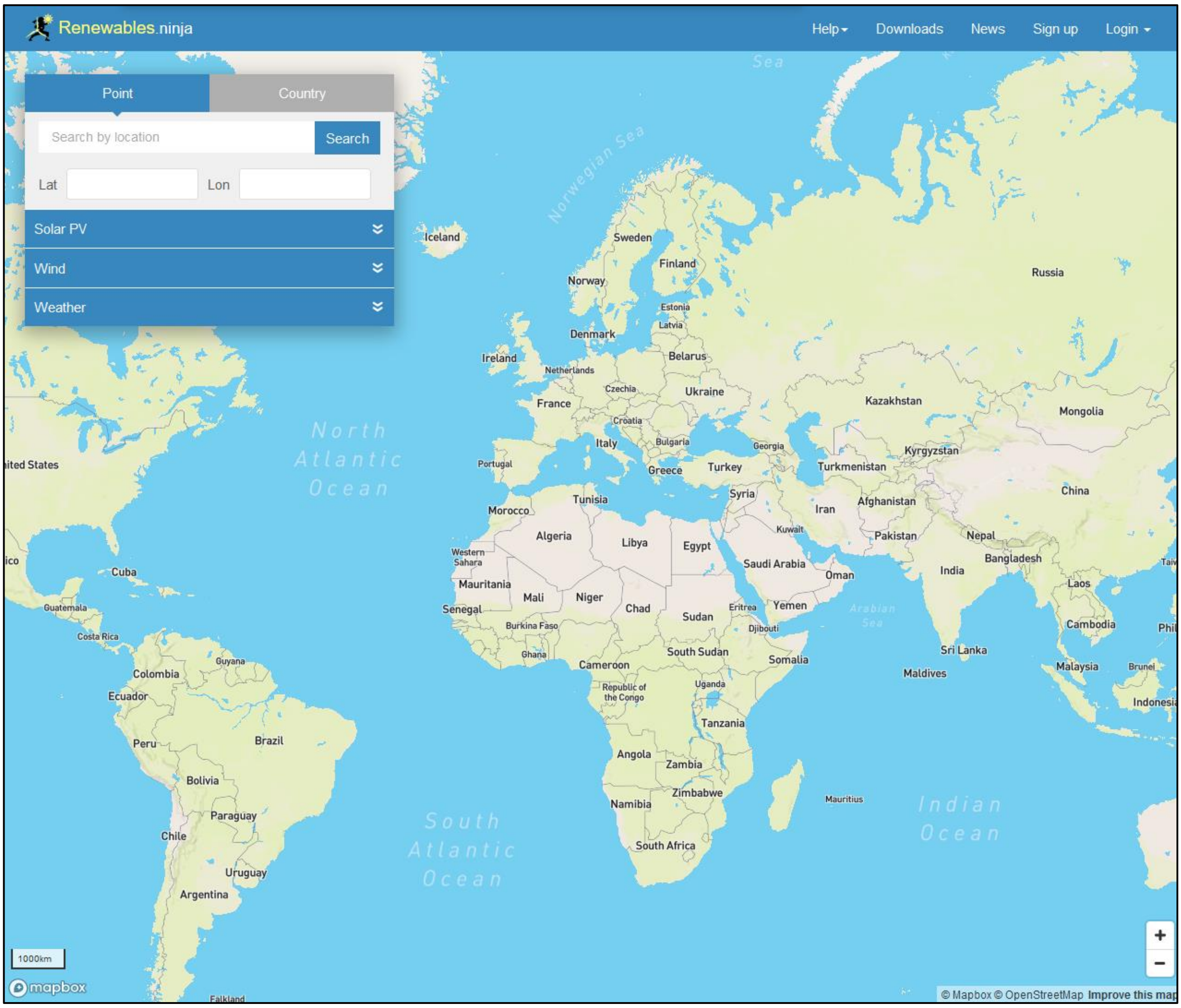


Figure 37 Screenshot of the Renewables.ninja homepage.

This tool helps import data from Renewables.ninja to the MUSE GRIDS Energy planning tool. To use this tool a user profile on Renewables.ninja is needed. Go to https://www.renewables.ninja/ , use the sign-up button and follow the guidelines provided on the homepage.

The tool can both download and import the data into the tool, so do not download the data from Renewables.ninja manually.

This tool consists of two separate sheets: one for wind power and one for photovoltaic. First the tool for wind power is presented, followed by the one for photovoltaic.

11.2.1 Wind Power from Renewable.ninja

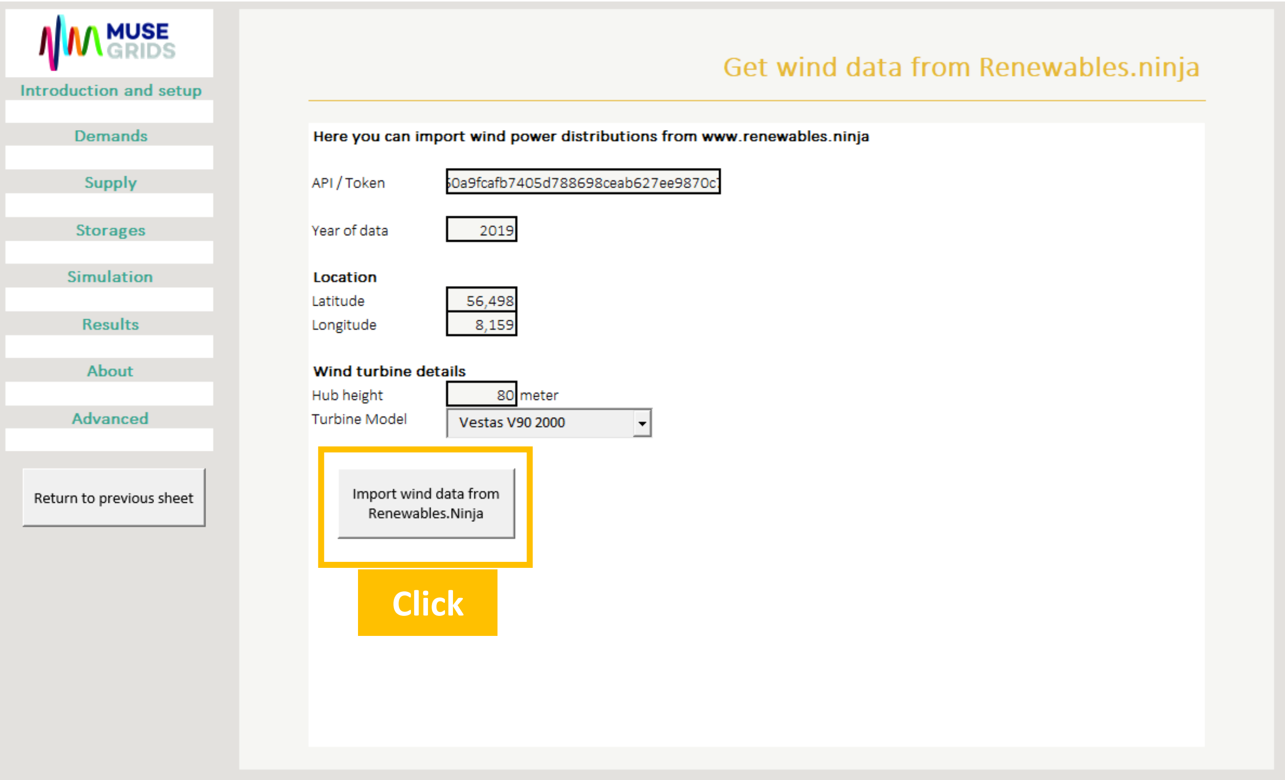


Figure 38 Screenshot of the "Help for Wind importing distributions from Renewables.ninja" in Simulation interface

- **API / Token**: This is a token that is generated for your user on Renewables.ninja. To find the Token associated with your user go to https://www.renewables.ninja/profile, then find Token at the bottom and copy the token to the input cell for API / Token. The API (*Application Programming Interface*) is so to speak the umbilical cord between the MUSE GRIDS Energy planning tool and the Renewables.ninja database.
- **Year of data**: set the year of data you want to use. Renewables.ninja has data from 2000-2019. In case a non-leap year is chosen the 31st of December will be imported twice in the distribution, to make sure that a total of 8,784 hours is in the distribution.
- **Location**: Insert the latitude and longitude for a representative location of the onshore wind power in the modelled energy system. These can be easily derived from Renewables.ninja by clicking the position on the world map used on the homepage.
- **Wind turbine details:** Insert the hub height and turbine model for a representative onshore wind power turbine in the area.
- **Import wind data from Renewables.ninja**: Once all inputs are correctly inserted press this button to download and import the data. If successful you will be prompted with a message box once the data has been imported.

11.2.2 Photovoltaic data from Renewable.ninja

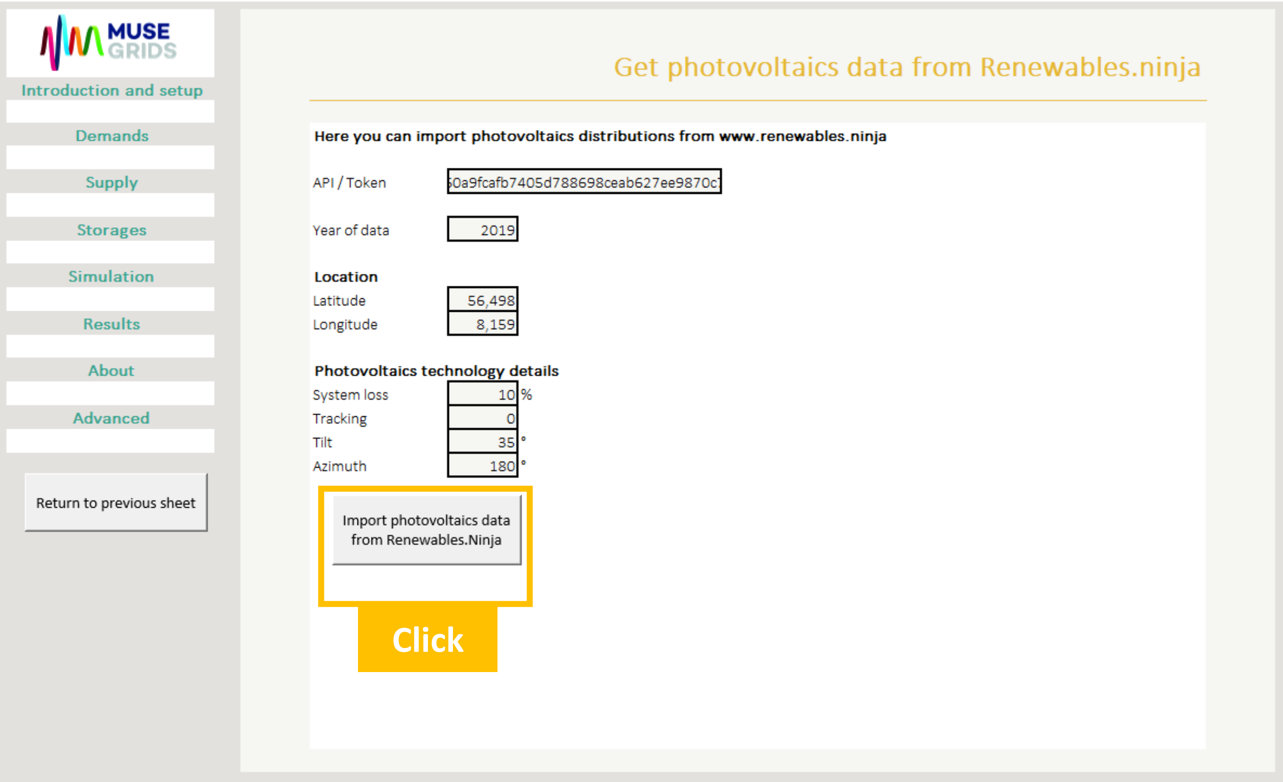


Figure 39 Screenshot of the "Help for PV importing distributions from Renewables.ninja" in Simulation interface

- **API / Token**: This is a token that is generated for your user on Renewables.ninja. To find the Token associated with your user go to https://www.renewables.ninja/profile, then find Token at the bottom and copy the token to the input cell for API / Token.
- **Year of data**: set the year of data you want to use. Renewables.ninja has data from 2000-2019. In case a non-leap year is chosen the 31^{st} of December will be imported twice in the distribution, as to make sure that a total of 8,784 hours is in the distribution.
- **Location**: Insert the latitude and longitude for a representative location of the photovoltaic in the modelled energy system. These can be easily derived from Renewables.ninja by clicking the position on the world map used on the homepage.
- **Photovoltaics technology details:** Insert the system loss, tacking, tilt, and azimuth of a representative photovoltaic plant in the area. Tilt is how far the panel is inclined from the horizontal, in degrees. A tilt of 0° is a panel facing directly upwards, 90° is a panel installed vertically, facing sideways. Azimuth is the compass direction the panel is facing (clockwise). An azimuth angle of 180 degrees means poleward facing, so for latitudes >=0 is interpreted as southwards facing, else northwards facing.

Import wind data from Renewables.ninja: Once all inputs are correctly inserted press this button to download and import the data. If successful you will be prompted with a message box once the data has been imported.

11.3 Prepare data for assessment tools

Before the following four assessment tools can be operated, the user will need to prepare data. This process is guided by the tool when the user selects the "Prepare data for assessment tool"-button. Here the user follows a six step process, as seen in Figure 40. This process includes locating a Georeferenced file (.geojson), and temperature data for the selected location, and finally some assumptions on average floor height, minimum building area (buildings below this area will be discarded), and winter/summer periods.

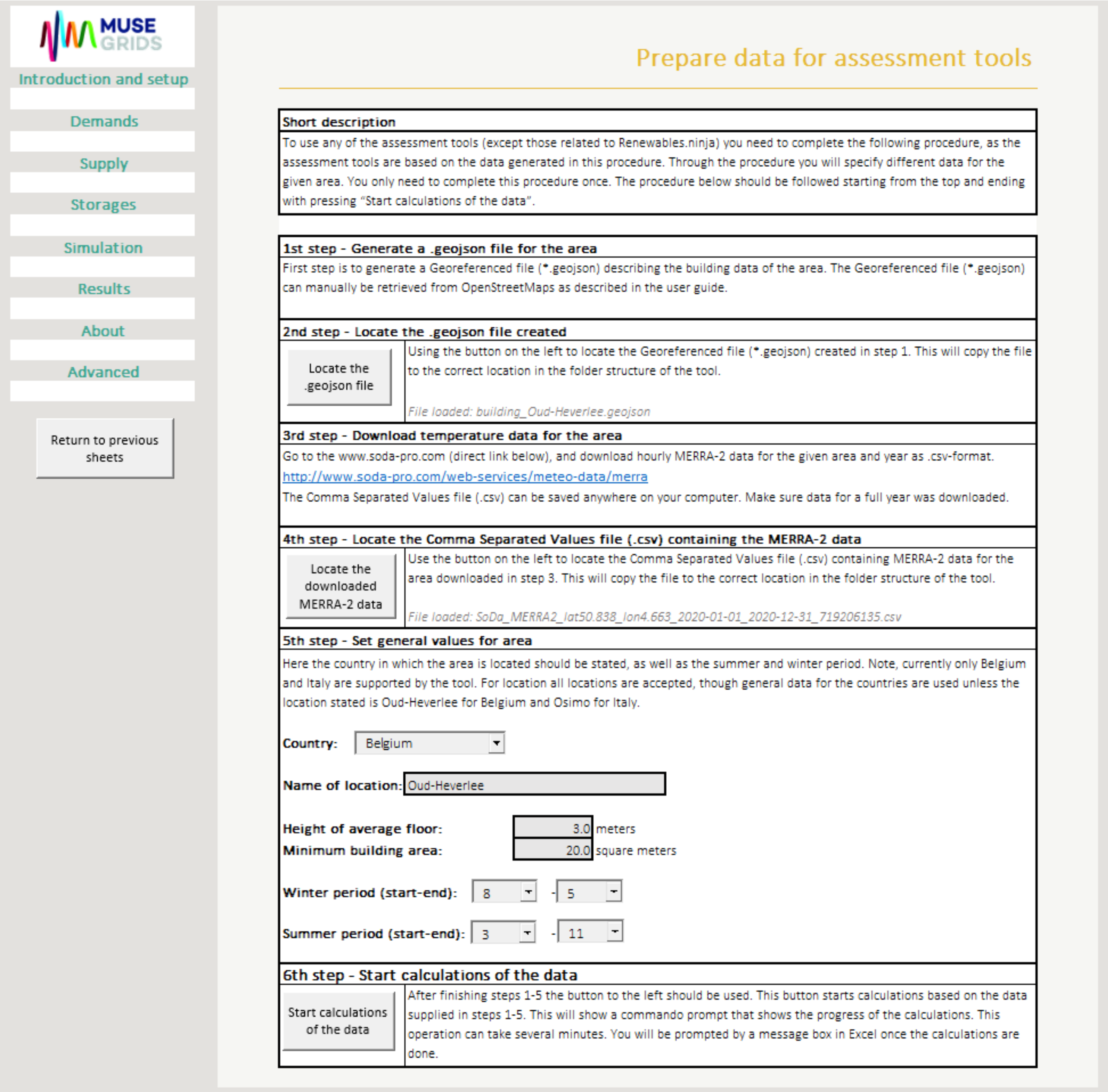


Figure 40 Screenshot of the prepare data for assessment tool process.

11.4 Assessment tool for identifying demands

This assessment tool provides estimates for the yearly heating and cooling demands of buildings in the area, as well as the used heating technology. For heating only, the space heating and domestic hot water consumption is included. It requires an input file containing the two following inputs:

Table 1 Input file requirements

Input	Manually retrieved from	Input location	Format	Reference to

Building	OpenStreetMaps	…//input_data//XXX.geojson	Georeferenced [GeoJSON]	D3.1. Section 3.2.1
Outdoor temperature	SoDa	…//Resources//XXX.csv	Comma- separated values [CSV]	D3.1. Section 3.2.1

These inputs should be placed in the subfolder "\Help tools\Heating_demands\". When the inputs are located correspondingly, the user can click on "Give assessment of heating and cooling demands" – Click 1 - button for running the execution, followed by the "Use the assessment of heating and cooling demands" – Click 2 - button for value assignation. The numeric values then appear in the Output from the tool box section, as seen in the following screenshot.

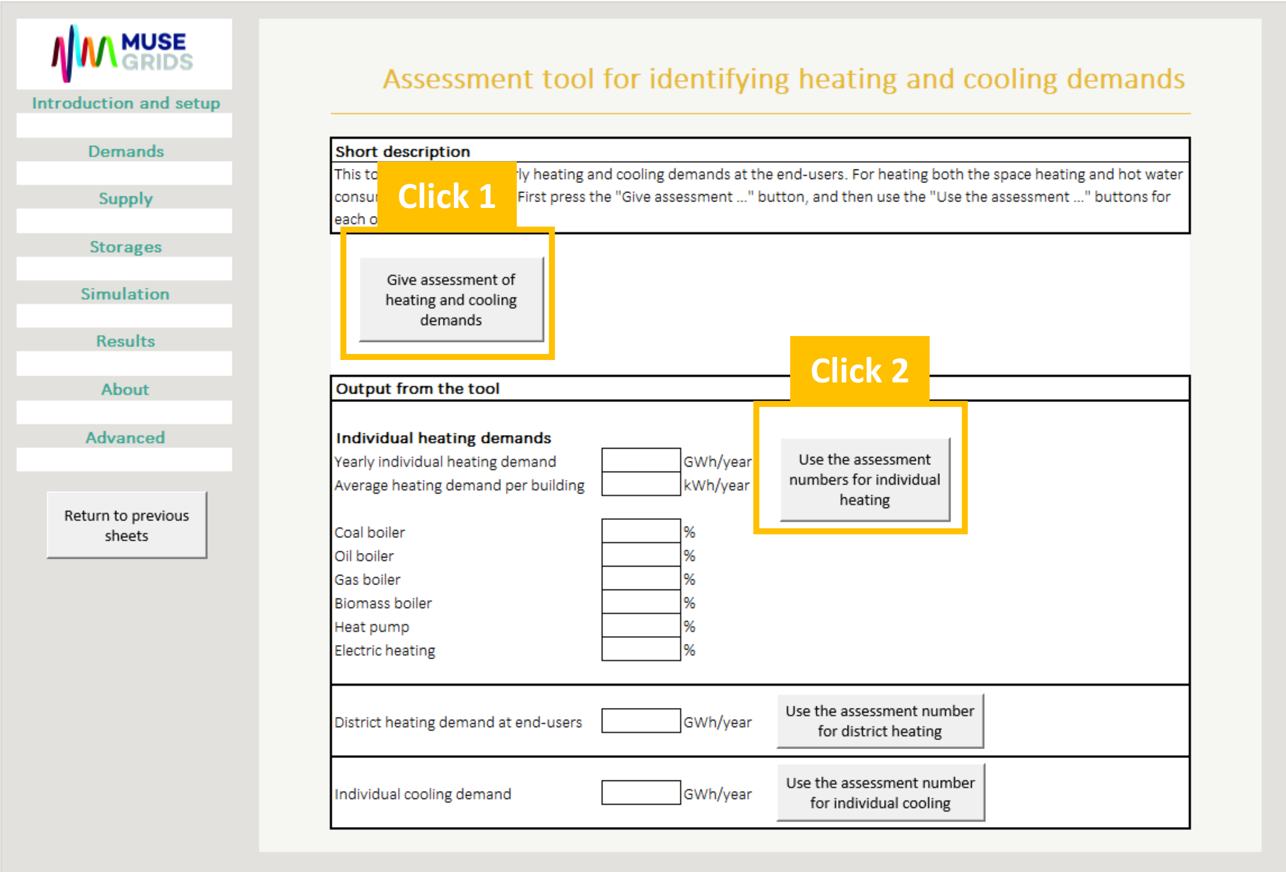


Figure 41 Screenshot of the "Assessment tool for identifying demands" in Simulation interface

- **Give assessment of heating and cooling demands**: Clicking this button will start the assessment tool. Note, the tool will operate in the background up to a couple of minutes since geo-processing tools are being executed. When the tool is done, data will appear below in Output from the tool.
- **Output from the tool**: Here the outputs from the assessment tool are shown. The outputs are separated into assessments for individual heating, district heating, and individual cooling. For each of these a button is available for copying the data in the cells to the relevant inputs. As the assessments do have some

uncertainties related to them it is important that the user evaluates whether the assessments are reasonable for the specific area.

11.5 Assessment tool for identifying heating and cooling distributions

This assessment tool outputs the hourly distribution of the heating and cooling end-user demand. The tool's pre-requisite is 11.4. It outputs the distributions after the "Give assessment of heating and cooling demands" button is executed and provides options for visualization to the user.

Prerequisites: 11.4

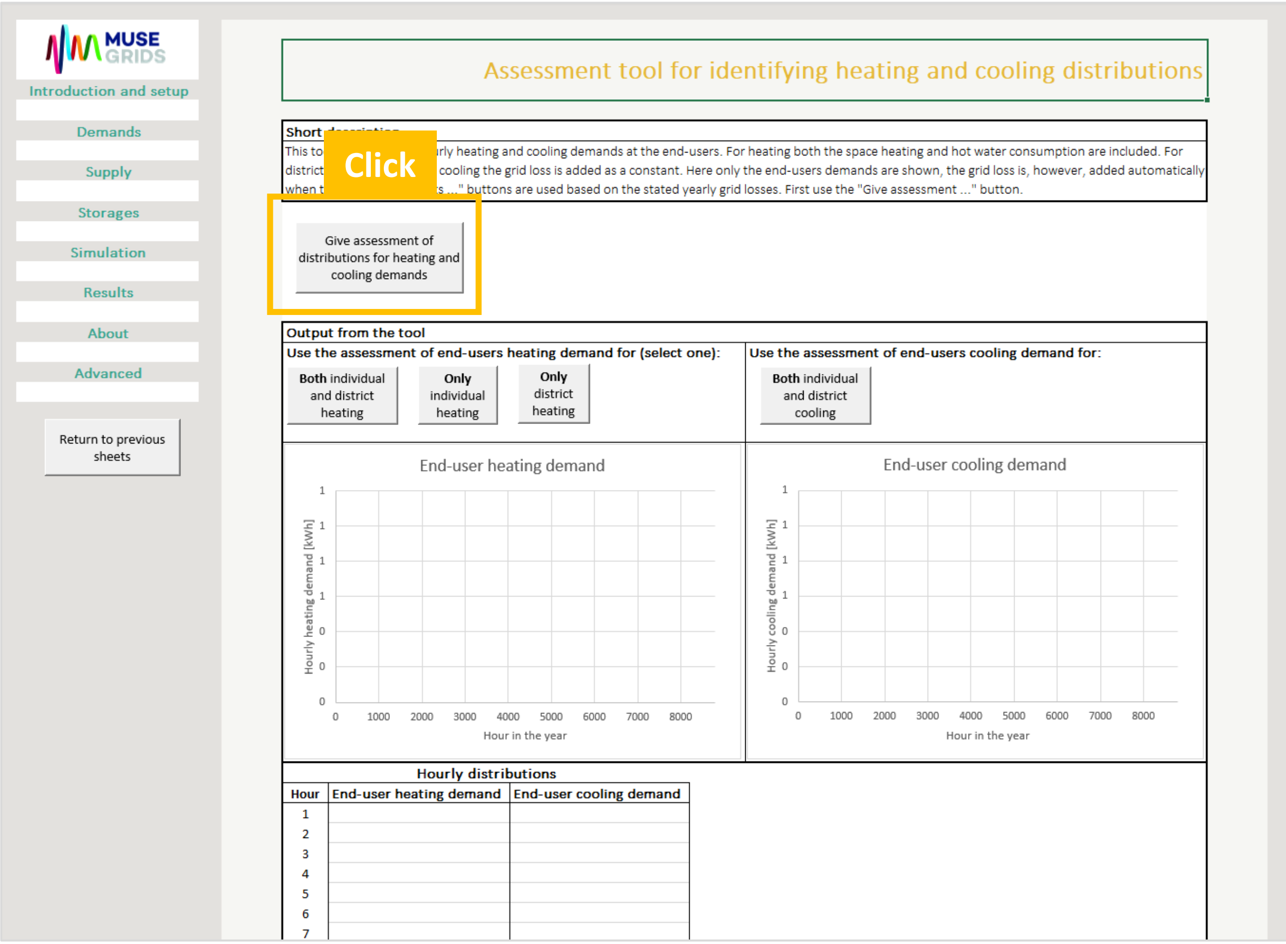


Figure 42 Screenshot of the "Assessment tool for identifying heating and cooling distributions" in Simulation interface

- **Give assessment of distributions for heating and cooling demands**: Clicking this button will start the assessment tool. Note, the tool will operate in the background up to a couple of minutes. When the tool is done data will appear below in Output from the tool.
- **Output from the tool**: Here the distributions from the assessment tool are shown. For heating, both the space heating and hot water consumption are included. For district heating and district cooling the grid loss is added as a constant. Here only the end-users' demands are shown, the grid loss is, however, added automatically when the "Use assessments ..." buttons are used based on the stated yearly grid losses. For the end-user heating demand three buttons are available for copying the distributions to the relevant inputs. The options are to copy the end-user heating demand to be used for both the individual and district heating distributions, to only be used for the individual heating distribution, and to only be used

for the district heating distribution. For end-user cooling demand the cooling distribution can be copied to both individual and district cooling end-user demands as these use the same distribution. As the assessments do have some uncertainties related to them it is important that the user evaluates whether the assessments are reasonable for the specific area.

11.6 Assessment tool for expansion of district heating

This assessment tool gets its input from the previously run heating and cooling demands assessment tool detailed in 11.4, and calculates district heating costs associated with the grid's expansion. Here, 11.4. tool outputs a georeferenced .TIF file format containing heat demand data on a 100x100m resolution for a certain geographical area. The output is then used as the input for this assessment tool which evaluates the end-user heat demand grid and calculates costs and loses using a 10% incremental step.

The tool does not know the current level of district heating in the area, and as such, its initial assumption is that no district heating exists in the area. If district heating exists in the area the tool can therefore be used to estimate grid loss and investment cost of the existing district heating system by identifying the share of the end-user heating demand that is currently served by district heating. The tool only considers space heating and domestic hot water consumption.

Prerequisites: 11.4

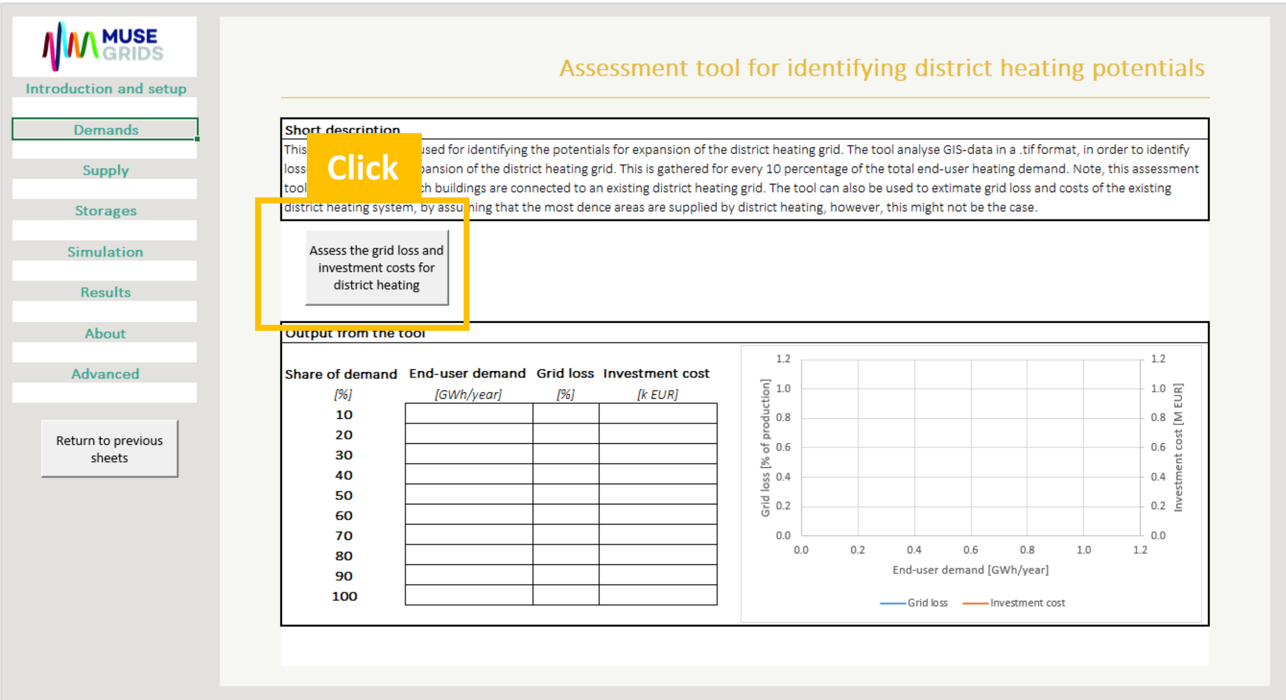


Figure 43 Screenshot of the "Assessment tool for expansion of district heating" in Simulation interface

- **Assess the grid loss and investment costs for district heating**: Clicking this button will start the assessment tool. Note, the tool will operate in the background up to a couple of minutes. When the tool is done data will appear in the table and graph below the button.
- **Output from the tool**: Here the outputs from the assessment tool are shown. For each 10% of the end-user demand the table shows the corresponding end-user demand in energy, the grid loss in the district

heating grid, and the investment cost that would be is expected. As the assessments do have some uncertainties related to them it is important that the user evaluates whether the assessments are reasonable for the specific area.

11.7 Assessment tool for PV roof-top potential

This assessment tool uses the georeferenced file input included by the user as described in 11.3. The user will however need to include estimates of how much of the building footprint is available for PV panels, based on e.g. the angle of roofs and local planning restrictions.

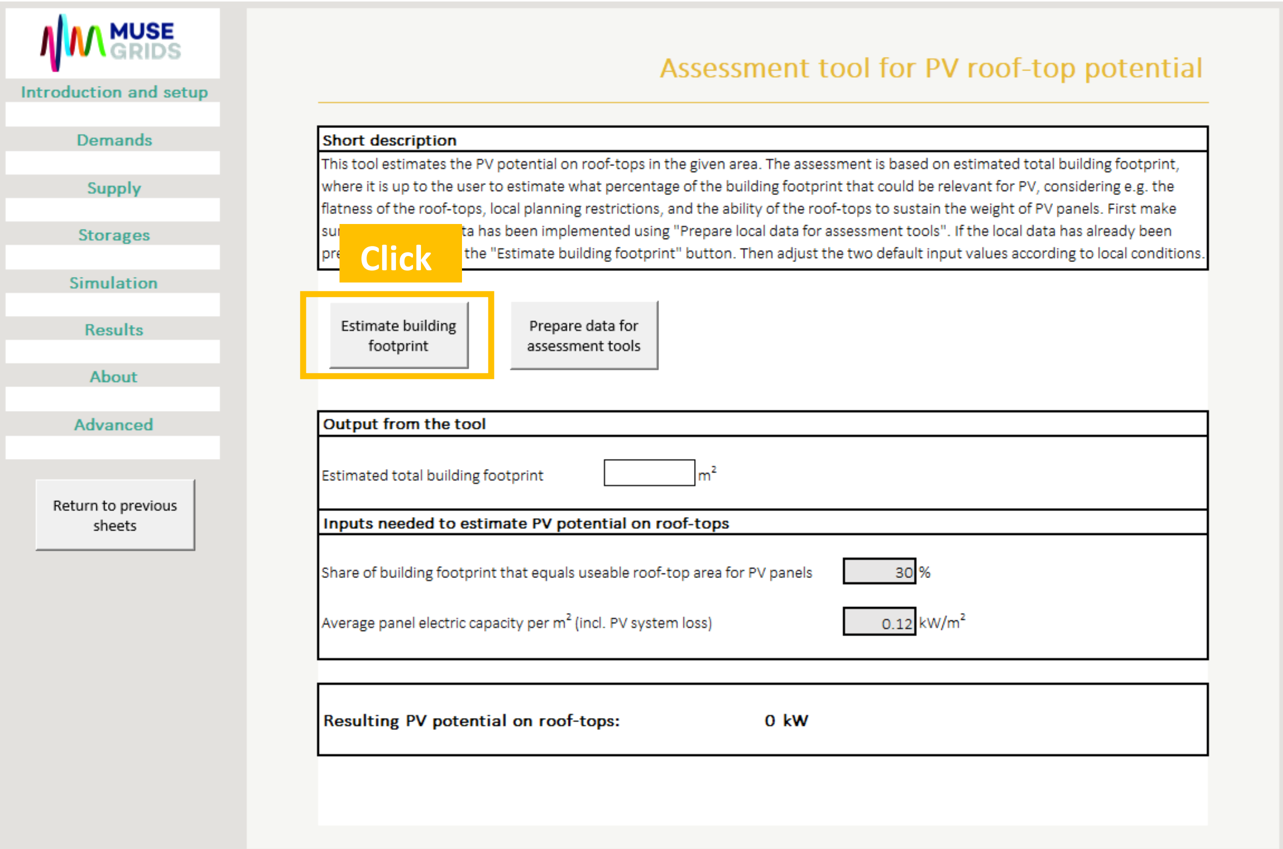
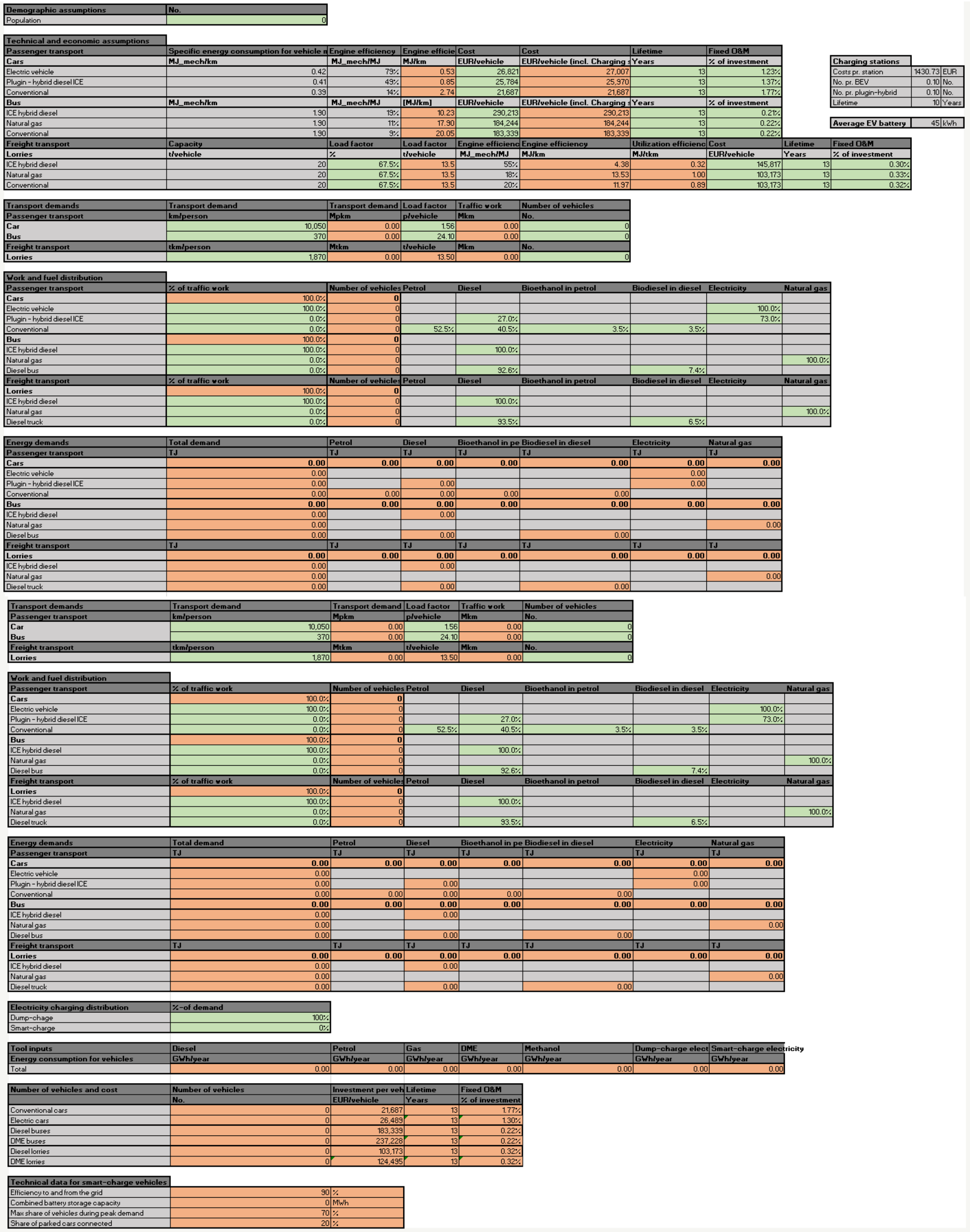


Figure 44 Screenshot of assessment tool for PV roof-top potential.

11.8 Assessment tool for transport demands

This assessment tool establishes inputs for the transport demand based on population number of the modelled area and a number of standard values for transport demand, efficiencies, and load factors for passenger and freight transport. Transport demands are limited to passenger transport and freight transport by lorries due to scope of the tool being municipal energy systems.

To determine transport demand, the user is able to specify transport demand in terms of average km/person for both car and bus transport, and for freight transport in terms of ton km/person. Load factors are also specified in terms of persons/vehicle, and for freight transport in ton/vehicle.



Demographic assumptions	No.
Population	0

Technical and economic assumptions									
Passenger transport	Specific energy consumption for vehicle m	Engine efficiency	Engine efficie	Cost	Cost	Lifetime	Fixed O&M		
Cars	MJ_mech/km	MJ_mech/MJ	MJ/km	EUR/vehicle	EUR/vehicle (incl. Charging s	Years	% of investment		
Electric vehicle	0.42	79%	0.53	26,821	27,007	13	1.23%		
Plugin - hybrid diesel ICE	0.41	49%	0.85	25,784	25,970	13	1.37%		
Conventional	0.39	14%	2.74	21,687	21,687	13	1.77%		
Bus	MJ_mech/km	MJ_mech/MJ	[MJ/km]	EUR/vehicle	EUR/vehicle (incl. Charging s	Years	% of investment		
ICE hybrid diesel	1.90	19%	10.23	290,213	290,213	13	0.21%		
Natural gas	1.90	11%	17.90	184,244	184,244	13	0.22%		
Conventional	1.90	9%	20.05	183,339	183,339	13	0.22%		
Freight transport	Capacity	Load factor	Load factor	Engine efficienc	Engine efficiency	Utilization efficienc	Cost	Lifetime	Fixed O&M
Lorries	t/vehicle	%	t/vehicle	MJ_mech/MJ	MJ/km	MJ/tkm	EUR/vehicle	Years	% of investment
ICE hybrid diesel	20	67.5%	13.5	55%	4.38	0.32	145,817	13	0.30%
Natural gas	20	67.5%	13.5	18%	13.53	1.00	103,173	13	0.33%
Conventional	20	67.5%	13.5	20%	11.97	0.89	103,173	13	0.32%

Charging stations		
Costs pr. station	1430.73	EUR
No. pr. BEV	0.10	No.
No. pr. plugin-hybrid	0.10	No.
Lifetime	10	Years

Average EV battery	45	kWh

Transport demands	Transport demand	Transport demand	Load factor	Traffic work	Number of vehicles
Passenger transport	km/person	Mpkm	p/vehicle	Mkm	No.
Car	10,050	0.00	1.56	0.00	0
Bus	370	0.00	24.10	0.00	0
Freight transport	tkm/person	Mtkm	t/vehicle	Mkm	No.
Lorries	1,870	0.00	13.50	0.00	0

Work and fuel distribution								
Passenger transport	% of traffic work	Number of vehicles	Petrol	Diesel	Bioethanol in petrol	Biodiesel in diesel	Electricity	Natural gas
Cars	100.0%	0						
Electric vehicle	100.0%	0					100.0%	
Plugin - hybrid diesel ICE	0.0%	0		27.0%			73.0%	
Conventional	0.0%	0	52.5%	40.5%	3.5%	3.5%		
Bus	100.0%	0						
ICE hybrid diesel	100.0%	0		100.0%				
Natural gas	0.0%	0						100.0%
Diesel bus	0.0%	0		92.6%		7.4%		
Freight transport	% of traffic work	Number of vehicles	Petrol	Diesel	Bioethanol in petrol	Biodiesel in diesel	Electricity	Natural gas
Lorries	100.0%	0						
ICE hybrid diesel	100.0%	0		100.0%				
Natural gas	0.0%	0						100.0%
Diesel truck	0.0%	0		93.5%		6.5%		

Energy demands	Total demand	Petrol	Diesel	Bioethanol in pe	Biodiesel in diesel	Electricity	Natural gas
Passenger transport	TJ	TJ	TJ	TJ	TJ	TJ	TJ
Cars	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Electric vehicle	0.00					0.00	
Plugin - hybrid diesel ICE	0.00		0.00			0.00	
Conventional	0.00	0.00	0.00	0.00	0.00		
Bus	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ICE hybrid diesel	0.00		0.00				
Natural gas	0.00						0.00
Diesel bus	0.00		0.00		0.00		
Freight transport	TJ	TJ	TJ	TJ	TJ	TJ	TJ
Lorries	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ICE hybrid diesel	0.00		0.00				
Natural gas	0.00						0.00
Diesel truck	0.00		0.00		0.00		

Transport demands	Transport demand	Transport demand	Load factor	Traffic work	Number of vehicles
Passenger transport	km/person	Mpkm	p/vehicle	Mkm	No.
Car	10,050	0.00	1.56	0.00	0
Bus	370	0.00	24.10	0.00	0
Freight transport	tkm/person	Mtkm	t/vehicle	Mkm	No.
Lorries	1,870	0.00	13.50	0.00	0

Work and fuel distribution								
Passenger transport	% of traffic work	Number of vehicles	Petrol	Diesel	Bioethanol in petrol	Biodiesel in diesel	Electricity	Natural gas
Cars	100.0%	0						
Electric vehicle	100.0%	0					100.0%	
Plugin - hybrid diesel ICE	0.0%	0		27.0%			73.0%	
Conventional	0.0%	0	52.5%	40.5%	3.5%	3.5%		
Bus	100.0%	0						
ICE hybrid diesel	100.0%	0		100.0%				
Natural gas	0.0%	0						100.0%
Diesel bus	0.0%	0		92.6%		7.4%		
Freight transport	% of traffic work	Number of vehicles	Petrol	Diesel	Bioethanol in petrol	Biodiesel in diesel	Electricity	Natural gas
Lorries	100.0%	0						
ICE hybrid diesel	100.0%	0		100.0%				
Natural gas	0.0%	0						100.0%
Diesel truck	0.0%	0		93.5%		6.5%		

Energy demands	Total demand	Petrol	Diesel	Bioethanol in pe	Biodiesel in diesel	Electricity	Natural gas
Passenger transport	TJ	TJ	TJ	TJ	TJ	TJ	TJ
Cars	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Electric vehicle	0.00					0.00	
Plugin - hybrid diesel ICE	0.00		0.00			0.00	
Conventional	0.00	0.00	0.00	0.00	0.00		
Bus	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ICE hybrid diesel	0.00		0.00				
Natural gas	0.00						0.00
Diesel bus	0.00		0.00		0.00		
Freight transport	TJ	TJ	TJ	TJ	TJ	TJ	TJ
Lorries	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ICE hybrid diesel	0.00		0.00				
Natural gas	0.00						0.00
Diesel truck	0.00		0.00		0.00		

Electricity charging distribution	%-of demand
Dump-chage	100%
Smart-charge	0%

Tool inputs	Diesel	Petrol	Gas	DME	Methanol	Dump-charge elect	Smart-charge electricity
Energy consumption for vehicles	GWh/year	GWh/year	GWh/year	GWh/year	GWh/year	GWh/year	GWh/year
Total	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Number of vehicles and cost	Number of vehicles	Investment per veh	Lifetime	Fixed O&M
	No.	EUR/vehicle	Years	% of investment
Conventional cars	0	21,687	13	1.77%
Electric cars	0	26,489	13	1.30%
Diesel buses	0	183,339	13	0.22%
DME buses	0	237,228	13	0.22%
Diesel lorries	0	103,173	13	0.32%
DME lorries	0	124,495	13	0.32%

Technical data for smart-charge vehicles		
Efficiency to and from the grid	90	%
Combined battery storage capacity	0	MWh
Max share of vehicles during peak demand	70	%
Share of parked cars connected	20	%

Figure 45 Screenshot of assessment tool for transport demand

Based on the user inputs on population, transport demands per person, and distribution of vehicle types (share of EV's, plug in hybrids, and conventional vehicles etc.), the assessment tool provides an estimated fuel demand for the transport sector.

12 FAQ

I get the error “Run-time error ’74’: Path not found” when I try to “Use existing EnergyPLAN distribution”, use an assessment tool or “Simulate reference model in EnergyPLAN.

This is likely due to the MUSE GRIDS Energy planning tool folder being located on a network drive. Copy the folder to a local drive (e.g. C:\ or D:\) and see if the problem persists.

Locating the MUSE GRIDS Energy planning tool on a OneDrive folder can also result in this error. If this is the case move the folder to a non-OneDrive folder on a local drive (e.g. C:\ or D:\).

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Appendix 1: Interview guide

Questionnaire regarding planning tool development

1 Introductory questions

1) What is your position and role in the municipality?
2) What is your professional background?
3) Are you engaged in energy planning[1]?
4) What type of energy planning tasks are you engaged in?

2 Goals (important qualitative inputs to scenario definition)

1) What is your municipality's long-term low carbon end target? E.g. 2030 zero carbon; reduction of air pollution, access to electricity, etc.
2) What current energy-related plans/strategies and goals do your municipality have, i.e. mobility, built environment, land-use, others?
   a) Which of these will you use within an integrated energy plan/strategy?
   b) What is your process to integrate these current plans into an overall integrated energy plan?
3) What technologies is there a focus on implementing – and what technologies still have an untargeted potential for implementing (for both questions e.g. wind power, photo voltaics, solar collectors, district cooling, energy savings, ...)

3 Practise (important qualitative inputs to scenario definition)

1) Do you work with quantitative and/or qualitative scenarios in the municipality?
   a) If no, how else will you identify the "right" technologies/actions/solutions for the future?
2) Do you use any other tools and processes (complementary to scenarios) for identifying technologies and solutions?
3) Do you use energy systems modelling tools in the municipal planning?
   a) If not – would that be likely to change in future?

4 Delimitation and criteria

1) What assessment criteria are applied to determine best or optimal scenarios? (e.g. cost to residents, external costs (e.g. from pollution), self-sufficiency, ease of implementation, ability to create a system in balance not relying on import/export, …)

[1] By energy planning is here meant the process of helping steer the development of the local, regional or national energy system by setting targets and establishing the means of measures for reaching the targets. For local level, it can include setting requirements for what heating technologies may be applied in given district, requirements for solar collectors, or setting minimum insulation standards.

2) What sectors are considered in present energy planning in the municipality – and if different - which should be considered in the future? (e.g. electricity, heating, cooling / residential, industrial, service, transport)
3) Do you have any thoughts on the geographical delimitation / boundaries of the area for energy planning?

5 Capacity and competences (Important for the tool development)

1. How many inside the municipality are involved in energy planning – and is this their primary focus or is it secondary to other planning tasks (spatial planning, traffic planning, environmental planning)
2. Is there access to external consultants?
3. What types of resources are available internally and externally? See table for examples.

	Internal resources	External resources
Human ressources	What are the municipal/city planners' • Educational background • Experience with energy (technical) • Experience with energy (planning/implementation) • Level of experience with Excel • Level of experience with GIS tools • Level of experience with MatLab • Level of experience with Python	Is there access (also e.g. within budgetary restraints) to experts with experience within • Energy (technical) • Energy (planning/implementation) • Excel • GIS tools • MatLAB • Python
Technical ressources	Access to computer with • Excel • GIS tools (E.g. ArcGIS or other) • MatLab • Python What OS do your work computers use: • Microsoft Windows • MacOS • Linux	