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MSc Program
Renewable Energy in Central and Eastern Europe

# Electricity Scenarios for the Lake City Aspern

## Dynamic Simulation of the Implementation of Photovoltaic, Wind Power and Geothermal Electricity Production

A Master's Thesis submitted for the degree of
"Master of Science"

Supervised by
DI Hubert Fechner, MAS, MSc

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Vienna, November 2010

# Affidavit

I, Cora James hereby declare

1. that I am the sole author of the present Master Thesis, “Electricity Scenarios for the Lake City Aspern. Dynamic Simulation of the Implementation of Photovoltaic, Wind Power and Geothermal Electricity Production”, 66 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
2. that I have not prior to this date submitted this Master Thesis as an examination paper in any form in Austria or abroad.

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# Abstract

Dynamic electricity scenarios for the Lake City Aspern were calculated for the implementation of photovoltaics, wind power and geothermal electricity. The EnergyPLAN model was used to simulate the scenarios with consideration of load profiles for electricity demand and supply. With the most ambitious demand assumptions and the highest assumed electricity production from photovoltaics and wind, the direct utilisation rate of the produced renewable electricity is 76% and 48% of the demand can be directly supplied with the produced renewable electricity. With an additional assumption of a stable geothermal electricity source, the same scenario shows a self sustainability of 70% and a renewable electricity utilisation rate of 73%. Flexible demand as a measure to increase utilisation rate of the produced electricity is only effective for the most ambitious demand scenarios. It is recommended that in a next step of assessing energy models for the Lake City Aspern, the heat and transport sector are included to fully assess the options of balancing the fluctuating energy supply of photovoltaics and wind. For this assessment the EnergyPLAN model can be recommended.

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# List of Acronyms

| | |
|---|---|
| HOMER | Hybrid Optimization Model for Electric Renewables |
| kWp | kiloWattpeak |
| ORC | Orgynic Rankine Cycle |
| PE | Primary Energy |
| PV | Photovoltaic |
| RES | Renewable Energy Sources |
| RES-E | Renewable Energy Sources – Electricity |
| SA | Sensitivity Analysis |
| ST | Solar Thermal |
| WEC | Wind Energy Converter |

# 1 Introduction

One of the major problems of today's world is the continuous population growth and at the same time a shift of people moving to urban areas. While in 1800, only 3 percent of the world's population lived in urban areas, today more than half the world's population is living in cities. By 2030, the urban population is expected to make up roughly 60 percent of the earth's population (Population Reference Bureau 2007). At the same time, we live in a world of environmental degradation and climate change where conventional energy sources are becoming scarce, even though societies are becoming increasingly dependent on a different range of energy intensive technologies.

In this light, city and town planning is and will be one of the main tasks of the human race in the centuries to come. Existing cities are constantly being restructured and renovated, and also in many parts of the world, completely new cities or city areas have been built and are being planned from scratch.

The aspects of energy efficiency and energy sustainability have become more important over time for town planning. Sustainability as a principle for political actions has first been used 1987 in the Report of the Brundtland Commission, "Our Common Future" (World Commission on Environment and Development 1987). Another important international document was adopted at the Earth Summit in Rio de Janeiro in 1992, where the important role of all political levels and members of society for a sustainable development is highlighted. On the European communal level, the Aalborg Charta was passed in 1994 (Danner 2005). The Aalborg Charta for example states: "The abatement of fossil fuel emissions will require policies and initiatives based on a thorough understanding of the alternatives and of the urban environment as an energy system. The only sustainable alternatives are renewable energy sources." (The Aalborg Charter 1994). The most recent goal of the European Union concerning the use of renewable energy is a package that was agreed on in December 2008. With this agreement the EU committed itself to reducing its overall emissions to at least 20% below 1990 levels by 2020 and set itself the target of increasing the share of renewable energy to 20% by 2020 (European Union 2008).

There are many townships or regions that are aiming to be energy self-sufficient or are already self-sufficient. A prominent example of an energy self-sufficient township is Güssing in Austria. Successful examples of city planning can be found in Quartier Vauban in Freiburg, Germany, where 65% of the used electricity is produced in the area itself and in Bo01 Västra Hamnen, Malmö, Sweden, where the energy self sufficiency has reached 100% (Hageneder & Lindenthal 2010).

The main problem that is faced with a high percentage of renewable electricity supply is the fluctuating nature of many renewable energy sources. Exceptions are bio energy, hydropower and geothermal energy. At present, if fluctuating renewable energy is produced in a grid-connected mode, the load can be expected to be balanced by the grid. In the future, however, if fluctuating energy is produced in many regions, this will not be the case. Therefore, even grid connected areas will need to be considered as divided into self-reliant subsystems, each with appropriate load following capabilities (Østergaard 2009). Looking at this, it seems to be an important aspect in town planning to regard the area under development as an electricity system of its own.

## *1.1 Objectives and scope of this work*

This work aims at assessing electricity scenarios with fluctuating supply for the Lake City of Aspern, a new city area in Vienna that will be built from scratch in the next decade. Based on data, findings and scenarios of the project NACH ASPERN (Pol & Shoshtari 2010), load electricity scenarios will be considered including load profiles. With including hourly load profiles for demand and electricity production, the direct utilisation rate will be calculated and with this the share of possible self sustainability for electricity for the Lake City Aspern will be assessed.

For electricity production, photovoltaic, wind energy and geothermal energy will be considered, and for the demand, the electricity consumption of households, offices and shops are looked at. Even though the proposed wind turbines are outside the energy system boundary, in this work the option of wind energy is assessed as part of the system. To show a possible way of optimising the direct utilisation ratio, different shares of flexible demand are introduced to the scenarios.

Another purpose of this work is to show the possible implementation of the EnergyPLAN tool for ctiy planning projects similar to the Aspern Lake City.

## *1.2 Modelling of Energy Systems*

This section gives an overview of energy modelling for energy systems with renewable energy sources (RES). Special mention is given to the aspects relevant to this work.

### 1.2.1 Overview of Different Tools for Analysing the Integration of Renewable Energy

Energy tools are used widely to study different aspects of integrating renewable energy into existing energy systems, or modelling energy systems run entirely on renewable energy. The studies range from analysing single projects to energy systems of a whole country or international regions. Different optimisation criteria are used.

Østergaard (2009) gives an overview of different optimisation criteria for energy systems analyses of renewable energy integration. Some studies put their focus more on the economic perspective, others put more emphasis on the techno-operational point of view. Examples of economic optimisation criteria are total energy systems costs, capacity costs and societal costs. Techno-operational optimisations criteria can be fuel savings, $CO_2$ emissions, reserve/back-up capacity, required condensing mode power generation (for combined heat and power plants), the minimisation of import and export and the elimination of excess power generation. However, in practice, the economic and techno-operational points can not always be separated completely.

A big variety of energy models and tools can be found in literature, using different approaches to various aspects of energy systems. The tools differ in the geographical area covered, in the timeframe considered and the included time steps. Some of the tools have been developed with a special focus and not all of the tools are suitable to analyse 100% renewable energy systems. Some models allow

the integration of all the energy sectors, others are confined to certain sectors. A good review and comparison of energy models, with special focus on their suitability for analysing the integration of renewable energy is given by Conolly et al. (2010a).

Seven types of different energy tools are defined in this review, as can be seen in the table below.

**Table 1** Different types of energy tools (Source: Conolly et al. 2010a)

| *Type* | *Description* |
|---|---|
| **1. Simulation tool** | Simulates the operation of a given energy-system to supply a given set of energy demands. Typically a simulation tool is operated in hourly time-steps over a one-year time-period. |
| **2. Scenario tool** | Combines a series of years into a long-term scenario. Typically scenario tools function in time-steps of 1 year and combine such annual results into a scenario of typically 20-50 years. |
| **3. Equilibrium tool** | Seeks to explain the behaviour of supply, demand, and prices in a whole economy or part of an economy (general or partial) with several or many markets. It is often assumed that agents are price takers and that equilibrium can be identified. |
| **4. Top-down tool** | A macroeconomic tool using general macroeconomic data to determine growth in energy prices and demands. typically top-down tools are also equilibrium tools. |
| **5. Bottom-up tool** | Identifies and analyses the specific energy technologies and thereby identifies investment options and alternatives. |
| **6. Operation optimisation tool** | Optimises the operation of a given energy-system. Typically operation optimisation tools are also simulation tools optimising the operation of a given system. |
| **7. Investment optimisation tool** | Optimises the investments in an energy-system. Typically optimisation tools are also scenario tools optimising investments in new energy stations and technologies. |

A list of energy tools that are suitable to analyse 100% renewable electricity scenarios and their characteristics is given in the following table.

**Table 2** Energy tools suitable for analysing 100% renewable electricity scenarios (Source: Connolly et al. 2010a)

| *Tool & Organisation* | *Type*[1] | *Energy Sectors* | *Geographical Area* | *Timeframe* | *Time Step* | *Availability* |
|---|---|---|---|---|---|---|
| **EnergyPLAN**<br>Aalborg University | 1, 2, 5, 6, 7 | Electricity, heat, transport | National, state, regional | 1 year[2] | Hourly | Free to download |
| **INFORSE**<br>The International Network for Sustainable Energy | 2 | Electricity, heat, transport | National, state, regional | 50+ years | Yearly | Distributed to non-governmental organisations |
| **Mesap PlaNet**<br>Seven2one | 2, 5 | Electricity, heat, transport | National, state, regional | No limit | Any | Commercial |
| **H2RES**<br>Instituto Superior Técnico and the University of Zagreb | 1, 2, 5, 6 | Electricity, heat, partly transport | Island | No limit | Hourly | Internal use only |
| **SimREN**<br>Institute of Sustainable Solutions and Innovations | - | Electricity, heat, partly transport | National, state, regional | No limit | Minutes | Projects completed for a fee |
| **energyPRO**<br>Energi-Og Mijødata (EMD) International A/S | 1, 2, 6, 7 | Electricity, partly heat | Single-project investigation | Max 40 years | Minutes | Commercial |

[1] The numbers given in this column correspond to the numbers of the types in Table 1.
[2] Tools can only simulate 1 year at a time, but these can be combined to create a scenario of multiple years.

| *Tool & Organisation* | *Type* | *Energy Sectors* | *Geographical Area* | *Timefr ame* | *Time Step* | *Availability* |
|---|---|---|---|---|---|---|
| **HOMER**<br>National Renewable Energy Laboratory and HOMER Energy LLC | 1, 5, 6, 7 | Electricity, heat | Local, community | 1 year | Minutes | Free to download |
| **TRNSYS16**<br>The University of Wisconsin Madison | 1, 2, 5, 6, 7 | Electricity, heat | Local, community | Multiple years | Seconds | Commercial |
| **PERSEUS**<br>Institute for Industrial Production, Universität Karlsruhe | 2, 3, 5, 7 | Electricity, heat, partly transport | International | Max 50 years | Based on typical days with 36-72 slots for 1 year | Commercial: only sold to large European utilities |
| **LEAP**<br>Stockholm Environment Institute | 1, 2, 4, 5, | Electricity, heat, transport | National, state, regional | No limit | Yearly | Commercial/ free for developing countries and students |
| **In*vert***<br>Energy Economics Group, Vienna University of Technology | 1, 2, 5, 7 | Electricity, heat, partly transport | National, state, regional | Max 50 years | Yearly | Free to download |
| **EMPS**<br>Stiftelsen for Industriell og Teknisk Forskning (SINTEF) | 6 | Electricity | International | 25 years | Weekly sample periods (with a load duration curve representing fluctuations within the week) | Commercial |

| *Tool & Organisation* | *Type* | *Energy Sectors* | *Geographical Area* | *Timefr ame* | *Time Step* | *Availability* |
|---|---|---|---|---|---|---|
| **ProdRisk**<br>Stiftelsen for Industriell og Teknisk Forskning (SINTEF) | 1, 6, 7 | Electricity | National, state, regional | Multiple years | Hourly | Commercial |
| **RETScreen**<br>RETScreen International | 2, 5, 7 | Electricity, heat | User-defined | Max 50 years | Monthly | Free to download |
| **MiniCAM**<br>Pacific Northwest National Laboratory | 1, 2, 3 partial, 4, 5 | Electricity, partly heat, transport | Global and regional | 50+ years | 15 years | Free to download once contacted |
| **SIVAEL**<br>Energinet.dk | - | Electricity, partly heat | National, state, regional | 1 year | Hourly | Free to download |

The energy tools listed above have been used for various purposes. Scenarios for 100% renewable energy or the integration of a large proportion of renewables have been calculated for different countries or regions.

For example, 100% renewable scenarios were described by Conolly et al. (2010b) for Ireland and by Lund & Mathiesen (2009) for Denmark. Mitchell et al. (2005) simulated a renewable energy system for the western Sydney area, comparing the grid connected mode and the stand-alone mode. Ostergard et al. (2010) modelled a renewable energy scenario for the municipality of Aalborg

Other studies looked at scenarios that are not based on 100% renewable energy sources. Göransson & Jonsson (2009) examined the effects of large-scale wind power integration in a power generation system with base load plants, using western Denmark as a case study. Albadi et al. (2009) evaluated the techno-economic aspects of a possible wind farm for a new city in Oman, concentrating on economic viability. The limits of large-scale integration of PV into a traditional electric power

system was examined by Denholm & Margolis (2007a), using data from Texas. Ai et al. (2003) assessed the optimum configuration of a PV – wind system for installation at Waglan island of Hong Kong.

Methods for mitigating the problems of fluctuating energy supply were for example considered by Nyamdash et al. (2010). They investigated the option of balancing wind energy with a large scale energy storage. Denholm & Margolis (2007b) considered methods to mitigate the limits of unusable PV in a system with inflexible baseload generators.

Cormio et al. (2003) showed a model for the Apulia region in Southern Italy, where environmental impacts and economic costs are reduced in a system of industrial combined heat and power systems and different renewable energy sources. A sustainable development of the Swiss energy sector was assessed by Ballistreri et al. (2010).

An evaluation of the effect of different promotion schemes on the technology mix and achievable $CO_2$ reductions in the building, electricity and transport sector till 2020 was performed by Stadler et al. (2007). Suganthi & Williams (2000) analysed critical parameters for the utilisation of renewable energy sources in India to help introducing appropriate promoting policies for renewables. Another tool, useful to decision makers for identifying desired policies is described by Cai et al. (2009).

### 1.2.2 Load profiles

For modelling energy systems with fluctuating energy sources, a very important aspect is the load profiles of the RES as well as of the energy demand.

One possibility to get load profile data is to take real data from demand measurements or production data from already existing projects. As it is often quite difficult to get actual data, it is also possible to generate synthetic load profiles.

In Austria, synthetic standardised load profiles for the electricity demand are provided by APCS Power Clearing Settlement AG. These profiles are used for the determination of the balance energy demand of end users with less than 100 MWh annual electricity demand and are scaled to an annual electricity use of 1000 kWh. Profiles for different user categories like for example residential, different categories of business or agriculture are provided (Kalab 2006).

The load profiles for “household” and “business” can be seen in the figures below.

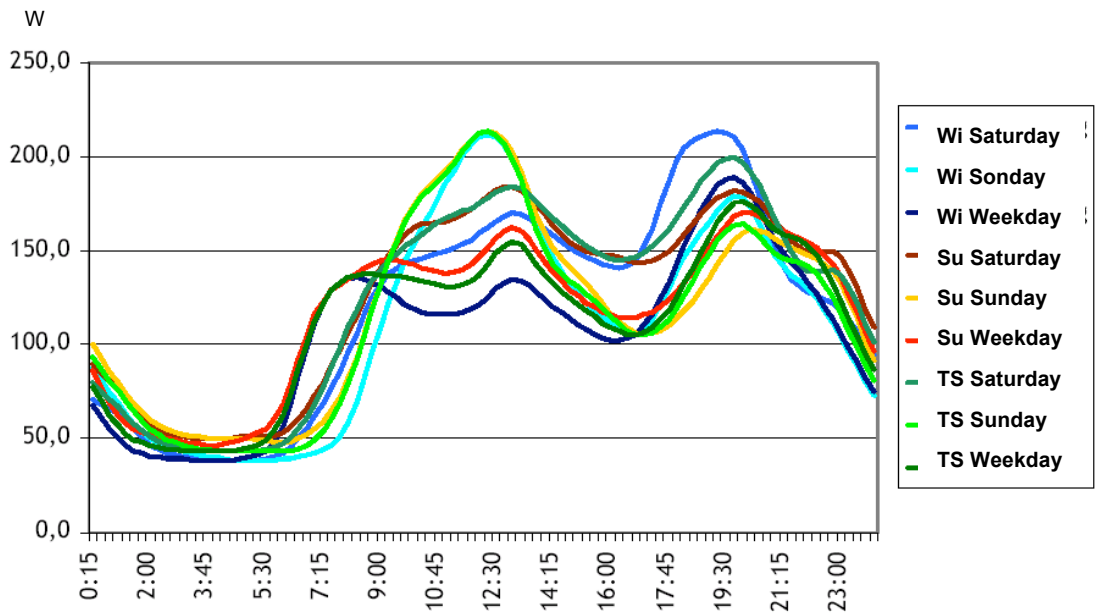



**Figure 1** Load profile provided by APCS Power Clearing for the category “household” (from Kalab 2006) (Wi=winter, Su=summer, TS=transitional season)

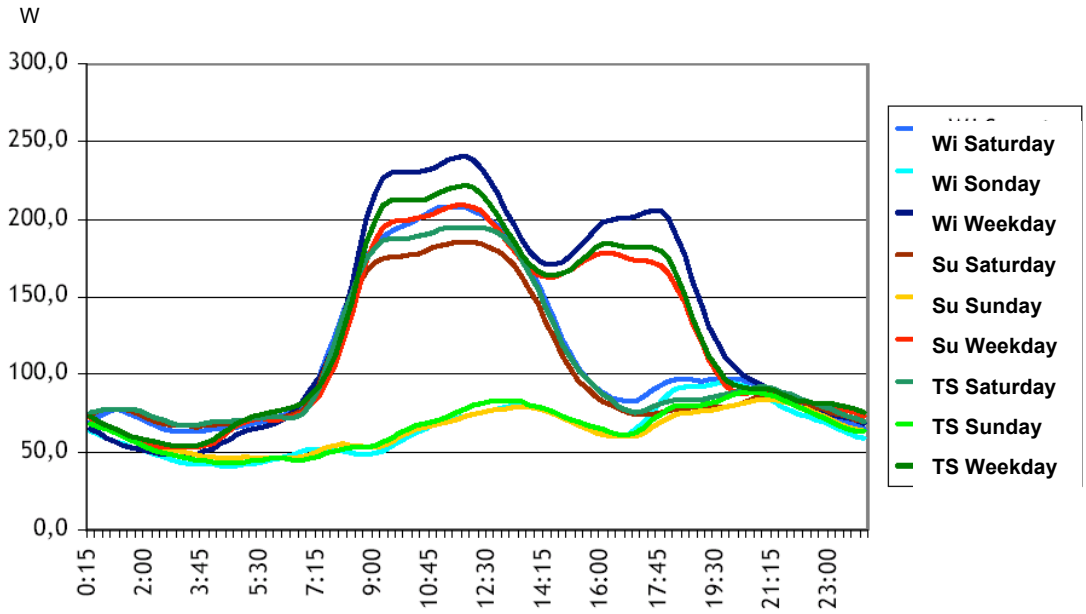



**Figure 2** Load profile provided by APCS Power Clearing for the category "household" (from Kalab 2006) (Wi=winter, Su=summer, TS=transitional season)

For generating load profiles for wind energy and PV important input values are meteorological data.

Graham & Hollands (1990) developed a stochastic procedure for generating sets of hourly solar irradiation values. With this method, data can be generated with only inputting the 12 means of daily irradiation. This method has been implemented in the HOMER model. A comparison of measured and synthetic solar irradiation data can be seen in the figure below.

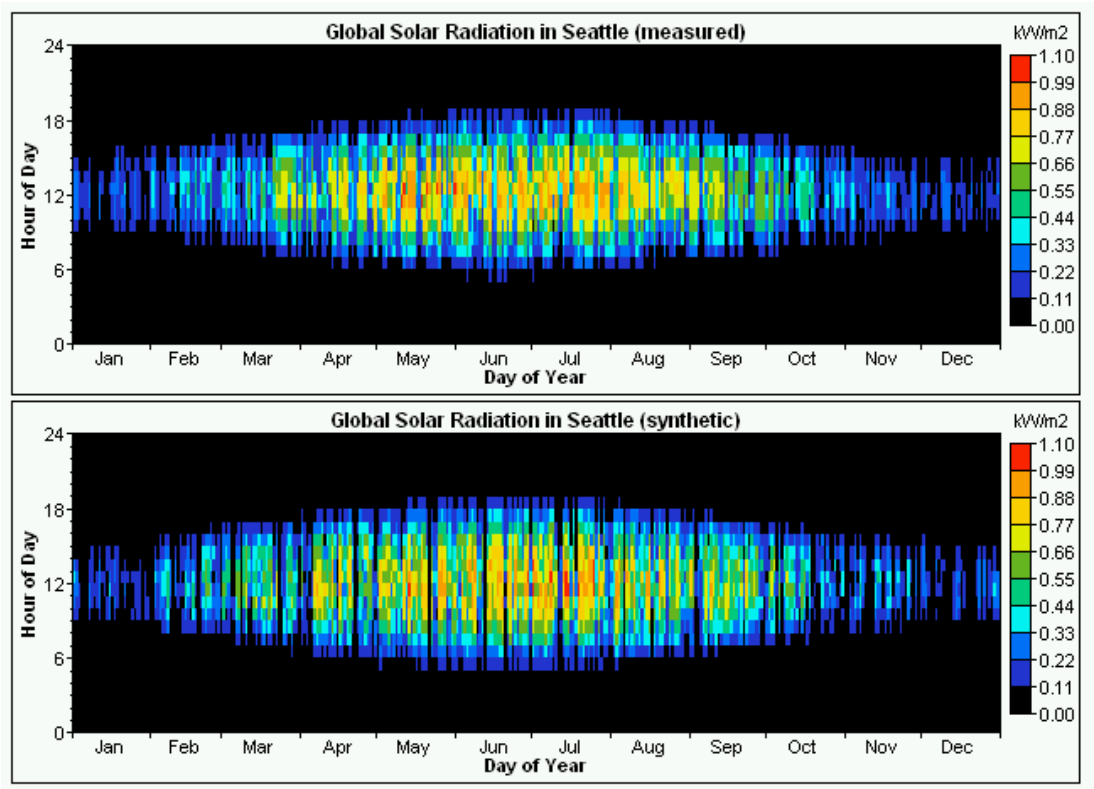



**Figure 3** Comparison of measured and synthetic solar irradiation data for Seattle (from Lambert 2010a)

HOMER can also be used for generating hourly wind speed data. A five-step algorithm, which needs the inputs of monthly average wind speed, Weibull factor, 1-hour autocorrelation factor, diurnal pattern strength and the hour of peak wind speed is used by the programme. The Weibull factor reflects the breadth of the distribution of wind speeds over the year. The 1-hour autocorrelation factor states how strongly the wind speed in one time step tends to depend on the wind speed in the previous time step. The diurnal pattern strength shows how strongly the wind speed depends on the time of day and the hour of peak wind speed indicates the hour of day that tends to be windiest on average (Lambert 2010b).

A comparison of measured and synthetic wind speed data created with HOMER can be seen in Figure 4.

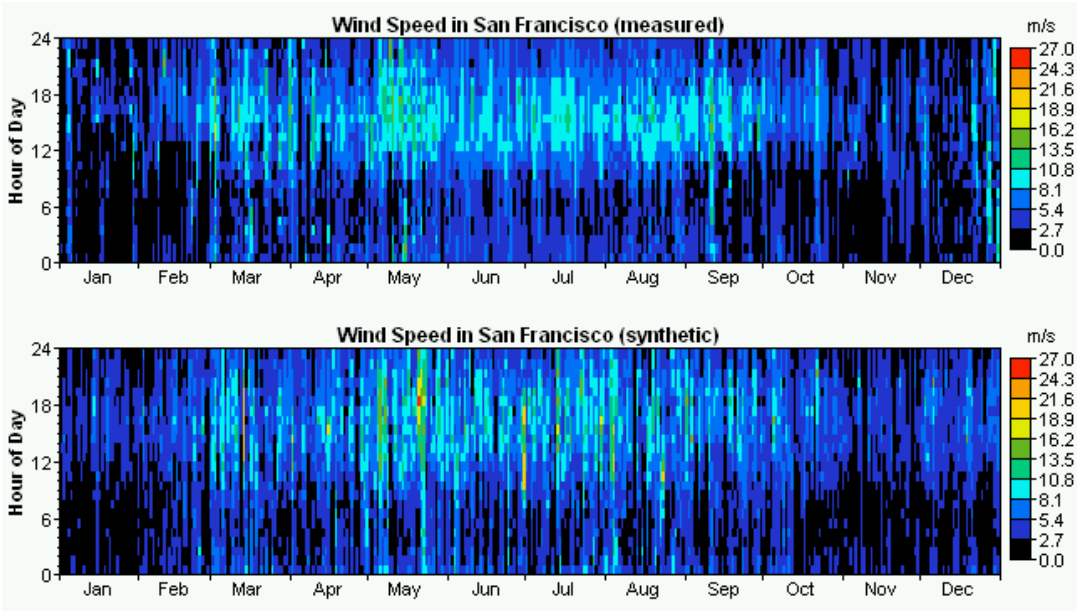



**Figure 4** Comparison of measured and synthetic wind speed data for San Fancisco (from Lambert 2010b)

A comprehensive database of interpolated meteorological data for any location of the world is available with the programme “METEONORM”. This programme also calculates hourly values of all parameters, however it is a commercial programme.

For generating load profiles for heat, one option is the commercial programme TRNSYS. An option of a freeware is IDA Raum, which only calculates load profiles for single days.

## *1.3 Renewable Energy Sources for Electricity Production*

In the following chapter, a short introduction into technologies for the production of electricity from renewable sources (RES-E) is given. Only the technologies that are relevant to for this work are covered.

### 1.3.1 Photovoltaic (PV)

The electricity yield from photovoltaic modules depends on various factors. First of all, the different technologies have different energy conversion efficiencies, which represents the ratio between the produced electrical power and the amount of

incident solar energy per second. There are two main different technologies on the market. The traditional modules are made with crystalline silicon (mono-crystalline or polycrystalline). The mono-crystalline modules are the most efficient and most expensive modules. Another technology that is growing quite rapidly on the market and accounts for 19% to 15% of global PV module sales is the thin film technology. Other emerging technologies are advanced thin films and organic cells. Concentrator technologies are currently being tested in pilot applications, where solar radiation is focused onto a small high-efficiency cell by optical concentrators. (IEA 2010)

An overview of efficiencies of the different systems is given in Figure 5.

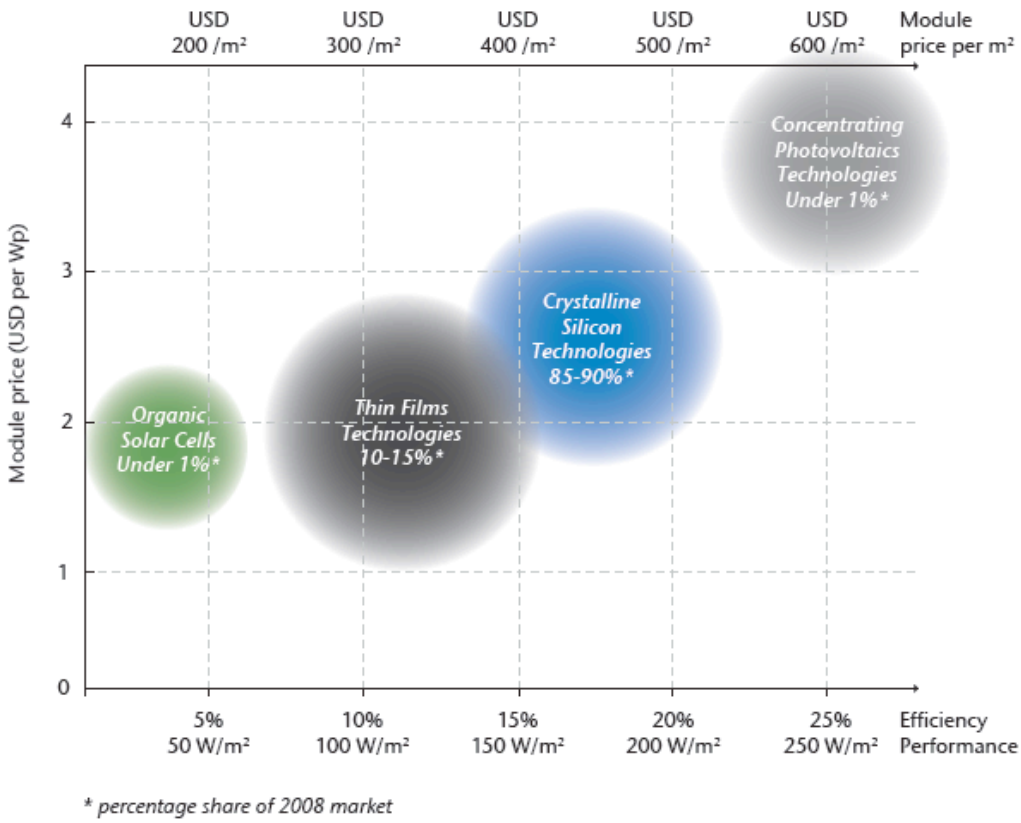



**Figure 5** Efficiencies and module price of different PV technologies (from IEA 2010)

With continuing falling prices of PV, the technology is expected to achieve grid parity by 2020 in many regions (IEA 2010).

In addition to the technology, the performance of PV modules depends on various other factors. Temperature and solar irradiance play a role in yields. The temperature can be influenced by factors like the mounting position or the air circulation behind the modules (differs with free standing or building integrated options.) Also the inclination angle (angle from the horizontal plane) and orientation angle (angle relative to the point of the compass) is important for non-tracking options. In addition to this, the percentage of diffuse radiation and annual radiation of the installation site influences the full load hours (JRC).

The most important parameters for assessing a PV system are energy yield, efficiency and performance ratio. The specific energy yield is the yield of a given time interval referring to the nominal power of the PV module in kWh per kWp. (Mau & Jahn 2004)

Values for minimal and maximal possible yields of PV modules in Austria can be seen in Table 3.

**Table 3** Possible yields from PV modules in Austria (from Pol & Shoshtari 2010, secondary sources)

| *Underlying values* | *Yield* | *Source* |
|---|---|---|
| **Minimal electrical yields of PV modules (with a performance ratio of 0.5)** | 650 kWh/kWp.a | Mau & Jahn 2004 |
| **Maximal electrical yields of PV modules (with a performance ratio of 0.8)** | 1000 kWh/kWp.a | Mau & Jahn 2004, in accordance with SUN power City |

### 1.3.2 Wind Energy

The technology of wind turbines has developed rapidly over the last 25 years. Compared to a capacity of 0.5 MW and a rotor diameter of 15 m in 1985, wind energy converters have reached dimensions of 7 MW with rotor diameters of 126 m in 2009. With a continuation of this development, bigger wind turbines with even higher capacities can be expected in the next years.

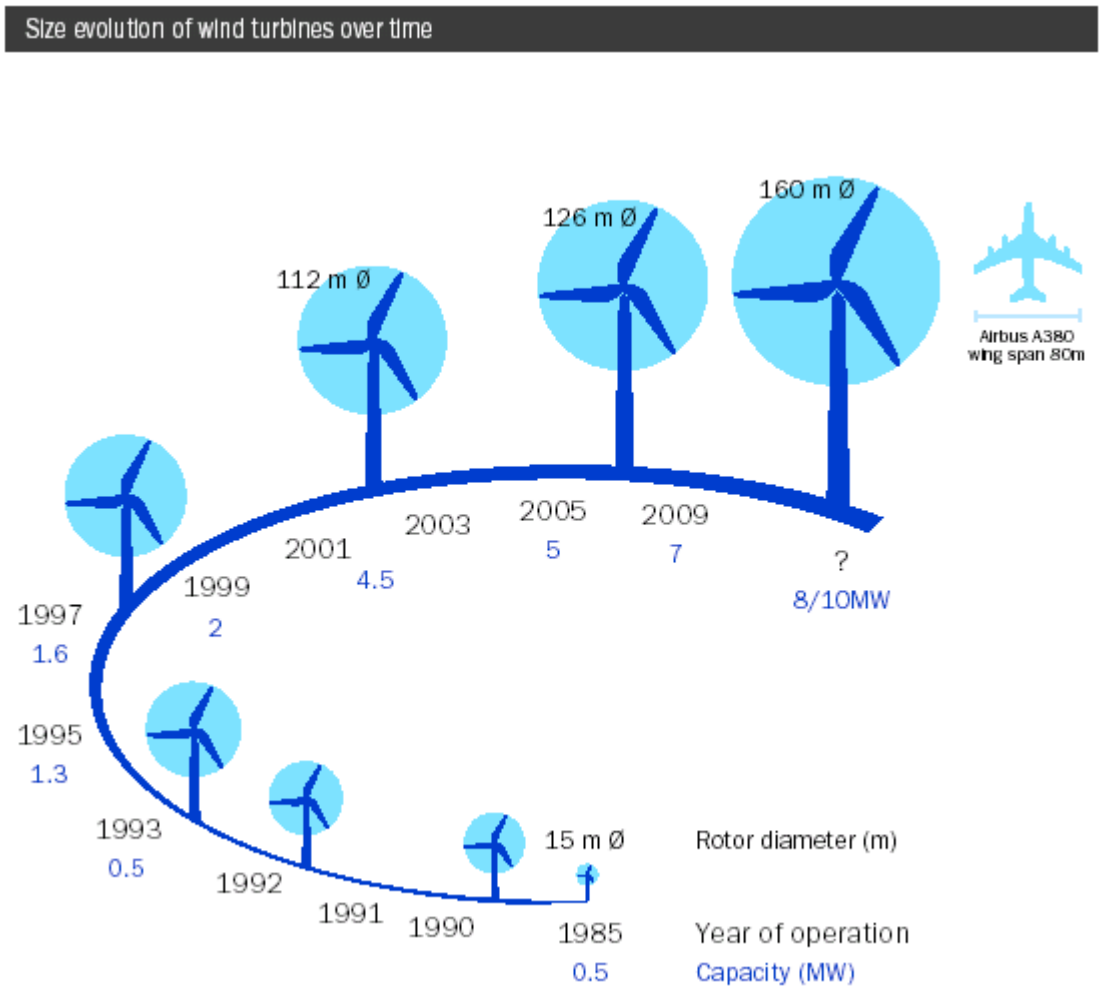



**Figure 6** Size evolution of wind turbines over time (from EWA 2010)

The average grid connected turbine has a rated capacity of 1.6 MW (IEA 2009).

There are many factors to be considered for the construction of an onshore wind park. First of all there are legal restrictions such as regulations regarding the minimal distance to settlements, distance between wind turbines, restricted areas like nature reserves. Other factors like the connection to the grid or the availability of roads for the delivery of the turbines have to be considered. Last but not least, the wind conditions and topography are the most important factors in the success of wind parks.

The average costs of onshore wind energy projects can be seen in Table 4.

**Table 4** Costs of Onshore Wind Energy (from IEA 2009)

| *Type of Cost* | *Cost of Onshore Wind Projects* |
|---|---|
| **Investment Costs** | €0.98 - €1.9 million/MW) |
| **Operation and maintenance costs** | € 12 - € 32/MWh |
| **Lifecycle Cost of Energy** | € 50 - € 90/MWh |

The best wind conditions in Austria are found in the East of Lower Austria and in the North of Burgenland. As a result of the interaction of two large-scale wind systems, the wind conditions in this area resemble the wind conditions on the North Sea Coast (IG Windkraft 2009).

Yields of different existing wind turbines in Vienna are shown in Table 5.

**Table 5** Yields of existing wind turbines in Vienna (from Pol & Shoshtari 2010)

| *Wind turbine* | *Vestas V44* | *Vestas V47* | *NEC Micon 750* | *Vestas V52* | *Vestas V44* | *Vestas V44* | *Bonus 33* |
|---|---|---|---|---|---|---|---|
| **Power** | 600 kW | 660 kW | 750 kW | 850 kW | 600 kW | 600 kW | 300 kW |
| **Geographical location in Vienna** | North-East | North-East | North-East | North-East | South | South | South |
| **Yearly yields [kWh/a]** | 1521 | 1753 | 1810 | 1684 | 1521 | 1521 | 855 |
| **Rotor area [$m^2$]** | 1100 | 1285 | 1416 | 2124 | 858 | 868 | 196 |
| **Specific yields [$kWh/m^2.a$]** | 723 | 741 | 782 | 793 | 564 | 571 | 229 |

The technology of small scale wind turbines (< 10 kW) is not as widely used as large scale wind power and therefore there are less experienced data available.

### 1.3.3 Geothermal Electricity Production

Another renewable energy source that could be considered for electricity production is geothermal energy. With an Organic Rankine Cycle (ORC) or Kalina cycle it is possible to exploit temperatures between 100 and 180ºC for electricity production. In Austria, there are two geothermal power plants, one in Altheim in Upper Austria and the other one in Blumau, Styria. In both these places the water is just above 100ºC.

# 2 Case Study

In this chapter, an introduction into the area under consideration is given. The aspects of the project of NACH ASPERN (Pol & Shoshtari 2010) that are relevant to this work, are described and finally the EnergyPLAN model is introduced.

## *2.1 Aspern – the new Lakeside City*

In Vienna, Europe's biggest urban development project is going to be realised on a surface of 240 hectares in the next two decades. In the area of the former airfield of Aspern in the 22nd district, the city of Vienna is planning to build a new "Lake City" for approximately 20,000 residents and 25,000 employees. The concept is to build a mixture of green areas, offices, flats, companies and scientific and educational institutions. With the upcoming of the Central- and Eastern European countries, the location in the eastern periphery of the city, is of strategic importance. A priority in the planning process for this city area has been the sustainability and a careful use of ressources (Aspern Airfield Masterplan).

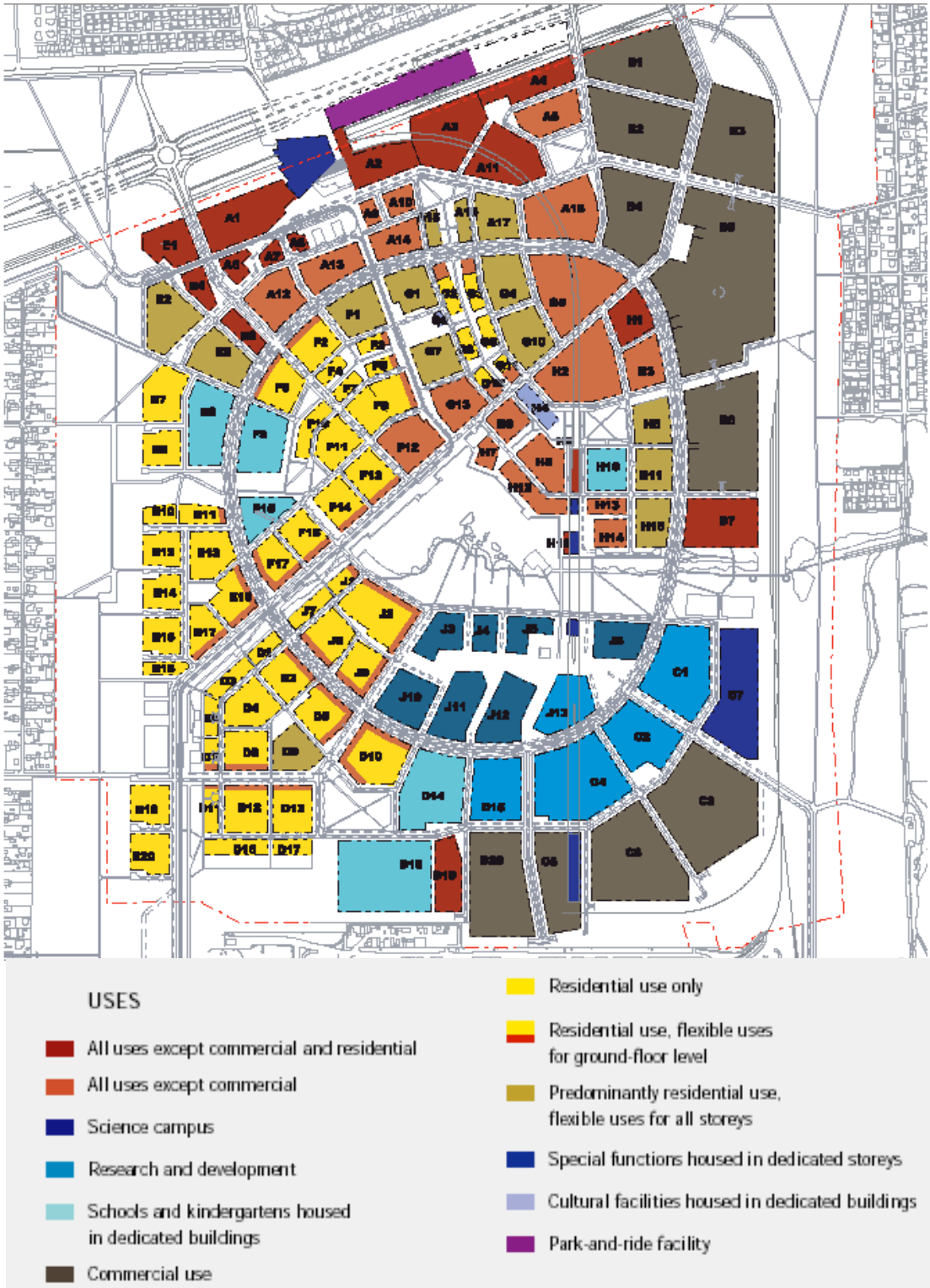



**Figure 7** Planned building structures and proposed use of Lake City Aspern (from Aspern Airfield Master Plan)

### 2.1.1 Project NACH ASPERN

Part of the planning process was the development of a master plan. Based on this master plan, an energy concept was developed by the Austrian Institute of Technology (Pol & Shoshtari 2010). Annual data for energy demand (heating, cooling, electricity) and the potential for possible renewable energy supply for were analysed. For the energy demand, three different scenarios were defined. The conventional scenario reflects a situation with building standards according to building laws of Austria (Vienna) and air ventilation only through the windows. The values for the average electricity consumption are taken from Voss et al. (2006). For a minimum and target scenario, more efficient building technologies and a lower electricity consumption were assumed.

With optimised building technology ¾ of the electricity used is accounted for by household devices. As the increased efficiency of appliances is compensated by the increased number of devices used, the assumed value for the target scenario is a very ambitious goal. Also for the office sector, the assumption for the target scenario is very ambitious, as the assumed value for the worst case scenario has been validated on the basis of various sources. For universities and other sectors, the same values are taken as for the office buildings, as there is no specific information on the use as yet. (Pol & Shoshtari 2010).

The assumed electricity use in $kWh/m^2$ gross-floor-area for the different scenarios can be seen in Table 6.

**Table 6** Assumptions for electricity demand in kWh/m$^2$ for different using categories and different scenarios. Values from Pol & Shoshtari 2010.

| | *Residential Buildings* | *Office Blocks* | | *Shops* |
|---|---|---|---|---|
| | *Electricity Demand* | *Electricity Demand (including cooling)* | *Electricity Demand (without cooling)* | *Electricity Demand* |
| **Target Scenario** | 25 | 31 | 28 | 31 |
| **Minimal Scenario** | 40 | 58 | 51 | 58 |
| **Conventional Scenario** | 65 | 90 | 80 | 90 |

For the office blocks, the option of district cooling was found to be viable, which reduces the electricity demand. As it is not yet clear, for which types of business the category “shops” will be used, it was difficult to estimate the cooling demand for this category. Therefore a worst case scenario was assumed. As the shops are planned in residential blocks and no cooling is planned for the residential use, district cooling was not considered viable for shops. The cooling demand was included in the electricity demand.

Figure 8 shows the calculated electricity demand with the option of district cooling for the different blocks of Lake City Aspern. The blue areas indicate the use of district cooling, which results in a lower electricity demand compared to a scenario without district cooling.

For the blocks that are designated to the use of industry, the electricity demand has not yet been calculated, as it highly depends on the type of use. In Figure 8 these blocks therefore are shown with an electricity demand of zero. For these blocks only a gas demand has been calculated.

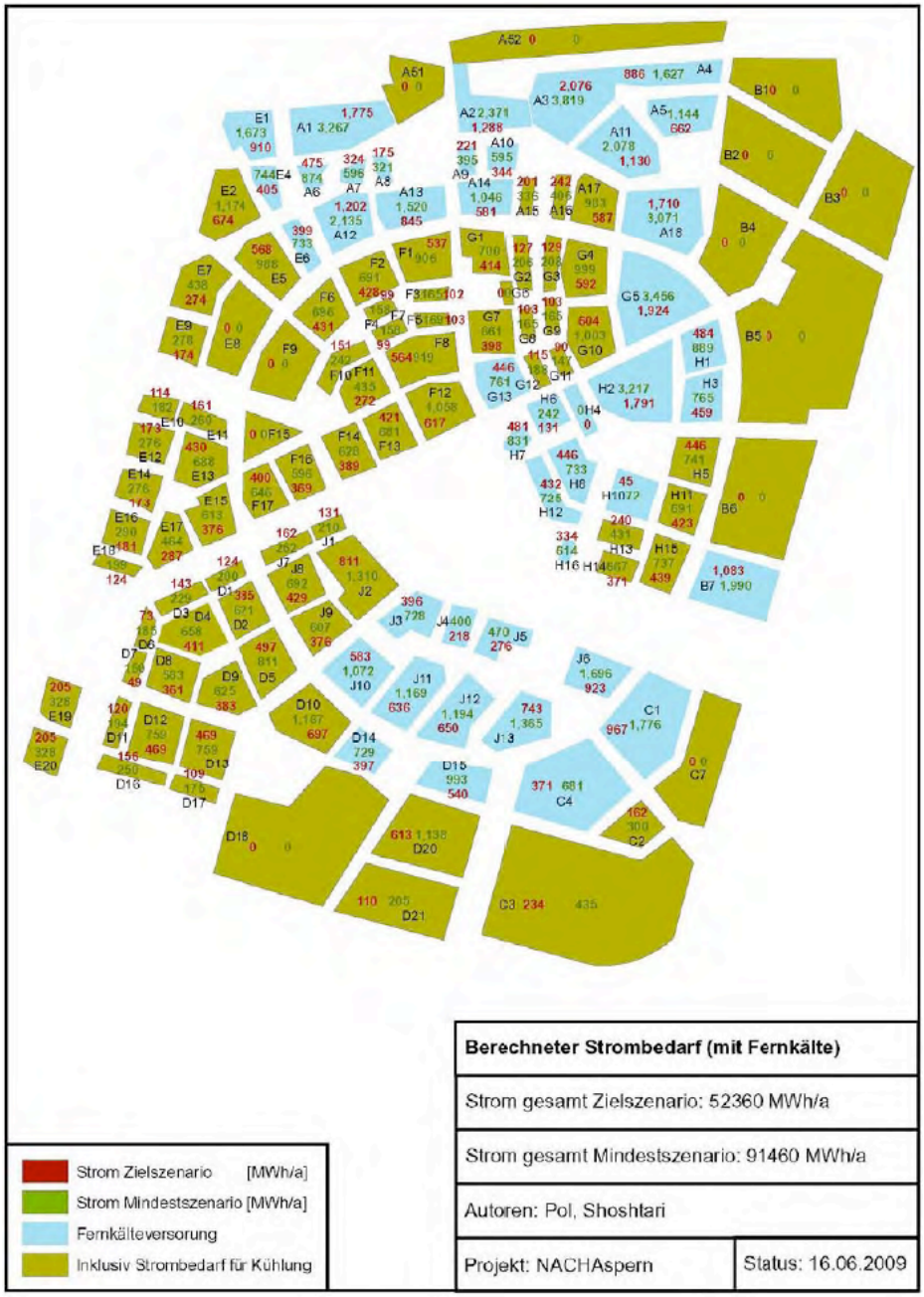



**Figure 8** Electricity demand for target and minimal scenario with the option of distirct cooling (from Pol & Shoshtari 2010).

The electricity demand of the different sectors can be seen in Figure 9. The sectors that are framed in the diagramm are the ones that are planned to be finished by 2014.

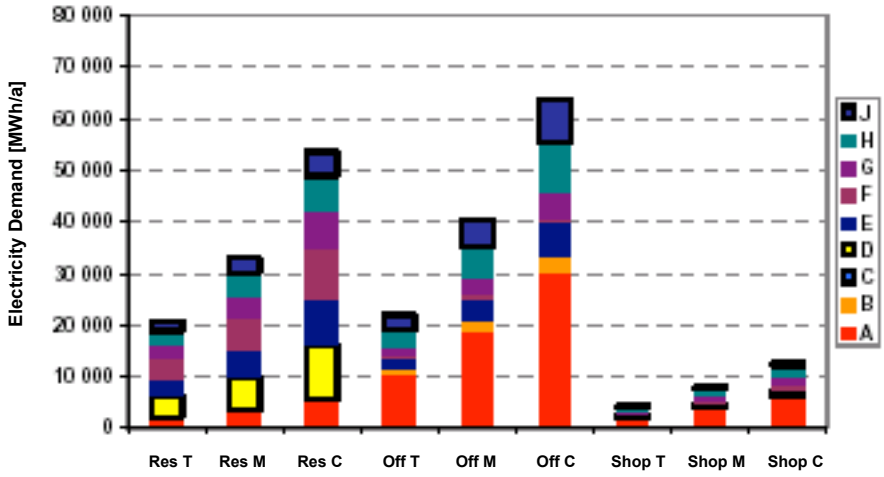



**Figure 9** Electricity demand for target (T), minimal (M) and conventional (C) scenario for residential (Res), office (Off) and shops, divided into the different sectors of the master plan (from Pol & Shoshtari 2010)

For the installation of PV or solar thermal collectors, the usable roof area is assumed to be 40% of the complete roof area. For the remaining 60% of the roof area, terraces, green roof areas, antennas and lift shafts are planned. The option of installing PV on this roof area was found to be favourable to installing solar thermal collectors. The primary energy (PE) demand for a scenario with PV is lower than for a scenario with solar thermal collectors, as the district heating of Vienna uses less PE than the electricity mix of the European Union.

A detailed analysis of the possible implementation of PV in one sector of the Lake City Aspern has been carried out by the project SUN power City (SUN power City 2010). As the project SUN power City assumes a higher efficiency of PV modules and also includes parts of the front area of buildings, the results of this study show a better energy balance than presented in the project NACH ASPERN. The very optimistic scenarios in SUN power City show a positive annual electricity balance for the J sector. (Pol & Shoshtari 2010)

With a pessimistic and optimistic assumption for the performance ratio of PV, the study arrives at an annual electricity production from PV of 13,500 MWh/a or 20,770 MWh/a respectively. This corresponds to an installed power of about 20 MWp.

For the use of a wind energy converter (WEC), a potential area was identified close to the Lake City of Aspern.

**Figure 10** Possible area for WEC, in the close vicinity of Lake City of Aspern (from Pol & Shoshtari 2010)

An installation of either 6x1 MW or 4x1.5 MW wind energy converters is regarded as realistic. With referring to values form already existing wind turbines, a possible electricity yield of 9,000 MWh/a or 12,000 MWh/a respectively can be expected for these two options.

As other options of RES-E production, biogas production from black water and the use of urban small scale wind turbines were discussed. It is recommended that both these technologies should be implemented in tryal projects, but not area-wide.

In addition to this, the geothermal potential of the area that was considered for district heating, could also be used for electricity production with ORC or Kalina process.

## 2.2 Description of the EnergyPLAN Model

The EnergyPLAN model has been developed and continuously expanded at Aalborg University, Denmark, since 1999. It is a deterministic model for technical and economic analysis of national or regional energy systems, including electricity as well as heat, transport and industrial sector. EnergyPLAN optimises the operation of a given system and not the economic feasibility. An economic feasibility analyses can be done by comparing different systems. Input parameters are demands, renewable energy sources, energy station capacities, costs and different regulation strategies for import/export and excess electricity production. The outputs of the models are energy balances with annual production, fuel consumption, import and export of electricity and total costs including income from the exchange of electricity (Connolly et al. 2009). As the EnergyPLAN model uses houly data, the influence of fluctuating renewable energy sources and the weekly and seasonal differences in energy demand is taken into account. The model analyses one year at a time.

The advantage of Energy PLAN is the user-friendly design as a series of tab sheets. In addition to this, the model is performing very fast calculations, as it is based on analytical programming rather than iterations, dynamic programming or advanced mathematical tools (Aalborg University a). The load profiles have to be entered as a text-file with 8784 data points. Usually the data points should be between 0 and 1, representing 0-100% of production or demand. However, distributions with values bigger than 1 are indexed by the program (Conolly 2010). This makes the generation of needed input files easier for the user.

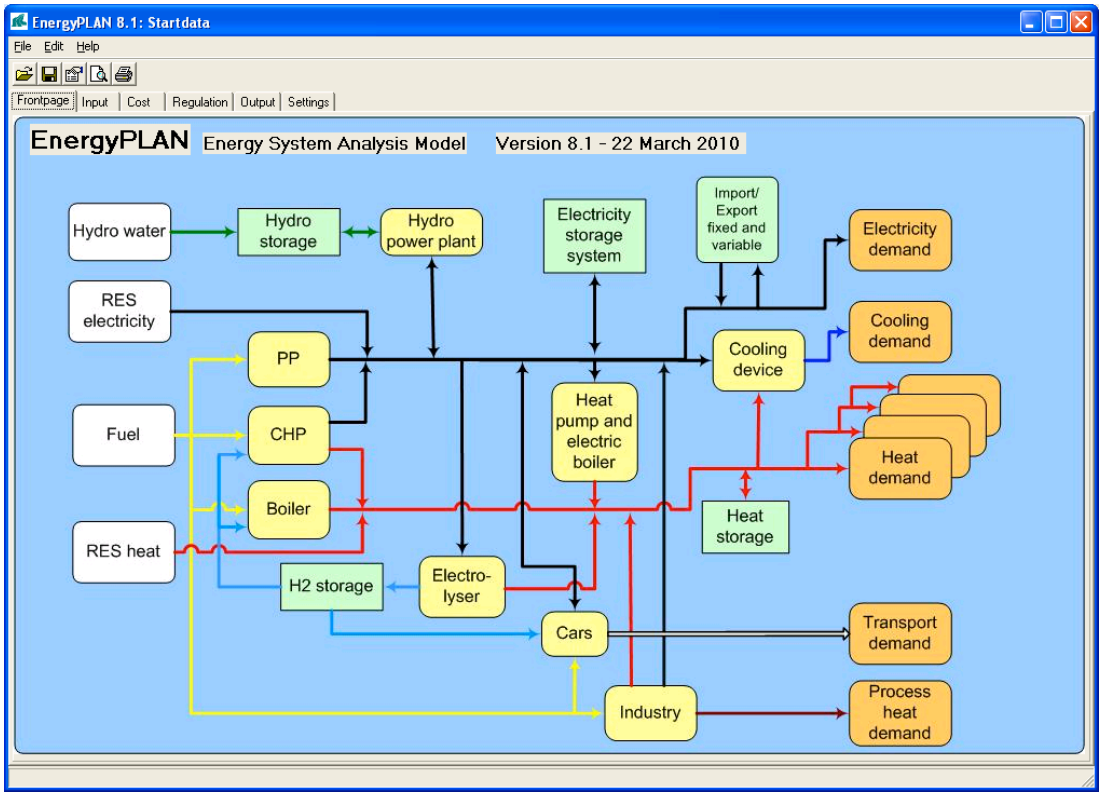



**Figure 11** Schematic overview of the EnergyPLAN model.

# 3 Methods

The yearly demand and supply data were taken from the energy concept of NACH ASPERN. The electricity demand refers to households, offices and shops, based on the assumption of district cooling. The load profiles for the electricity demand were taken from APCS Power Clearing Settlement (2010). The load profiles for the electricity production with PV and Wind energy was generated with the Homer programme. The scenarios were based on the scenarios used in NACH ASPERN project. Additionally, the introduction of a stable geothermal electricity production was assumed.

## *3.1 Definition of scenarios*

An overview of the abbreviations and the underlying assumptions is given in the following table.

**Table 7** Abbreviations and underlying assumptions for scenarios used

| *Abbreviation* | *Explanation* | *Assumptions* |
|---|---|---|
| **T** | Target demand scenario | Annual electricity demand: 52.36 GWh |
| **M** | Minimal demand scenario | Annual electricity demand: 91.460 GWh |
| **C** | Conventional demand scenario | Annual electricity demand: 144.66 GWh |
| **PVo** | PV production optimal scenario | Annual production: 20.7 GWh |
| **PVp** | PV production pessimistic scenario | Annual production: 13.5 GWh |
| **W+** | Implementation of wind power | Annual production: 12 GWh |
| **W-** | No implementation of wind power | No annual production |
| **FlexX%** | Introduction of flexible demand | X percent of total demand assumed flexible. Assumed values are 10%, 20%, 30% and 40%. |
| **GT** | 2 MW Geothermal Electricity Production | Annual electricity production: 17.57 GWh |

## *3.2 Electricity Demand*

### 3.2.1 Annual Electricity Demand

The three scenarios for the yearly electricity demand are based on the assumption of the implementation of district cooling. The assumed values can be seen in the table below.

**Table 8** Electricity demand for the Lake City Aspern for different scenarios (Pol & Shoshtari 2010)

| *Scenario* | *Electricity demand in GWh/a (with district cooling)* |
|---|---|
| **Target** | 52.36 |
| **Minimal** | 91.46 |
| **Worst Case** | 144.66 |

### 3.2.2 Load profile for Electricity Demand

Load profiles for the electricity demand were taken from APCS Power Clearing (2010). The load profiles are provided in time steps of 15 minutes. Therefore the average value for each hour was taken to generate profiles with time steps of one hour.

For the different user categories of the energy concept of NACH ASPERN, different profile categories were taken. For the categories residential the APCS category “household” was taken, for the categories office and university the APCS cateogy “business weekdays 8-18” were taken. For the category shops, the profie “shop/hairdresser” was taken.

For the input into the EnergyPLAN Model, one single load profile is needed. Therefore the load profiles of the different categories had to be combined to one load profile. The values of the different categories were multiplied with the share of the total annual electricity demand. Finally the relative values of the different categories were added together to one load profile.

The APCS profiles start on the 1st January at midnight. As the profiles that were generated with HOMER start on the 1st January at 1:00 am, the first hourly value of the APCS profiles was put at the end of the data series. The values of 28th Febuary were duplicated, as the EnergyPLAN programme calculates with a year of 366 days.

## *3.3 Electricity Production*

### 3.3.1 PV – Annual Production

The assumption for the annual production of PV was based on the optimistic and pessimistic scenarios from NACH ASPERN. The needed input parameter in the EnergyPLAN model is the installed capacity. The model then calculates the annual production. This annual production can be corrected with a correction factor.

With this method, an optimistic annual production of 20.71 GWh and a pessimistic annual production of 13.51 GWh were assumed.

### 3.3.2 PV – Generation Profiles

The hourly values for solar radiation were generated with the HOMER programme. The calculation was based on climate data from NASA (2010) for the location of Aspern (latitude 48º13', longitude 16º30').

The hourly values for the electricity production of electricity with PV was then also generated with HOMER, assuming a default mounting slope of 48.2167 degrees (=latitude at the location) and an orientation towards south.

A series of hourly data were generated for a period of one year of 365 days. As the EnergyPLAN programme uses hourly loads with 366 days, the values of 28$^{th}$ of February were copied and used twice.

### 3.3.3 Wind – Annual Production

The electricity production with wind energy converters is considered optional. Based on the findings Pol & Shoshtari (2010), an installed capacity of 4x1.5 MW and an annual production of 12 GWh were assumed.

Even though these assumed wind turbines are not within the borders of the energy system, the produced electricity was treated as if belinging to the energy system of Aspern.

### 3.3.4 Wind – Generation Profiles

The hourly wind data were generated with HOMER. The average monthly wind speed data were taken from the years 2005-2008 from the weather station Unterlaa in Vienna. (ZMAG 2010)

A Weibull factor of 1.5 was assumed, the 1-hour autocorrelation factor was set to 0.9, as the topography in the area is relatively uniform. The diurnal pattern strength was assumed as 0.2 (typical range 0.0-0.4) and the hour of peak windspeed was set to 15 (typical range 14-16).

The hourly electricity generation data were then also generated with HOMER, using the generated wind profile. The electricity production with 4 Vestats V82 wind turbines were simulated, as this type of wind turbine is offered in the HOMER programme and with 1.65 MWp has a similar capacity of the ones assumed in this project.

Same as described above for the PV generation profile, data of the 28$^{th}$ of February were duplicated.

### 3.3.5 Geothermal Electricity Production

For the scenarios with geothermal electricity production a capacity of 2 MW was assumed, which corresponds to an annual electricity production of 17.57 GWh. The load profile was assumed to be constant.

## *3.4 Sensitivity Analysis (SA)*

In addition to the annual demand and production values, the energy scenarios calculated have 8784 input values for each load profile. For a course graining of the SA, only the five input parameters, annual demand, flexible demand, annual PV, wind energy production and geothermal electricity production were chosen as these are the five input parameters that can be influenced by planners.

Two reference scenarios were chosen, one ambitious scenario with high values of RES-E production and a low value for demand. For the basic reference scenario, values with less production of RES-E and a higher demand was assumed. Wind and geothermal power were treated optional, which results in a total of 6 reference scenarios. A summary of the input values for the different scenarios is given in the table below.

**Table 9** Reference Scenarios for SA

| *Scenario* | *Annual Demand [GWh]* | *Flexible Demand (=Part of Annual Demand) [GWh]* | *Produ-ction of PV [GWh]* | *Production of Wind Energy [GWh]* | *Geothermal Electricity Production [GWh]* |
|---|---|---|---|---|---|
| **Reference Scenario** | 70 | 7 | 15 | 10 (optional) | 13 (optional) |
| **Target Reference Scenario** | 50 | 5 | 21 | 12 (optional) | 18 (optional) |

The change of the output parameters of self sustainability and utilisation rate relative to the respective input parameter were calculated with the following function.

$$\frac{\partial g}{\partial x}\left(x^{\circ}\right) \approx \frac{\left(g\left(x^{\circ}+h\right)-\left(g\left(x^{\circ}\right)\right)\right)}{h}$$

$g$ = function of output (self sustainability or utilisation rate)

$x$ = variable input parameter (annual demand, flexible demand, PV, wind power, geothermal power)

$x^{\circ}$ = value of input parameter in reference scenario

$h$ = change of input parameter

# 4 Results

In the first section of this chapter the results of the main scenarios for the Lake City Aspern that were based on the scenarios of the project NACH ASPERN (Pol & Shoshtari 2010) are given. The self sustainability and utilisation rate is shown for scenarios with different demand and different PV output and optional wind power. The two demand scenarios with lower demand are shown with the introduction of flexible demand. After this, the same parameters are shown for the same scenarios, only with the introduction of a stable geothermal electricity production. In the last section, the results of the sensitivity analysis is presented for the input parameters of annual demand, flexible demand, RES-E production with PV, wind power and geothermal power.

The utilisation rate of RES-E described in the following sections always refers to all RES-E produced in Aspern Lake City in the respective scenarios. The self sustainability described refers to the share of demand that can be supplied directly by RES-E at the time of use.

Detailed results for all the scenarios with the calculated amounts for import and export of electricity from the energy system of Lake City Aspern can be seen in the Annex.

## *4.1 Main Results*

With minimised demand (51 GWh/a) and maximum proposed electricity production from wind (12 GWh/a) and PV (21 GWh/a), 25 GWh/a can be supplied directly by the production of RES-E for the Lake City Aspern. This corresponds to a self sustainability of 47.7% and a direct utilisation rate of 76.2% of produced RES-E.

In the worst case scenario with a maximum electricity demand (145 GWh/a) and minimum RES-E production (14 GWh/a), only 9.3% self sustainability can be reached, but 99.9% of the RES-E that is produced in the Lake City can be used.

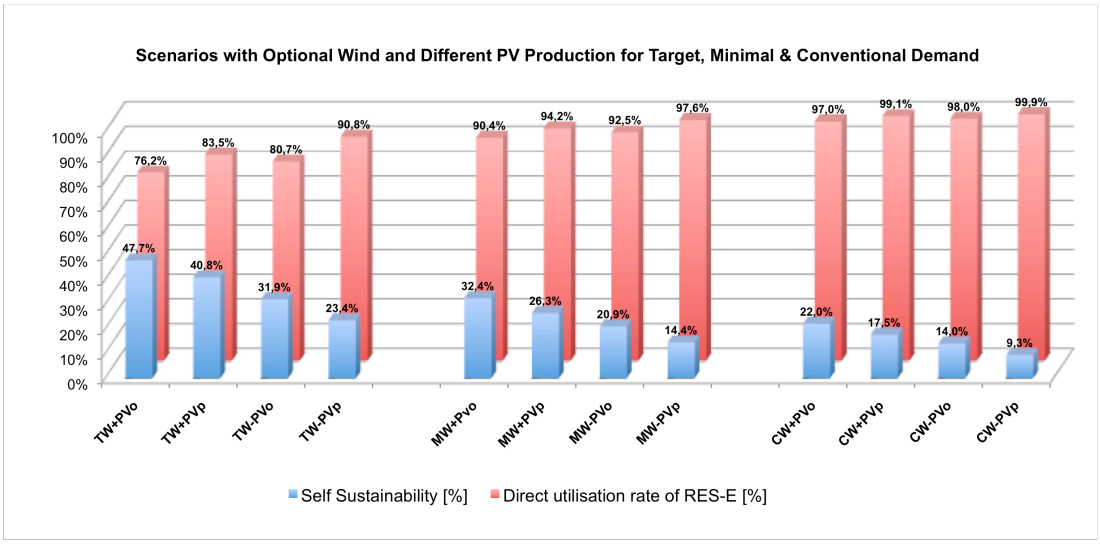



**Figure 12** Self sustainability and utilisation rate of RES-E. Target, minimal and conventional demand scenarios with different PV output and optional wind power. (Demand: T: 51 GWh/a, M: 91 GWh/a, C: 145 GWh/a; Wind: W+: 12 GWh/a, W-: no wind power; PVo: 21 GWh/a, PVp: 14 GWh/a)

It can be seen in all three demand scenarios that the self sustainability increases with increased production of RES-E. The utilisation rate, however, does not necessarily decrease with increased RES-E production. It can be observed in all three demand scenarios that the scenarios with wind power and pessimistic PV production (W+PVp) has higher utilisation rates that the scenarios without wind power and optimistic PV production (W-PVo) even though the total RES-E production is higher in W+PVp than in W-PVo.

The following graph shows that in the target demand scenario with the introduction of 30% flexible demand, the utilisation rate of W+PVp and W-PVo are nearly the same.

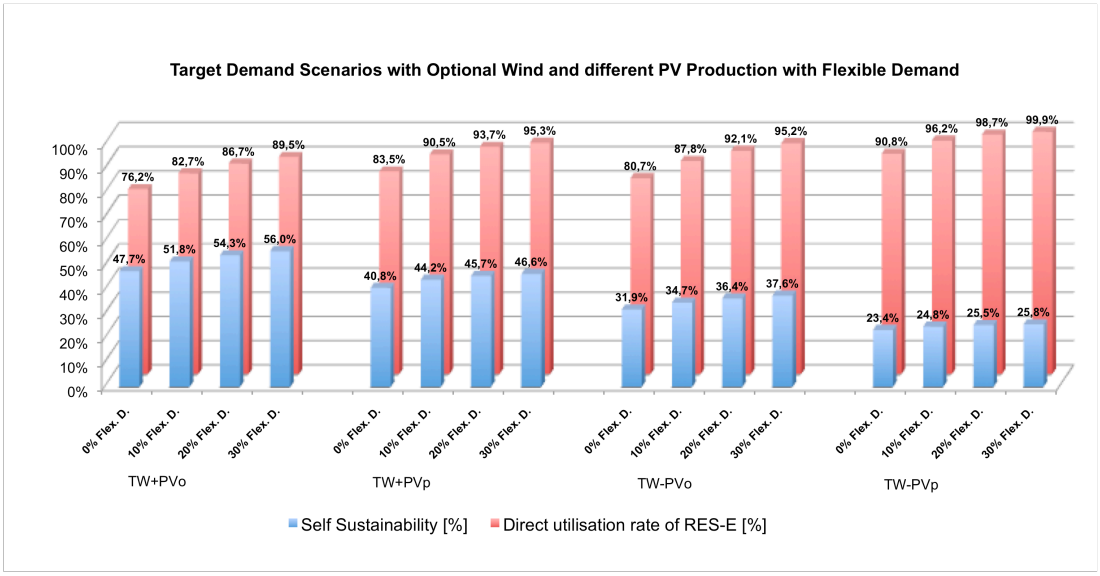



**Figure 13** Self sustainability and utilisation rate of RES-E. Target demand scenarios with different RES-E production and the introduction of flexible demand. (Demand: T: 51 GWh/a; Wind: W+: 12 GWh/a, W-: no wind power; PVo: 21 GWh/a, PVp: 14 GWh/a)

Generally it can be seen that in the target demand scenario the introduction of flexible demand increases the utilisation rate by 9% to 14% and to a lesser extent also the self sustainability. In the scenario with the least RES-E production (TW-PVp), the limits of self sustainability and utilisation rate are reached with 25.8% self sustainability and 9.9% utilisation rate of RES-E..

The minimal demand scenarios with flexible demand can be seen in Figure 14.

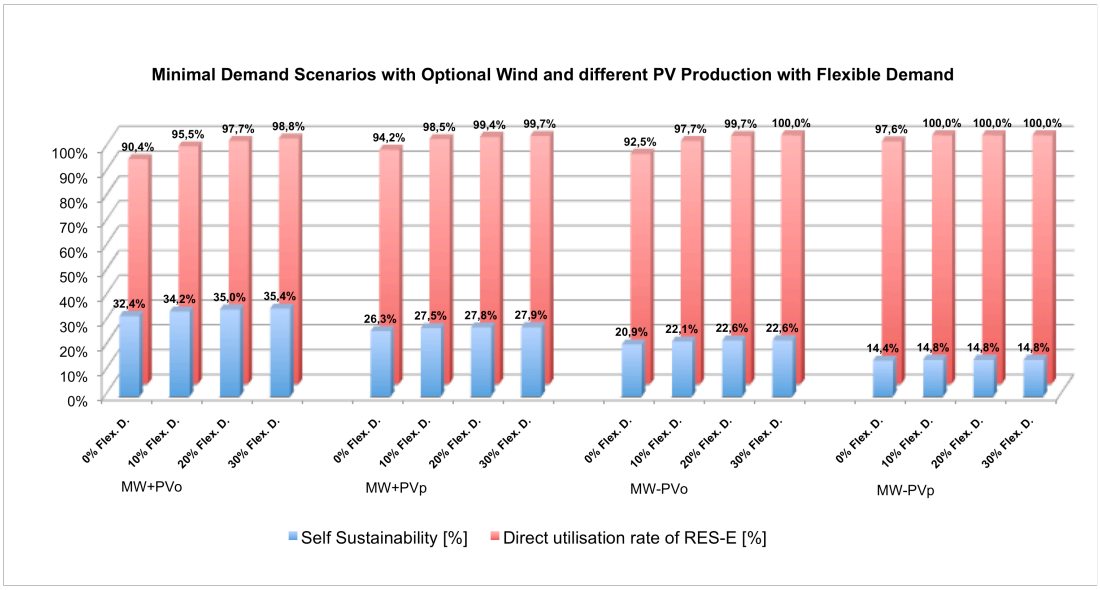



**Figure 14** Self sustainability and utilisation rate of RES-E. Minimal demand scenarios with different RES-E production and the introduction of flexible demand. (Demand: M: 91 GWh/a; Wind: W+: 12 GWh/a, W-: no wind power; PVo: 21 GWh/a, PVp: 14 GWh/a)

In the minimal demand scenarios it can be seen that the self sustainability does not show substantial changes with flexible demand, the maximum increase resulting in a 3% increase. In this demand scenario, the utilisation rate of W-PVo is higher than the rate of MW+PVp with 20% flexible demand. The utilisation rate reaches 100% or a value close to 100% in all the minimal scenarios with 30% flexible demand.

## *4.2 Scenarios with Geothermal Electricity Production*

With an additional introduction of a stable electricity source of 17.6 GWh/a to the electricity system of Aspern, a maximum of 70.4% self sustainability with a utilisation rate of 73.3% can be reached, if all other RES-E production is assumed to be at a maximum (33 GWh/a) and the demand is put to the lowest scenario (51 GWh/a).

With pessimistic assumptions for demand (145 GWh/a) and PV output (14 GWh/a) and without wind power, 21.4% self sustainability can be reached with additional geothermal electricity production. The utilisation rate of RES-E of this scenario is 99.6%.

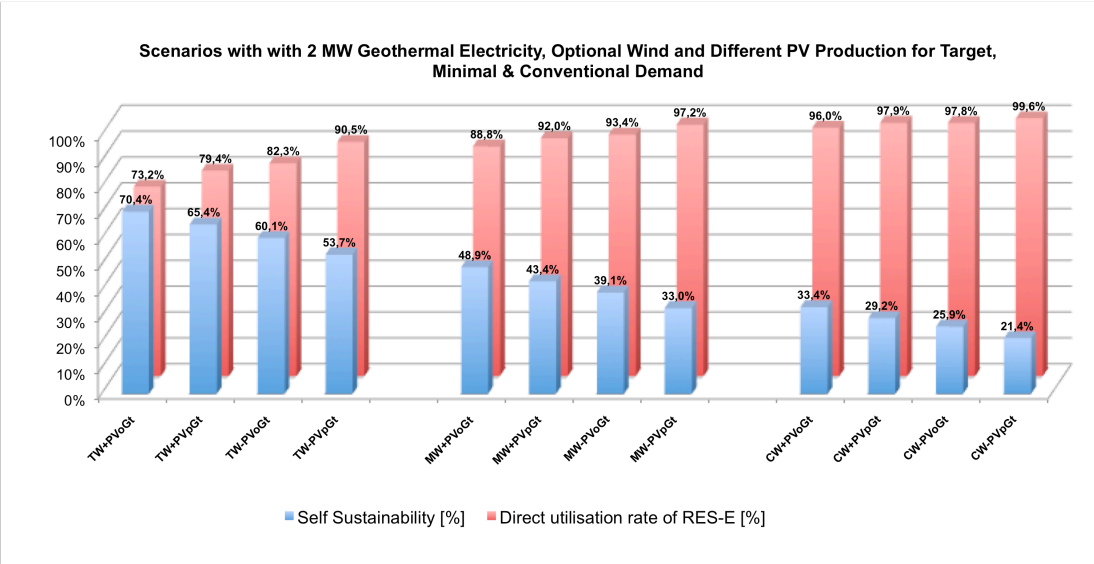



**Figure 15** Self sustainability and utilisation rate of RES-E. Target, minimal and conventional demand scenarios with 17.6 GWh/a geothermal electricity production with different PV and wind energy production. (Demand: T: 51 GWh/a, M: 91 GWh/a, C: 145 GWh/a; Wind: W+: 12 GWh/a, W-: no wind power; PVo: 21 GWh/a, PVp: 14 GWh/a)

In the scenarios with a stable geothermal electricity production, the decrease in utilisation rate from the W+PVp scenario to the W-PVo scenario cannot be observed like described in the section above. However, the increase in utilisation rate between these scenarios is comparatively small with a 2.9% increase in the target scenario and a 1.4% increase in the minimal scenario. Only in the conventional demand scenario the utilisation rate of W+PVp and W-PVo are nearly the same.

The effect of introducing flexible demand to the scenarios with geothermal electricity is shown in Figure 16 and Figure 17. With introducing flexible demand to the target demand scenario, a maximum of 78.9% self sustainability with a RES-E utilisation rate of 83.1% can be achieved. The highest utilisation rate that can be reached in the geothermal target scenario with flexible demand is 97.8%.

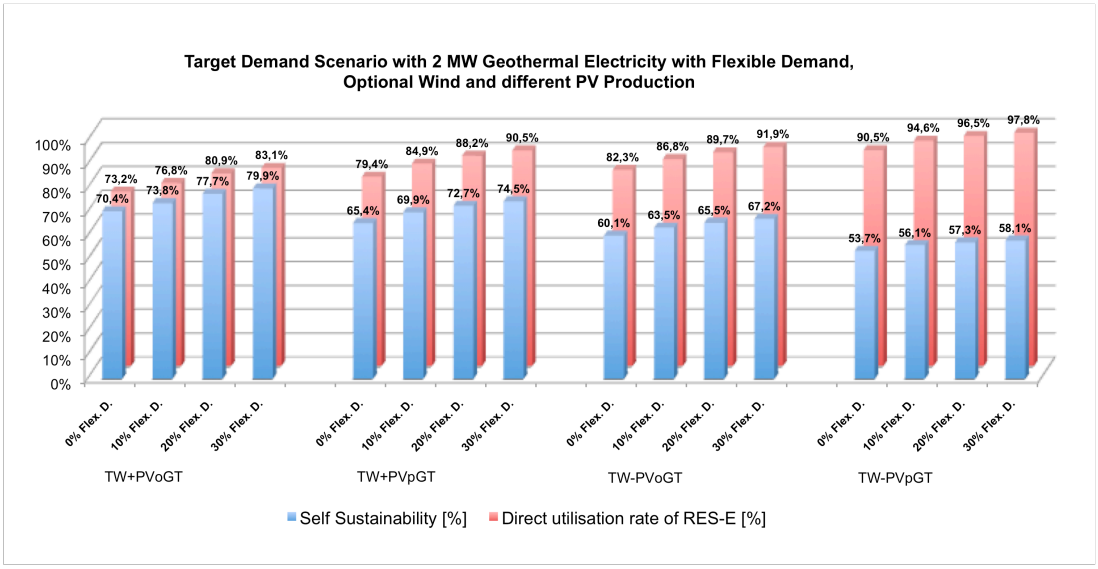



**Figure 16** Self sustainability and utilisation rate of RES-E. Target demand scenarios with 17.6 GWH/a geothermal electricity production, different RES-E production and the introduction of flexible demand. (Demand: T: 51 GWh/a; Wind: W+: 12 GWh/a, W-: no wind power; PVo: 21 GWh/a, PVp: 14 GWh/a)

In all the minimal scenarios, over 97% utilisation rate can be reached with flexible demand. In the minimal scenario with a pessimistic assumption of PV, 100% utilisation rate is reached with 10% flexible demand.

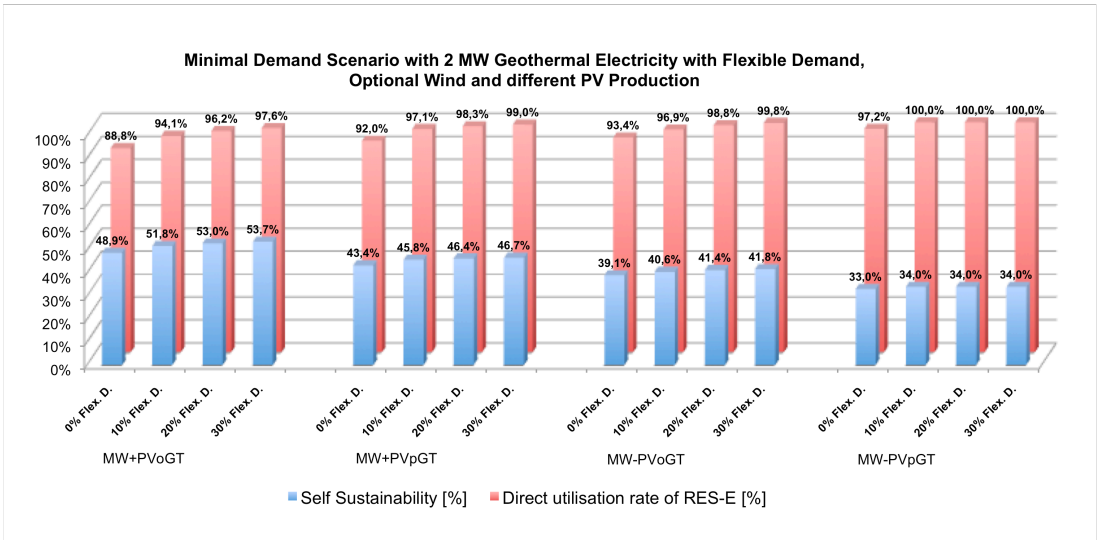



**Figure 17** Self sustainability and utilisation rate of RES-E. Minimal demand scenarios with 17.6 GWh/a geothermal electricity production, different RES-E production and the introduction of flexible demand. (Demand: M: 91 GWh/a; Wind: W+: 12 GWh/a, W-: no wind power; PVo: 21 GWh/a, PVp: 14 GWh/a)

## *4.3 Results of SA*

In this section the results of the sensitivity analysis are given for each of the input parameters under consideration. For PV, annual demand and flexible demand, results for 6 reference scenarios are shown. For wind power and geothermal electricity only 4 reference scenarios are given, as two reference scenarios were chosen without wind power and two without geothermal electricity.

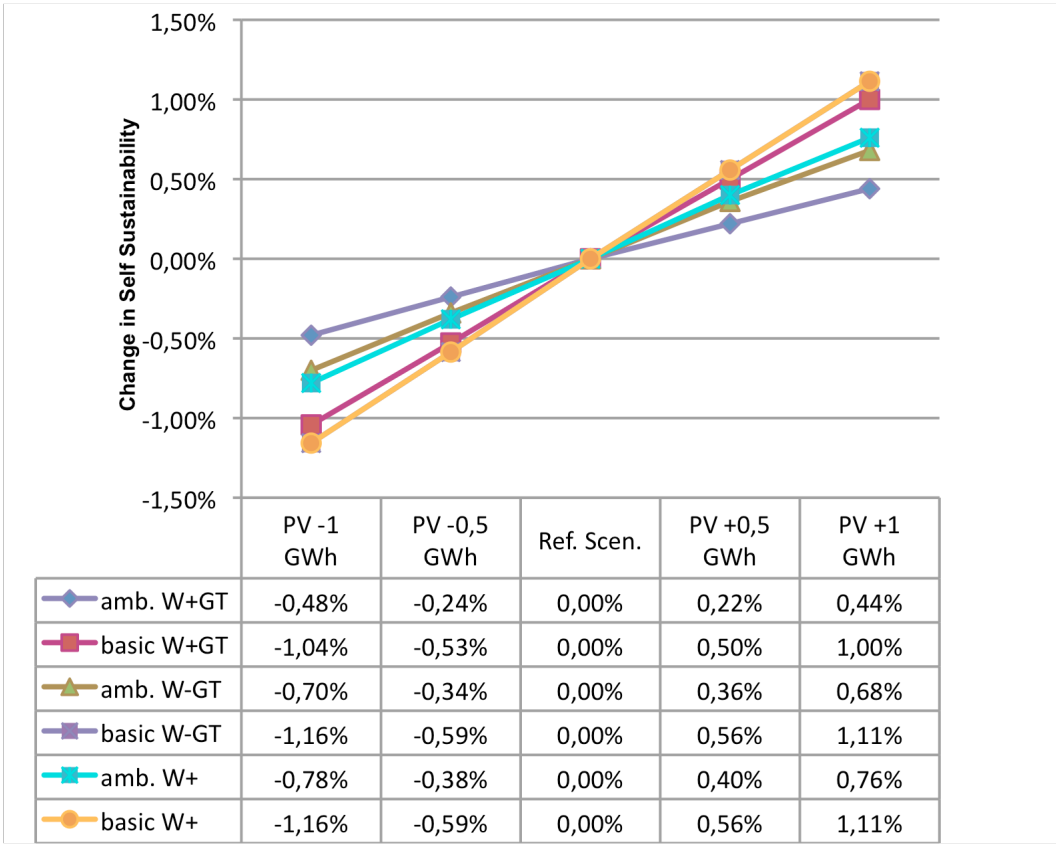
For each input parameter the change in self sustainability and the change in utilisation rate is shown. The graphs in the following sections do not show absolute values. Only the change of output parameters in comparison to the reference scenarios is given. The absolute values of the output parameters for the reference scenarios are given in Table 10.

**Table 10** Input parameters and results for output parameters for reference scenarios for the SA.

| *Ref. Scen.* | *Annual Demand [GWh/a]* | *Flexible Demand [GWh/a]* | *PV Produ. [GWh/a]* | *Wind Power Output [GWh/a]* | *Geothermal Electricity Production [GWh/a]* | *Self Sust. [%]* | *Ut. Rate of RES-E [%]* |
|---|---|---|---|---|---|---|---|
| **amb. W+GT** | 50 | 5 | 21 | 12 | 18 | 76,18% | 74,69% |
| **basic W+GT** | 70 | 7 | 50 | 5 | 15 | 50,77% | 93,53% |
| **amb. W-GT** | 50 | 5 | 21 | 12 | 18 | 65,88% | 84,46% |
| **basic W-GT** | 70 | 7 | 15 | 10 | 13 | 38,94% | 97,36% |
| **amb. W+** | 50 | 5 | 21 | 12 | 18 | 52,02% | 78,82% |
| **basic W+** | 70 | 7 | 15 | 10 | 13 | 33,93% | 95,00% |

### 4.3.1 Influence of PV

Figure 18 shows the dependence of self sustainability on the annual electricity production of PV. Self sustainability increases with the increase of PV output. The strongest influence can be seen in the two basic scenarios with either wind or geothermal electricity production, where an additional 1 GWh/a of PV results in an increase of self sustainability by 1.1%. The basic scenario with both wind and geothermal shows slightly less influence of PV. In the ambiguous scenarios, PV influences self sustainability to a lesser extent. The ambitious scenario with wind and geothermal energy shows the least influence. An increase of 1 MWh/a PV results in only 0.4% change in self sustainability.




| | PV -1 GWh | PV -0,5 GWh | Ref. Scen. | PV +0,5 GWh | PV +1 GWh |
|---|---|---|---|---|---|
| amb. W+GT | -0,48% | -0,24% | 0,00% | 0,22% | 0,44% |
| basic W+GT | -1,04% | -0,53% | 0,00% | 0,50% | 1,00% |
| amb. W-GT | -0,70% | -0,34% | 0,00% | 0,36% | 0,68% |
| basic W-GT | -1,16% | -0,59% | 0,00% | 0,56% | 1,11% |
| amb. W+ | -0,78% | -0,38% | 0,00% | 0,40% | 0,76% |
| basic W+ | -1,16% | -0,59% | 0,00% | 0,56% | 1,11% |

**Figure 18** Change of self sustainability with increase of annual production of PV.

The utilisation rate is influenced negatively by the increase of PV. The dependence is very similar in all three basic reference scenarios. The highest influence can be seen in the ambiguous reference scenarios with optional wind and geothermal energy.

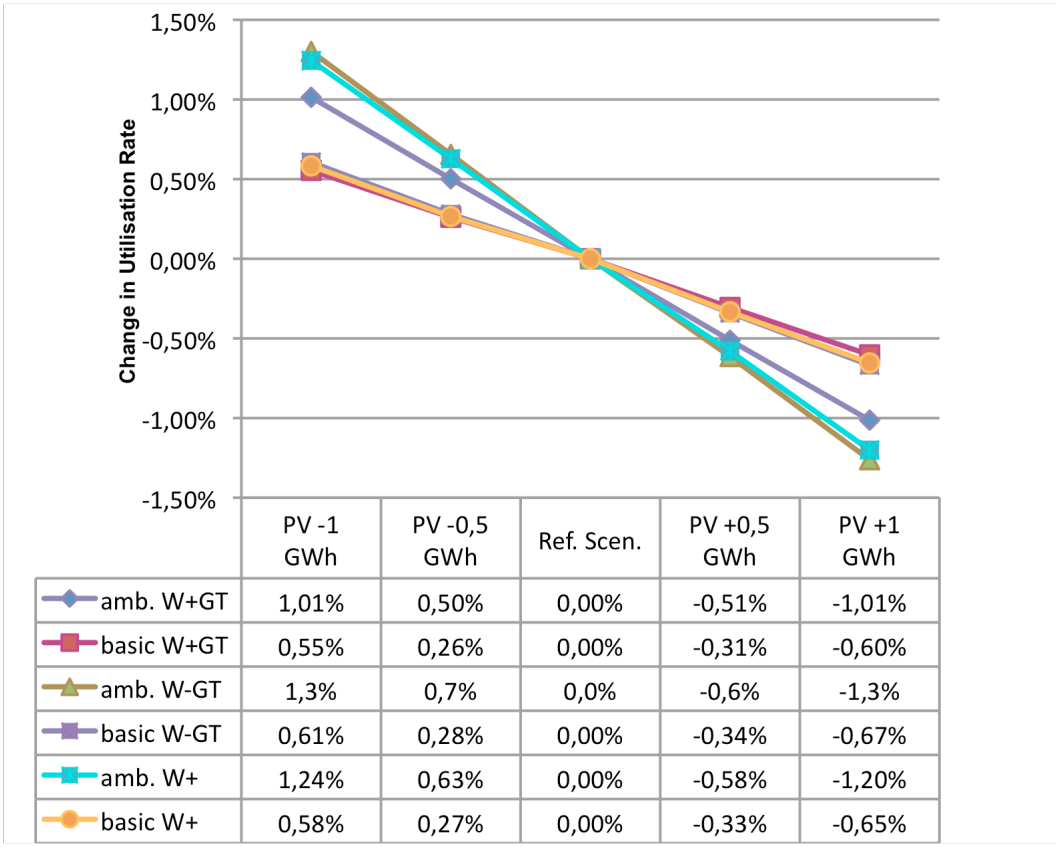



**Figure 19** Change of utilisation rate with increase of annual production of PV.

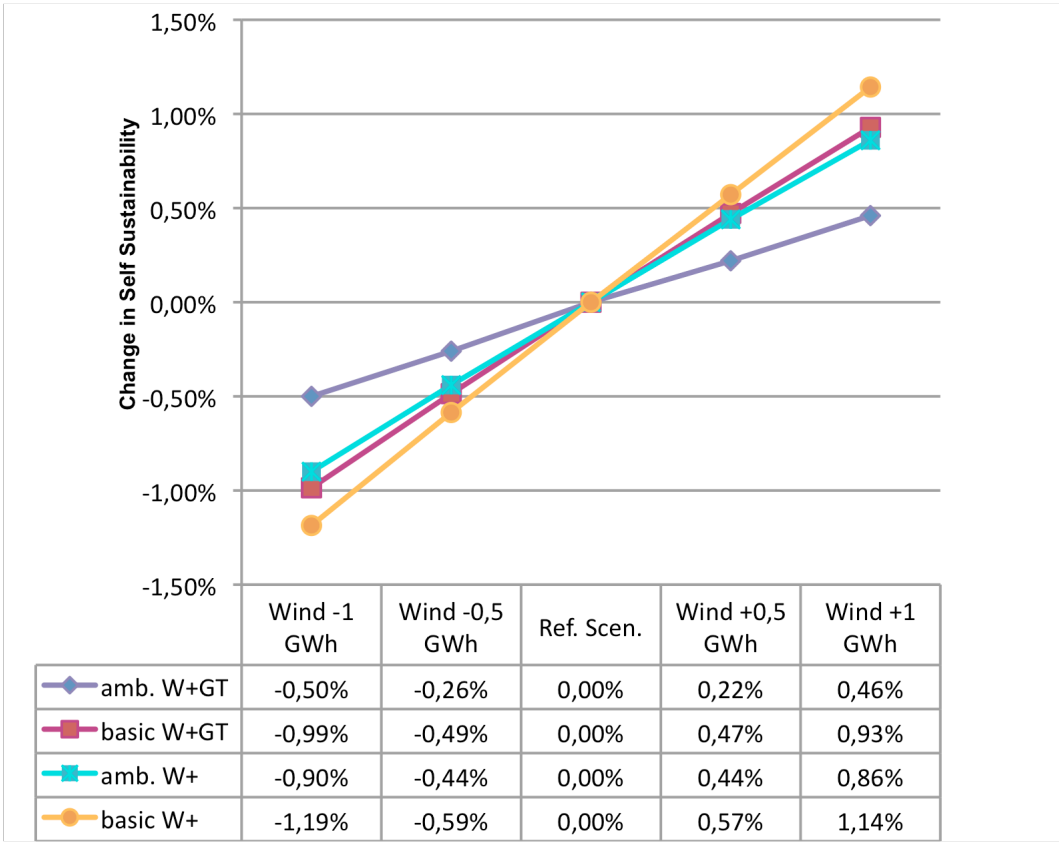
The results of the SA for the input parameter of PV are summarised in Table 11. $\frac{\partial g}{\partial x_1}\left(x^{\circ}\right)$ is negative for the output of utilisation rate, as output parameter decreases with an increase of the input parameter.

**Table 11** Resluts of SA for the input of PV.

| *Scenario* | $\frac{\partial g}{\partial x}\left(x^{\circ}\right)$ *g=Self Sustainability x=PV* | $\frac{\partial g}{\partial x}\left(x^{\circ}\right)$ *g=Utilisation Rate x=PV* |
|---|---|---|
| **amb. W+GT** | 0.0046 | -0.0101 |
| **basic W+GT** | 0.0103 | -0.0057 |
| **amb. W-GT** | 0.0070 | -0.0128 |
| **basic W-GT** | 0.0114 | -0.0063 |
| **amb. W+** | 0.0078 | -0.0121 |
| **basic W+** | 0.0114 | -0.0060 |

### 4.3.2 Influence of Wind Energy

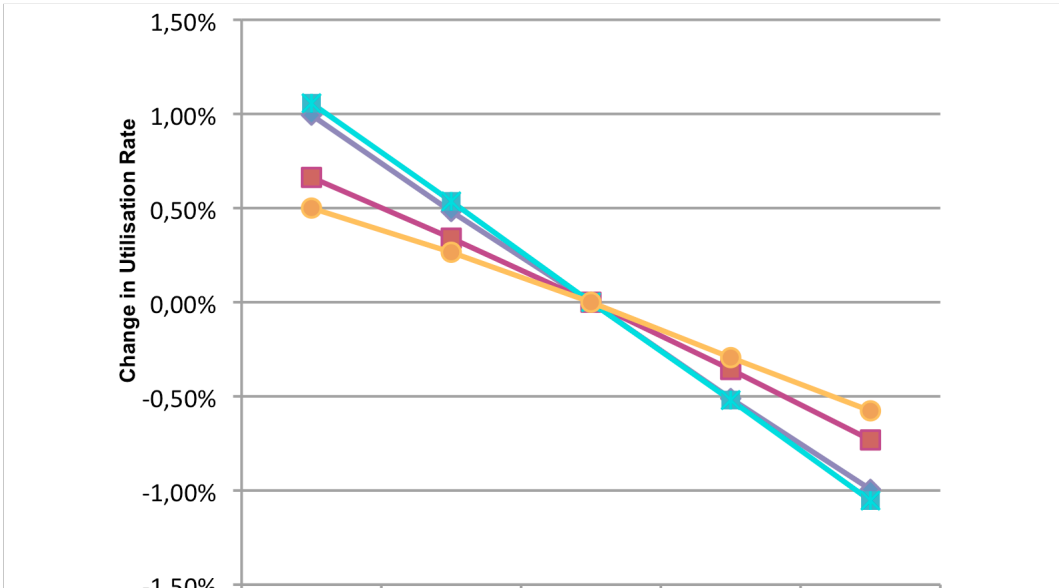
Similar to PV, the self sustainability increases with the increase of annual wind power output. Also, the input parameter of wind energy shows the least influence on self sustainability in the ambitious scenario with wind and geothermal energy. However, the influence is stable within the considered range of input.




| | Wind -1 GWh | Wind -0,5 GWh | Ref. Scen. | Wind +0,5 GWh | Wind +1 GWh |
|---|---|---|---|---|---|
| amb. W+GT | -0,50% | -0,26% | 0,00% | 0,22% | 0,46% |
| basic W+GT | -0,99% | -0,49% | 0,00% | 0,47% | 0,93% |
| amb. W+ | -0,90% | -0,44% | 0,00% | 0,44% | 0,86% |
| basic W+ | -1,19% | -0,59% | 0,00% | 0,57% | 1,14% |

**Figure 20** Change of self sustainability with change of annual production of wind energy.

The utilisation rate shows a decrease with increasing wind power output. In contrast to the output parameter of self sustainability, the rate of decrease of the utilisation ratio is very similar for the two ambitious scenarios.




| | Wind -1 GWh | Wind -0,5 GWh | Ref. Scen. | Wind +0,5 GWh | Wind +1 GWh |
|---|---|---|---|---|---|
| amb. W+GT | 0,99% | 0,48% | 0,00% | -0,51% | -0,99% |
| basic W+GT | 0,66% | 0,34% | 0,00% | -0,36% | -0,73% |
| amb. W+ | 1,06% | 0,54% | 0,00% | -0,52% | -1,05% |
| basic W+ | 0,50% | 0,27% | 0,00% | -0,29% | -0,58% |

**Figure 21** Change of utilisation rate of RES-E with increase of annual production of wind energy.

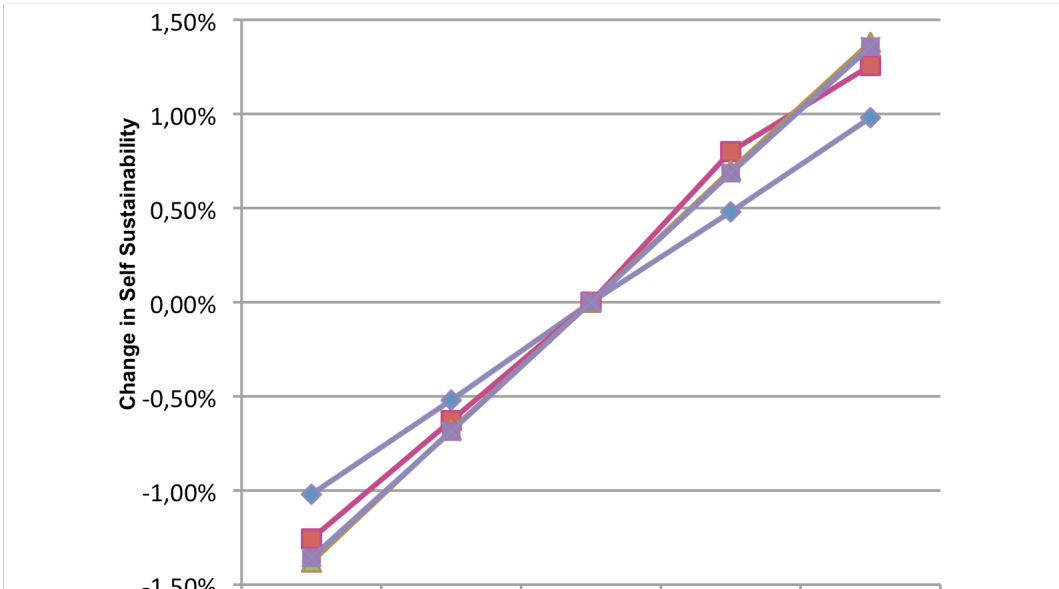
The summarised results for the SA of wind power in Table 12 show that wind energy has the highest influence on self sustainability in the basic scenario without geothermal electricity. This scenarios also shows the least negative influence on utilisation rate.

**Table 12** Resluts of SA for the input of wind power.

| *Scenario* | $\frac{\partial g}{\partial x}(x^{\circ})$ *g=Self Sustainability x=Wind Energy* | $\frac{\partial g}{\partial x}(x^{\circ})$ *g=Utilisation Rate x=Wind Energy* |
|---|---|---|
| **amb. W+GT** | 0.0048 | -0.0095 |
| **basic W+GT** | 0.0096 | -0.0070 |
| **amb. W+** | 0.0088 | -0.0106 |
| **basic W+** | 0.0116 | -0.0055 |

### 4.3.3 Influence of Geothermal Electricity Production

Geothermal electricity shows the biggest impact on self sustainability out of all the input parameters under investigation. In both the scenarios without wind power, self sustainability increases by 1.4% with an increase of 1 GWh/a of stable geothermal electricity output. The lowest impact can be observed in the ambitious scenario with wind power where an increase of 1 GWh/a geothermal power results in a 1% increase in self sustainability.




| | GT -1 GWh | GT -0,5 GWh | Ref. Scen. | GT +0,5 GWh | GT +1 GWh |
|---|---|---|---|---|---|
| amb. W+GT | -1,02% | -0,52% | 0,00% | 0,48% | 0,98% |
| basic W+GT | -1,26% | -0,63% | 0,00% | 0,80% | 1,26% |
| amb. W-GT | -1,38% | -0,68% | 0,00% | 0,70% | 1,38% |
| basic W-GT | -1,36% | -0,69% | 0,00% | 0,69% | 1,36% |

**Figure 22** Change of self sustainability with change of annual production of geothermal electricity.

In contrast to self sustainability, the utilisation rate is not highly influenced by the change of geothermal electricity production. In the basic scenarios, a change of geothermal output by 1 GWh/a changes the utilisation by a value of around 0.1%. The ambitious scenarios show a change of 0.4 to 0.5% per additional GWh/a.

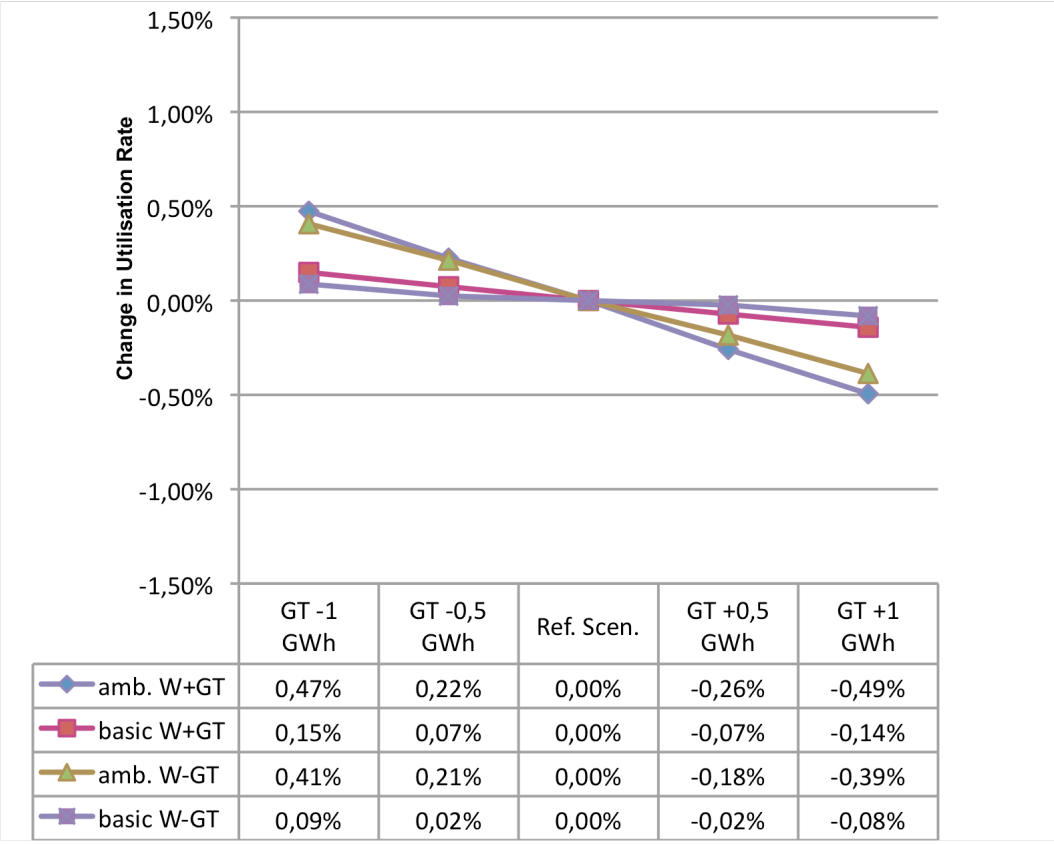



**Figure 23** Change of utilisation rate of RES-E with change of annual production of geothermal electricity.

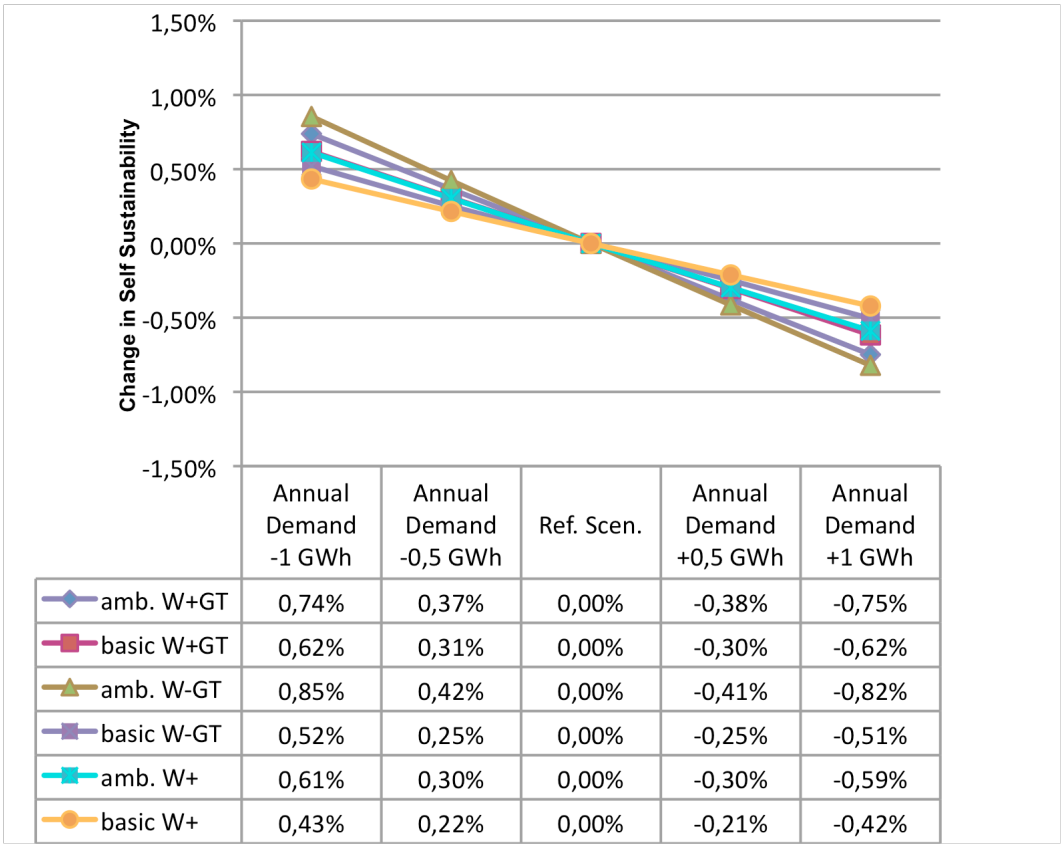
Table 13 shows that there is no reference scenario that has the most favourable result for both output parameters.

**Table 13** Resluts of SA for the input of geothermal electricity.

| *Scenario* | $\frac{\partial g}{\partial x}\left(x^{\circ}\right)$ *g=Self Sustainability x=Geothermal Electricity* | $\frac{\partial g}{\partial x}\left(x^{\circ}\right)$ *g=Utilisation Rate x=Geothermal Electricity* |
|---|---|---|
| **amb. W+GT** | 0.0100 | -0.0048 |
| **basic W+GT** | 0.0134 | -0.0015 |
| **amb. W-GT** | 0.0138 | -0.0040 |
| **basic W-GT** | 0.0136 | -0.0007 |

### 4.3.4 Influence of Annual Demand

Figure 24 shows that the self sustainability is reduced with increase of demand. The highest influence can be seen in the ambitious scenario with only PV and geothermal electricity. In the basic scenario with PV and wind, the self sustainability is least dependent on annual demand.




| | Annual Demand -1 GWh | Annual Demand -0,5 GWh | Ref. Scen. | Annual Demand +0,5 GWh | Annual Demand +1 GWh |
|---|---|---|---|---|---|
| amb. W+GT | 0,74% | 0,37% | 0,00% | -0,38% | -0,75% |
| basic W+GT | 0,62% | 0,31% | 0,00% | -0,30% | -0,62% |
| amb. W-GT | 0,85% | 0,42% | 0,00% | -0,41% | -0,82% |
| basic W-GT | 0,52% | 0,25% | 0,00% | -0,25% | -0,51% |
| amb. W+ | 0,61% | 0,30% | 0,00% | -0,30% | -0,59% |
| basic W+ | 0,43% | 0,22% | 0,00% | -0,21% | -0,42% |

**Figure 24** Change of self sustainability with change in annual demand.

For the impact of annual demand on RES-E utilisation rate, the results are similar in all three ambitious scenarios and all three basic scenarios. In the basic scenarios the utilisation rate only increases by 0.1-0.2% with the increase of 1 GWh of annual demand, whereas in the ambitious scenarios the influence is stronger. Here the utilisation rate increases around 0.7% with the increase of 1 GWh of annual demand.

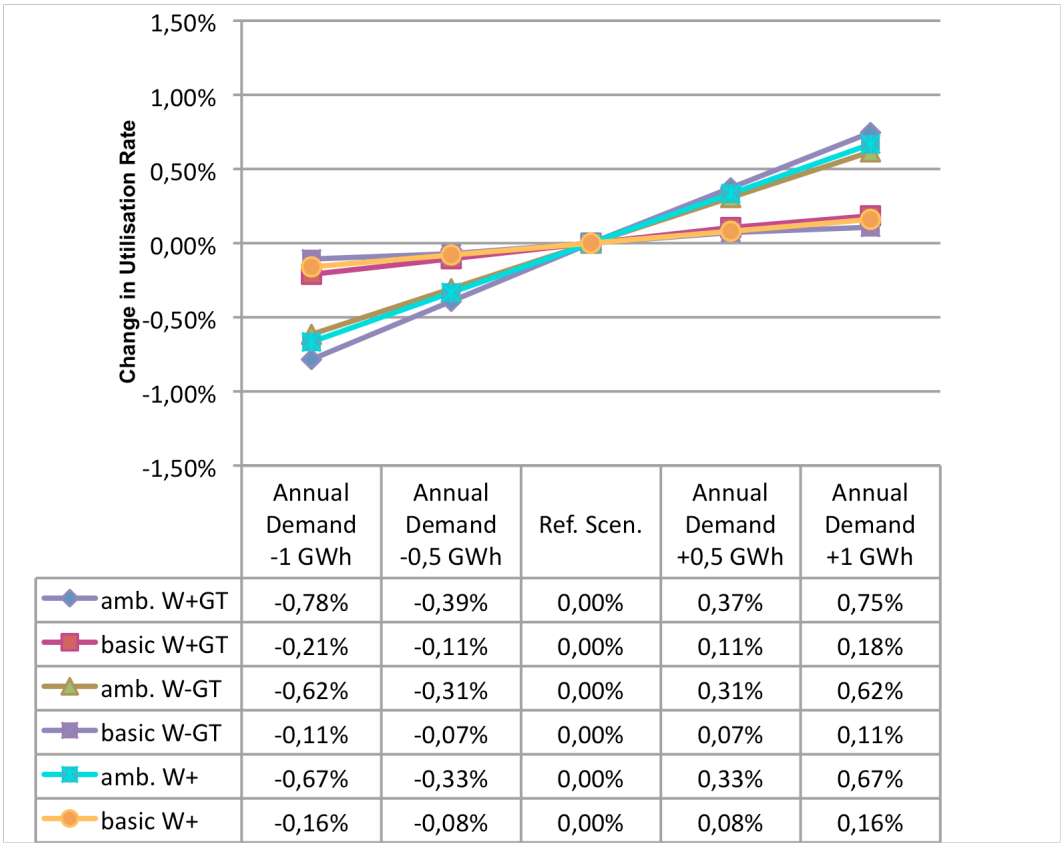



**Figure 25** Change of utilisation rate with change in annual demand.

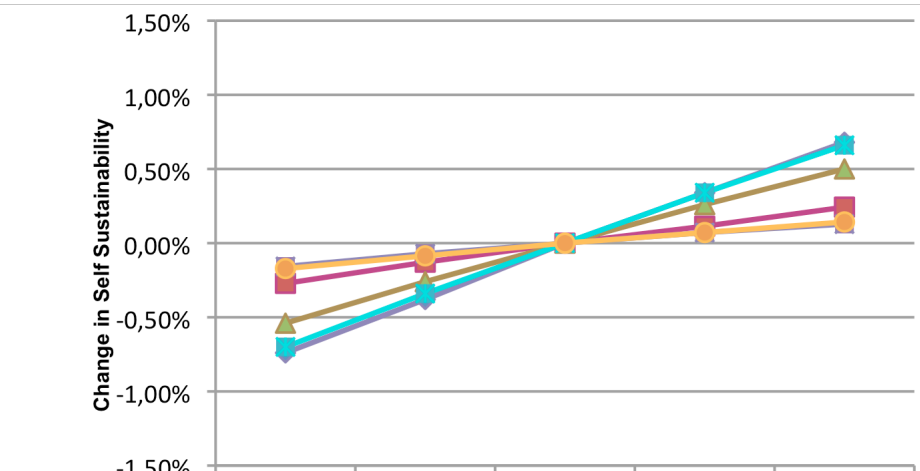
A summary of results of the SA is given in Table 14.

**Table 14** Resluts of SA for the input of annual demand.

| *Scenario* | $\frac{\partial g}{\partial x}(x^{\circ})$ *g=Self Sustainability x=Annual Demand* | $\frac{\partial g}{\partial x}(x^{\circ})$ *g=Utilisation Rate x=Annual Demand* |
|---|---|---|
| **amb. W+GT** | -0.0074 | 0.0076 |
| **basic W+GT** | -0.0061 | 0.0020 |
| **amb. W-GT** | -0.0084 | 0.0062 |
| **basic W-GT** | -0.0051 | 0.0013 |
| **amb. W+** | -0.0060 | 0.0067 |
| **basic W+** | -0.0043 | 0.0016 |

### 4.3.5 Influence of Flexible Demand

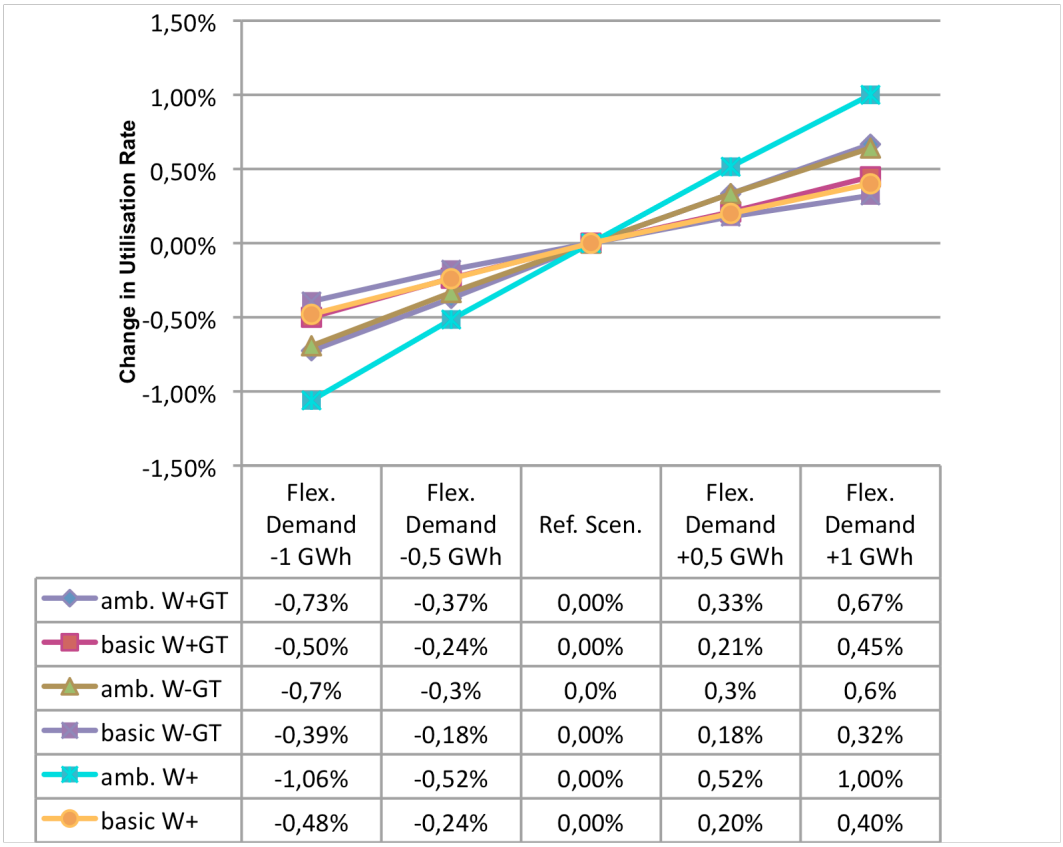
Flexible demand is the only input parameter that increases both, self sustainability and utilisation rate of RES-E with increased input. However, especially in the basic scenarios, flexible demand has a very low impact on self sustainability. In the ambitious reference scenarios with PV and geothermal electricity and optional wind power, an addition of 1 GWh/a flexible demand can increase the self sustainability by 0.7%.




| | Flex. Demand -1 GWh | Flex. Demand -0,5 GWh | Ref. Scen. | Flex. Demand +0,5 GWh | Flex. Demand +1 GWh |
|---|---|---|---|---|---|
| amb. W+GT | -0,74% | -0,38% | 0,00% | 0,34% | 0,68% |
| basic W+GT | -0,27% | -0,13% | 0,00% | 0,11% | 0,24% |
| amb. W-GT | -0,54% | -0,26% | 0,00% | 0,26% | 0,50% |
| basic W-GT | -0,16% | -0,07% | 0,00% | 0,07% | 0,13% |
| amb. W+ | -0,70% | -0,34% | 0,00% | 0,34% | 0,66% |
| basic W+ | -0,17% | -0,09% | 0,00% | 0,07% | 0,14% |

**Figure 26** Change of self sustainability with increase in flexible demand.

As mentioned above, the utilisation rate can be influenced positively with an addition of flexible demand. The highest positive effect can be reached in the ambitious scenarios with PV and wind power, where an increase of 1 GWh/a of flexible demand increases the utilisation rate by 1%.




| | Flex. Demand -1 GWh | Flex. Demand -0,5 GWh | Ref. Scen. | Flex. Demand +0,5 GWh | Flex. Demand +1 GWh |
|---|---|---|---|---|---|
| amb. W+GT | -0,73% | -0,37% | 0,00% | 0,33% | 0,67% |
| basic W+GT | -0,50% | -0,24% | 0,00% | 0,21% | 0,45% |
| amb. W-GT | -0,7% | -0,3% | 0,0% | 0,3% | 0,6% |
| basic W-GT | -0,39% | -0,18% | 0,00% | 0,18% | 0,32% |
| amb. W+ | -1,06% | -0,52% | 0,00% | 0,52% | 1,00% |
| basic W+ | -0,48% | -0,24% | 0,00% | 0,20% | 0,40% |

**Figure 27** Change of utilisation rate with increase in flexible demand.

Even though it is difficult to define the reference scenario with the best impact of flexible demand on both output parameters, the scenario with the least impact can be defined clearly. As can be seen in Table 15, in the basic reference scenario without wind, flexible demand has the smallest influence on self sustainability as well as on utilisation rate.

**Table 15** Resluts of SA for the input of flexible demand.

| *Scenario* | $\frac{\partial g}{\partial x}\left(x^{\circ}\right)$ *g=Self Sustainability x=Flexible Demand* | $\frac{\partial g}{\partial x}\left(x^{\circ}\right)$ *g=Utilisation Rate x=Flexible Demand* |
|---|---|---|
| **amb. W+GT** | 0.0071 | 0.0070 |
| **basic W+GT** | 0.0025 | 0.0046 |
| **amb. W-GT** | 0.0052 | 0.0067 |
| **basic W-GT** | 0.0014 | 0.0036 |
| **amb. W+** | 0.0068 | 0.0103 |
| **basic W+** | 0.0016 | 0.0044 |

# 5 Discussion

After looking at the EnergyPLAN modelling tool, the main results of the calculated scenarios and the results of the sensitivity analysis will be discussed. The last two sections of the discussion give an outlook for planners and future research.

## *5.1 Discussion of EnergyPLAN modelling tool*

The EnergyPLAN model was found to be easy to use and it was easy to learn the necessary functions, as there are training excercises provided for free download on the EnergyPLAN webpage (Aalborg University b). In combination with the HOMER modelling tool for creating load profiles, necessary data could be generated with a reasonable expenditure of time. Also the calculation of the one year scenarios is performed very fast by the EnergyPLAN programme. Looking at these aspects, the EnergyPLAN model is a very useful tool for energy planning, moreover as it is freely available for download.

However, for the available data and scope of the scenarios calculated in this work, the potential of the EnergyPLAN model was by far not exhausted. To make use of the many features of the programme, the heat and transport sector and possible

energy storage options should be included into the model. In addition to this, economic aspects could be included. This would need, however, the input of hourly electricity prices, which is again not an easy set of data to generate or obtain.

## 5.2 Discussion of Main Results

In the main results of the electricity scenarios it can be seen that with the assumption of a very high demand of 145 GWh/a for the Lake City Aspern, the PV and wind energy production that was proposed by Pol & Shoshtari 2010 can be implemented with a utilisation rate close to 100%. With only 23% or less of the annual demand covered by RES-E, the utilisation rate does not fall below 97% even with the implementation of the optimistic PV output and proposed wind power. Also with an annual demand of 91 GWh/a the utilisation rate still stays above 90% with the most optimistic assumptions for PV and wind power. In these two demand scenarios the maximum self sustainability that can be reached with consideration of load profiles is 22.0% and 32.4%. Only in the target demand scenarios with an annual demand of 51 GWh/a, the self sustainability falls much lower than 90% and reaches a minimum of 72.6% in the most ambitious scenario. Here the self sustainability reaches 47.7% when considering load profiles, compared to 62.6% when only looking at annual values. This shows that in the target scenario with annual demand values around 50 GWh the limits of fluctuating electricity sources for the system are reached and exceeded. The RES-E production in peak times is often higher than the demand at these times. This explains, why the utilisation rate shows substantial changes in the target demand scenario, whereas in the minimal and conventional demand scenarios it does not fall below 90% (see Figure 12).

The scenarios with an additional geothermal electricity production show a similar behaviour regarding the utilisation rate (see Figure 15), even though the total electricity produced is higher with the same assumptions of demand. This shows that the energy system can take the introduction of a stable electricity source of the proposed scale, as the times of low or zero production of the fluctuating electricity sources is covered with the stable electricity. However, even this setting comes to its limits in the target demand scenario, as there is no other measure to balance the remaining differences in production and demand load profiles.

As shown above, the utilisation rate of RES-E is dependent on the share of RES-E of annual demand. However, it can be seen in Figure 12 that the utilisation rate does not necessarily always decrease with an increased share of RES-E production. Figure 12 shows that for all three demand scenarios the scenario without wind power and with an optimistic PV output (W-PVo) has lower utilisation rates than the scenario with wind power and a pessimistic PV output (W+PVp). This is in spite of the fact that the share of RES-E production of annual demand is also lower in the W-PVo scenario than in the W+PVp scenario. Figure 28 shows the utilisation rate of the four target demand scenarios with their respective annual production of RES-E. This highlights the influence of the different load profiles of PV and wind power on the utilisation rate.

While PV production always has its peak during the day, wind power has the production peaks at time of strong wind speeds, which might occur during the day or during the night. With a combination of both, PV and wind power, it can be seen that the utilisation rate of RES-E can be optimised, compared to a sole increase of PV output.

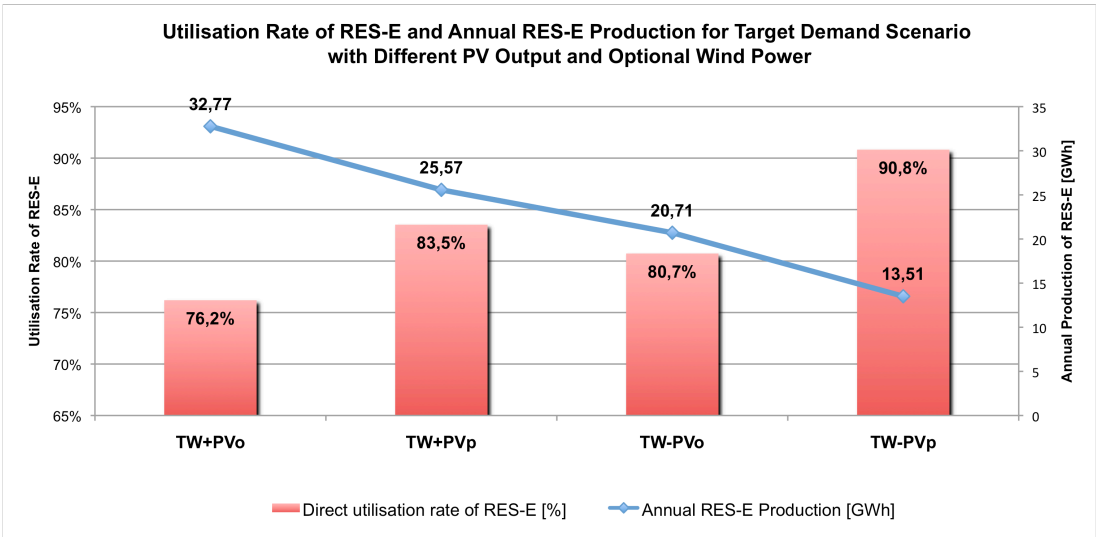



**Figure 28** Utilisation rate of RES-E and annual RES-E Production for target Demand Scenario with different PV output and optional Wind Power. (Demand: 51 GWh/a, Wind: W+: 12 GWh/a, W-: no wind power; PVo: 21 GWh/a, PVp: 14 GWh/a)

With the additional introduction of a stable geothermal electricity source, the effect described above is not as strong as without a stable electricity source. Here, the stable electricity production can supply some of the demand that cannot be covered

by PV. In this case, the utilisation rate for the scenario with the higher share of RES-E (W+PVp) is lower than for W-PVo. However, in this case the utilisation rate only decreases by 3%, while between the other scenarios, a decrease of 6 to 8% can be seen (see Figure 29).

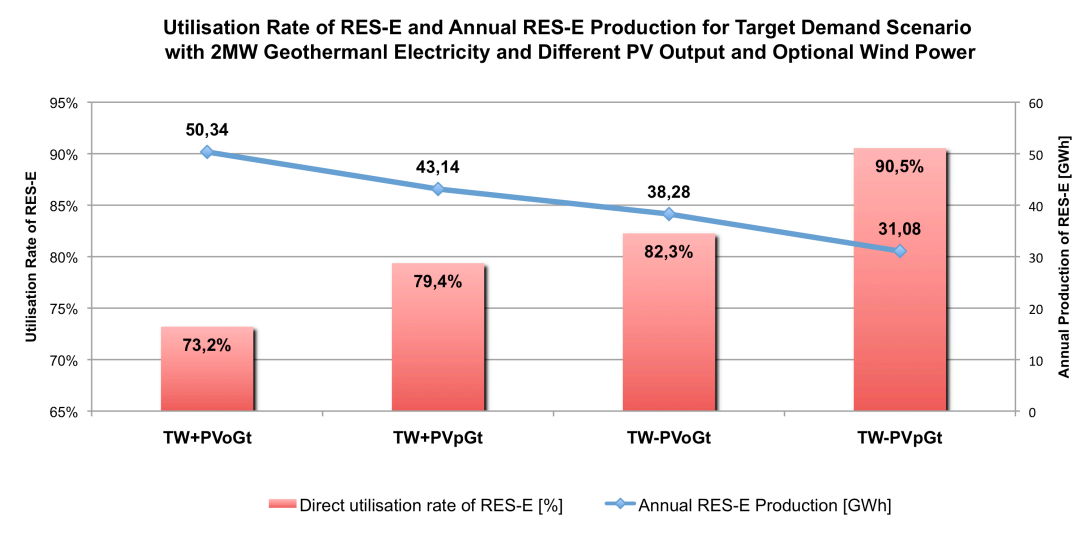



**Figure 29** Utilisation rate of RES-E and annual RES-E Production for target Demand Scenario with 18 GWh/a geothermal electricity production and different PV output and optional Wind Power. (Demand: 51 GWh/a, Wind: W+: 12 GWh/a, W-: no wind power; PVo: 21 GWh/a, PVp: 14 GWh/a)

Figure 30 shows a comparison between self sustainability calculated with annual values and calculated with load profiles. The comparison is only given for the target and minimal demand scenarios, as in the conventional demand scenario (145 GWh/a) the values of self sustainability with load profiles are close to the possible limits (see Annex). Even in the minimal demand scenario (91 GWh/a), the maximum difference in self sustainability amounts to 3.4%, as the utility rates of RES-E with this demand are above 90%. Consequently, the introduction of flexible demand is only sensible in the target demand scenario or in the minimal demand scenario with maximum proposed RES-E.

The possible contribution of flexible demand to self sustainability can be seen in Figure 30. In most of the scenarios the full potential of self sustainability can be tapped with the introduction of 30% flexible demand. Only in the most ambitious scenario (TW+PVo), the potential of self sustainability is 6.6% higher than the value

that can be reached with flexible demand. Here the peaks of RES-E production are too high in comparison to demand. It would be necessary to introduce further measures for balancing supply and demand.

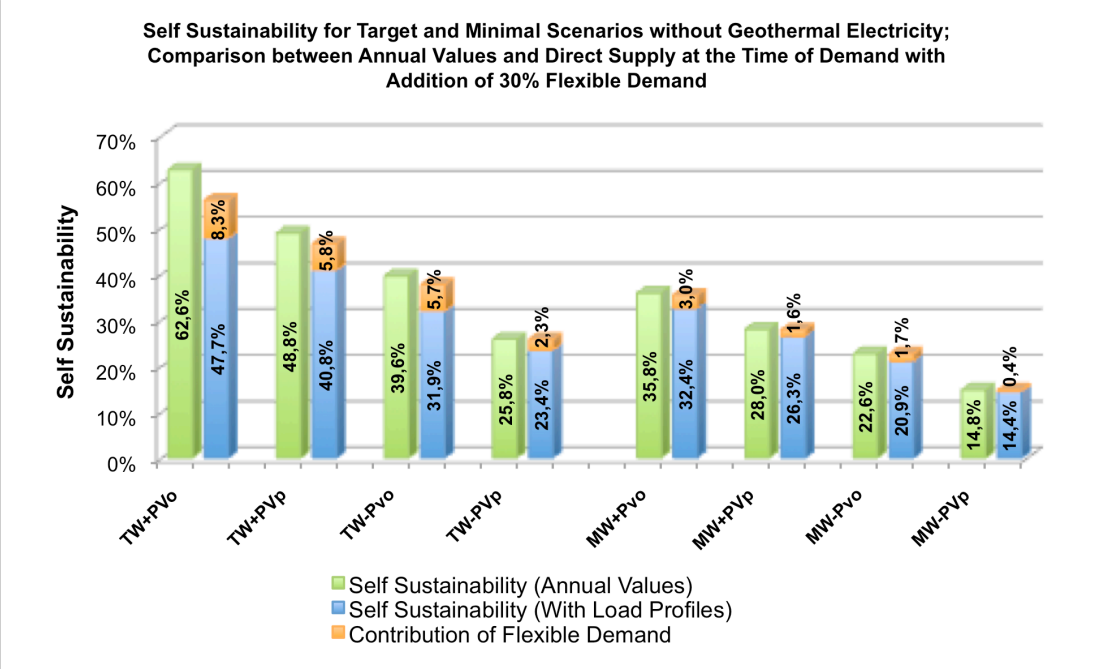



**Figure 30** Self sustainability for target and minimal demand scenarios without geothermal electricity. Comparison between calculation with annual values and with load profiles and with addition of 30% flexible demand. (Demand: T: 51 GWh/a, M: 91 GWh/a; Wind: W+: 12 GWh/a, W-: no wind power; PVo: 21 GWh/a, PVp: 14 GWh/a)

The possible contributions of flexible demand for the scenarios with geothermal electricity can be seen in Figure 31. In these scenarios, the difference between self sustainability calculated with annual values and with consideration of load profiles is higher than without geothermal electricity. Only in the minimal demand scenario with the lowest RES-E production, flexible demand cannot contribute much towards increasing self sustainability. In the target scenario, the limits of flexible demand can be seen much stronger than without geothermal electricity. In the most ambitious scenario (TW+PVoGT), even with 30% of flexible demand, the self sustainability with considering load profiles is 9% lower than the calculation with annual values. This scenario would be nearly 100% electricity self sufficient, when looking at annual demand and production values.

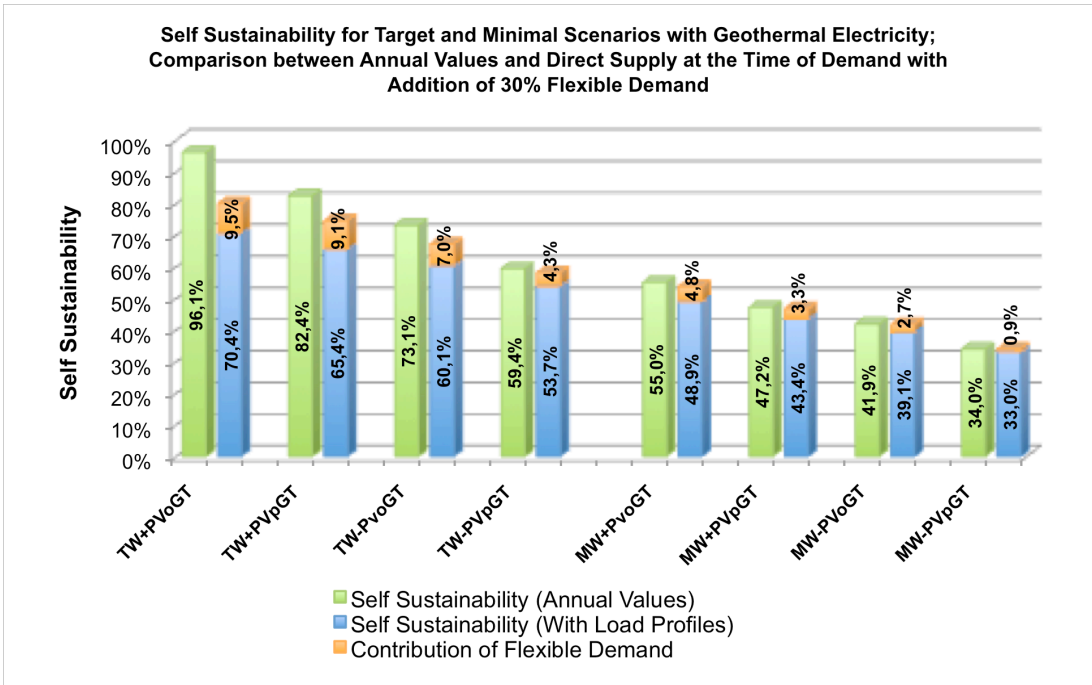



**Figure 31** Self sustainability for target and minimal demand scenarios with 18 GWh/a geothermal electricity. Comparison between calculation with annual values and with load profiles and with addition of 30% flexible demand. (Demand: T: 51 GWh/a, M: 91 GWh/a; Wind: W+: 12 GWh/a, W-: no wind power; PVo: 21 GWh/a, PVp: 14 GWh/a)

## *5.3 Influence of Input Parameters (PV, Wind, Geothermal, Annual Demand, Flexible Demand)*

An overview of the results of the sensitivity analysis for the basic and ambitious scenario is given in Table 16 and Table 17. It can be seen that for the electricity system of Lake City Aspern, in terms of increasing self sustainability, the introduction of stable geothermal electricity is the most effective input factor to the system. Also the negative influence on utilisation rate is the lowest with geothermal electricity. This shows that in both the reference scenarios the additional potential for a stable electricity source is higher than for fluctuating sources. In the basic scenarios, the utilisation rate only falls by 0.8% to 0.14% with the introduction of 1 GWh/a of geothermal electricity, which means that most of the additional electricity can be used at times of too little PV and wind production. In the ambitious scenario without wind power, the effect of geothermal electricity on self sustainability is very similar to the basic scenarios, however, the negative effect on utilisation rate is higher, with a decrease of 0.4% of utilisation rate per additional GWh/a. This means that at times of high PV production, the demand in this scenario is covered and the additional electricity production cannot be used. In the ambitious scenario with wind

energy, also the effect on self sustainability is lower, as wind energy supplies electricity at other times than PV, and therefore additional supply is not needed for these periods of time.

Both input parameters, PV and wind energy, show very similar effects on the output parameters, as they are both fluctuating electricity sources. They both show a highly negative influence on utilisation rate, as they have peak hours of production and once the demand is covered in these peak hours, an addition of extra production results in overproduction. In the basic scenario, the difference between the effects of PV and wind power is very small, as the relatively high electricity demand with lower RES-E production leaves a potential for both technologies. In the ambitious scenario without geothermal power, a bigger difference between the effects of PV and wind power can be. This highlights the different load profiles of the two energy sources and shows that as a result of the higher PV production in this scenario, the demand is already covered in most of the PV peak hours, whereas in times of wind peak hours there is still demand that is not covered. In the basic scenario with geothermal electricity, the difference between wind and PV is again very small, as the geothermal electricity reduces the need of wind energy at times of low or zero PV production.

Annual demand has a negative influence on self sustainability and a positive influence on the utilisation rate, as the aim is to reduce demand. The influence on utilisation rate with reducing demand is only slightly higher than that of adding geothermal electricity. However, the impact on self sustainability is even lower than the impact of PV and wind in most scenarios. This points out the different nature of the load profile of demand. Unlike wind energy and PV, the demand load profile does not have hours of zero demand. The influence of demand on utilisation rate is lower than the influence of PV and wind, because the decrease of demand also affects times of zero production of PV and wind. If the demand is reduced at a time without electricity production within the system, less electricity has to be imported to the system and self sustainability is increased. However, the utilisation rate of the RES-E is not affected. Only in the two ambitious scenarios with geothermal electricity, the effect of annual demand on self sustainability is stronger than the effect of wind power and PV, as in these scenarios, wind power and PV are closer to the limits.

Flexible demand has a very different effect on the output, as it increases both, self sustainability and utilisation rate. A big difference can be seen between the basic and the ambitious scenario. In the basic scenario an effect can be seen for the utilisation rate. However, this does not influence the self sustainability, as the utilisation rate for these scenarios is over 90%. The potential for flexible demand is bigger in the ambitious scenarios, where utilisation rates are between 75% and 85%.

**Table 16** Summary of results for SA of basic scenario.

| | *W+GT+* | | *W+* | | *W-GT+* | |
|---|---|---|---|---|---|---|
| *Parameter* | $\frac{\partial g}{\partial x}\left(x^{\circ}\right)$ *g=Self Sust.* | $\frac{\partial g}{\partial x}\left(x^{\circ}\right)$ *g=Ut. Rate* | $\frac{\partial g}{\partial x}\left(x^{\circ}\right)$ *g=Self Sust.* | $\frac{\partial g}{\partial x}\left(x^{\circ}\right)$ *g=Ut. Rate* | $\frac{\partial g}{\partial x}\left(x^{\circ}\right)$ *g=Ut. Rate* | $\frac{\partial g}{\partial x}\left(x^{\circ}\right)$ *g=Ut. Rate* |
| **PV** | 0.0103 | -0.0057 | 0.0114 | -0.0060 | 0.0114 | -0.0063 |
| **Wind Energy** | 0.0096 | -0.0070 | 0.0116 | -0.0055 | - | - |
| **Geothermal El.** | 0.0134 | -0.0015 | - | - | 0.0136 | -0.0007 |
| **Annual Demand** | -0.0061 | 0.0020 | -0.0043 | 0.0016 | -0.0051 | 0.0013 |
| **Flexible Demand** | 0.0025 | 0.0046 | 0.0016 | 0.0044 | 0.0014 | 0.0036 |

**Table 17** Summary of Results for SA of ambitious scenario.

| | W+GT+ | | W+ | | W-GT+ | |
|---|---|---|---|---|---|---|
| *Parameter* | $\frac{\partial g}{\partial x_1}(x^o)$ *g= Self Sust.* | $\frac{\partial g}{\partial x_1}(x^o)$ *g= Self Sust.* | $\frac{\partial g}{\partial x_1}(x^o)$ *g=Ut. Rate* | $\frac{\partial g}{\partial x_1}(x^o)$ *g=Ut. Rate* | $\frac{\partial g}{\partial x_1}(x^o)$ *g=Ut. Rate* | $\frac{\partial g}{\partial x_1}(x^o)$ *g=Ut. Rate* |
| **PV** | 0.0046 | -0.0101 | 0.0078 | -0.0121 | 0.0070 | -0.0128 |
| **Wind Energy** | 0.0048 | -0.0095 | 0.0088 | -0.0106 | - | - |
| **Geothermal El.** | 0.0100 | -0.0048 | - | - | 0.0138 | -0.0040 |
| **Annual Demand** | -0.0074 | 0.0076 | -0.0060 | 0.0067 | -0.0084 | 0.0062 |
| **Flexible Demand** | 0.0071 | 0.0070 | 0.0068 | 0.0103 | 0.0052 | 0.0067 |

## *5.4 Implementations for Planning*

The question that would be the most interesting for planners is which kind of RES-E production or other management measure is the most effective for increasing self sustainability and increasing the RES-E utilisation rate in the electricity system of Aspern Lake City. However, this is not a straightforward question to answer, as results vary especially with values of annual electricity demand, the input factor that is hardest to control for planners.

If the demand will not be kept to the very ambitious goal of 51 GWh/a, an implementation of both, PV and wind power can be highly recommended. Additionally, a stable geothermal electricity production can increase the self sustainability from around 30% to around 50%. In this case, a demand side management with flexible demand would be advisable. Otherwise, if not all proposed RES-E is implemented in settings with higher demand, one should be careful with putting efforts into flexible demand, as it will not be effective in every case.

In case the demand is kept close to the ambitious target of around 50 GWh/a, the implementation of RES-E should be accompanied by measures to balance the fluctuating electricity sources. If only PV is implemented without wind power or geothermal electricity, flexible demand is sufficient to balance the fluctuations of PV. If wind power and maybe geothermal electricity are implemented in addition to PV, flexible demand is not sufficient to balance electricity production and demand. Consequently, if demand is kept low, the possibility of other balancing measures, e.g. of a combined heat and power plant should be investigated instead of a stable geothermal electricity source.

## *5.5 Perspectives*

This thesis looked at electricity scenarios for the Lake City Aspern, taking wind power, PV and geothermal electricity into account. Other possibilities of electricity generation (e.g. combined heat and power plants) or the options of energy storage were not considered. Also the transport sector was not included in the calculations, as there were no data available.

The heat- and cooling sector was not considered as the generation of load profiles for heat and cooling demand exceeded the scope of this project. The generation of load profiles with the program IDA Raum was investigated. With the online freeware version of the programme it is only possible to generate load profiles of single days. There would have been the possibility of, e.g. generating one sample profile for each month and then duplicating this sample profile for every day of the month. As this would have been done with average climate data for each month, with this method, peak days would not have been shown in the profiles. As one of the main aims of comparing the yearly data with load profiles would have been to assess the performance on peak events, this did not seam to be a relevant method.

It is recommended that for a next step of assessing energy scenarios for the Lake City Aspern, the heat and tansport sector should be included. More investigations should be put into the demand load profile, especially after the planned uses are defined more clearly. Also heat and cooling loads and wind generation profiles should be investigated further. In a second step, after finding technologically suitable

scenarios, the economic aspects could be considered. For all these aspects, technological and economic, the EnergyPLAN model can be recommended as a suitable tool.

# 6 Conclusion

In the most ambitious scenario with a low demand of 51 GWh/a, a PV production of 21 GWh/a and wind power output of 12 GWh/a, 48% self sustainability with 76% RES-E utilisation rate can be reached in the Lake City Aspern. An additional stable geothermal electricity supply of 18 GWh/a increases the self sustainability to 70% and with a decreased RES-E utilisation rate of 73%.

Flexible demand as a measure of increasing self sustainability and utilisation rate is only effective for the target demand scenarios of 51 GWh/a and for the minimal demand scenario of 91 GWh/a with geothermal electricity. In the target scenarios with geothermal electricity and the target scenario with maximum wind power and PV, flexible demand cannot tap the full potentials of self sustainability and utilisation rate. Additional measures for balancing supply and demand are needed in these scenarios.

For further research on possible balancing measures for the Lake City Aspern, the heat and transport sector should be included. The EnergyPLAN model can be recommended for this next step of research.

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# Annex

## Results of Main Scenarios

| Szenario | Annual Demand [GWh] | Flexible Demand [%] | RES-E Production [GWh] | Import [GWh] | Export [GWh] | Share of Annual Demand covered [%] | Share of demand directly supplied [%] | Direct utili-sation rate [%] | Direct use [GWh] |
|---|---|---|---|---|---|---|---|---|---|
| TW+PVo | 52,36 | 0 | 32,77 | 27,39 | 7,80 | 62,6 | 47,7 | 76,2 | 24,97 |
| TW+PVo Flex10% | 52,36 | 10 | 32,77 | 25,27 | 5,67 | 62,6 | 51,8 | 82,7 | 27,10 |
| TW+PVo Flex20% | 52,36 | 20 | 32,77 | 23,94 | 4,35 | 62,6 | 54,3 | 86,7 | 28,42 |
| TW+PVo Flex30% | 52,36 | 30 | 32,77 | 23,04 | 3,45 | 62,6 | 56,0 | 89,5 | 29,32 |
| TW+PVp | 52,36 | 0 | 25,57 | 31,00 | 4,21 | 48,8 | 40,8 | 83,5 | 21,36 |
| TW+PVp Flex10% | 52,36 | 10 | 25,57 | 29,22 | 2,42 | 48,8 | 44,2 | 90,5 | 23,15 |
| TW+PVp Flex20% | 52,36 | 20 | 25,57 | 28,42 | 1,62 | 48,8 | 45,7 | 93,7 | 23,95 |
| TW+PVp Flex30% | 52,36 | 30 | 25,57 | 27,99 | 1,19 | 48,8 | 46,6 | 95,3 | 24,38 |
| TW-Pvo | 52,36 | 0 | 20,71 | 35,63 | 3,99 | 39,6 | 31,9 | 80,7 | 16,72 |
| TW-PVo Flex10% | 52,36 | 10 | 20,71 | 34,17 | 2,52 | 39,6 | 34,7 | 87,8 | 18,19 |
| TW-PVo Flex20% | 52,36 | 20 | 20,71 | 33,29 | 1,64 | 39,6 | 36,4 | 92,1 | 19,07 |
| TW-PVo Flex30% | 52,36 | 30 | 20,71 | 32,65 | 1,00 | 39,6 | 37,6 | 95,2 | 19,71 |
| TW-PVp | 52,36 | 0 | 13,51 | 40,09 | 1,24 | 25,8 | 23,4 | 90,8 | 12,27 |
| TW-PVp Flex10% | 52,36 | 10 | 13,51 | 39,37 | 0,51 | 25,8 | 24,8 | 96,2 | 13,00 |
| TW-PVp Flex20% | 52,36 | 20 | 13,51 | 39,02 | 0,17 | 25,8 | 25,5 | 98,7 | 13,34 |
| TW-PVp Flex30% | 52,36 | 30 | 13,51 | 38,87 | 0,02 | 25,8 | 25,8 | 99,9 | 13,49 |
| MW+Pvo | 91,46 | 0 | 32,77 | 61,83 | 3,15 | 35,8 | 32,4 | 90,4 | 29,62 |
| MW+PVo Flex10% | 91,46 | 10 | 32,77 | 60,15 | 1,46 | 35,8 | 34,2 | 95,5 | 31,31 |
| MW+PVo Flex20% | 91,46 | 20 | 32,77 | 59,45 | 0,76 | 35,8 | 35,0 | 97,7 | 32,01 |
| MW+PVo Flex30% | 91,46 | 30 | 32,77 | 59,10 | 0,40 | 35,8 | 35,4 | 98,8 | 32,37 |
| MW+PVp | 91,46 | 0 | 25,57 | 67,38 | 1,49 | 28,0 | 26,3 | 94,2 | 24,08 |
| MW+PVp Flex10% | 91,46 | 10 | 25,57 | 66,29 | 0,39 | 28,0 | 27,5 | 98,5 | 25,18 |
| MW+PVp Flex20% | 91,46 | 20 | 25,57 | 66,05 | 0,16 | 28,0 | 27,8 | 99,4 | 25,41 |
| MW+PVp Flex30% | 91,46 | 30 | 25,57 | 65,96 | 0,07 | 28,0 | 27,9 | 99,7 | 25,50 |
| MW-Pvo | 91,46 | 0 | 20,71 | 72,30 | 1,55 | 22,6 | 20,9 | 92,5 | 19,16 |
| MW-PVo Flex10% | 91,46 | 10 | 20,71 | 71,23 | 0,48 | 22,6 | 22,1 | 97,7 | 20,23 |
| MW-Pvo Flex20% | 91,46 | 20 | 20,71 | 70,81 | 0,06 | 22,6 | 22,6 | 99,7 | 20,65 |
| MW-Pvo Flex30% | 91,46 | 30 | 20,71 | 70,75 | 0,00 | 22,6 | 22,6 | 100,0 | 20,71 |

| Szenario | Annual Demand [GWh] | Flexible Demand [%] | Production [GWh] | Import [GWh] | Export [GWh] | Share of Annual Demand covered [%] | Share of demand directly supplied [%] | Direct utili-sation rate [%] | Direct use [GWh] |
|---|---|---|---|---|---|---|---|---|---|
| MW-PVp | 91,46 | 0 | 13,51 | 78,28 | 0,33 | 14,8 | 14,4 | 97,6 | 13,18 |
| MW-PVp Flex10% | 91,46 | 10 | 13,51 | 77,96 | 0,00 | 14,8 | 14,8 | 100,0 | 13,51 |
| MW-PVp Flex20% | 91,46 | 20 | 13,51 | 77,95 | 0,00 | 14,8 | 14,8 | 100,0 | 13,51 |
| MW-PVp Flex30% | 91,46 | 30 | 13,51 | 77,96 | 0,00 | 14,8 | 14,8 | 100,0 | 13,51 |
| CW+Pvo | 144,66 | 0 | 32,77 | 112,87 | 0,98 | 22,7 | 22,0 | 97,0 | 31,79 |
| CW+Pvo Flex10% | 144,66 | 10 | 32,77 | 112,01 | 0,11 | 22,7 | 22,6 | 99,7 | 32,66 |
| CW+Pvo Flex20% | 144,66 | 20 | 32,77 | 111,90 | 0,01 | 22,7 | 22,6 | 100,0 | 32,76 |
| CW+Pvo Flex30% | 144,66 | 30 | 32,77 | 111,89 | 0,00 | 22,7 | 22,7 | 100,0 | 32,77 |
| CW+PVp | 144,66 | 0 | 25,57 | 119,33 | 0,23 | 17,7 | 17,5 | 99,1 | 25,34 |
| CW+PVp Flex10% | 144,66 | 10 | 25,57 | 119,10 | 0,00 | 17,7 | 17,7 | 100,0 | 25,57 |
| CW+PVp Flex20% | 144,66 | 20 | 25,57 | 119,10 | 0,00 | 17,7 | 17,7 | 100,0 | 25,57 |
| CW+PVp Flex30% | 144,66 | 30 | 25,57 | 119,09 | 0,00 | 17,7 | 17,7 | 100,0 | 25,57 |
| CW-Pvo | 144,66 | 0 | 20,71 | 124,36 | 0,41 | 14,3 | 14,0 | 98,0 | 20,30 |
| CW-Pvo Flex10% | 144,66 | 10 | 20,71 | 123,95 | 0,00 | 14,3 | 14,3 | 100,0 | 20,71 |
| CW-Pvo Flex20% | 144,66 | 20 | 20,71 | 123,95 | 0,00 | 14,3 | 14,3 | 100,0 | 20,71 |
| CW-Pvo Flex30% | 144,66 | 30 | 20,71 | 123,95 | 0,00 | 14,3 | 14,3 | 100,0 | 20,71 |
| CW-PVp | 144,66 | 0 | 13,51 | 131,16 | 0,01 | 9,3 | 9,3 | 99,9 | 13,50 |
| CW-PVp Flex10% | 144,66 | 10 | 13,51 | 131,16 | 0,00 | 9,3 | 9,3 | 100,0 | 13,51 |
| CW-PVp Flex20% | 144,66 | 20 | 13,51 | 131,15 | 0,00 | 9,3 | 9,3 | 100,0 | 13,51 |
| CW-PVp Flex30% | 144,66 | 30 | 13,51 | 131,15 | 0,00 | 9,3 | 9,3 | 100,0 | 13,51 |

## Results of Main Scenarios with Geothermal Electricity

| Szenario | Annual Demand [GWh] | Flexible Demand [%] | RES-E Production [GWh] | Import [GWh] | Export [GWh] | Share of Annual Demand covered [%] | Share of demand directly supplied [%] | Direct utili-sation rate [%] | Direct use [GWh] |
|---|---|---|---|---|---|---|---|---|---|
| TW+PVoGt | 52,36 | 0 | 38,28 | 20,87 | 6,79 | 73,1 | 60,1 | 82,3 | 31,49 |
| TW+PVoGt Flex10% | 52,36 | 10 | 38,28 | 19,13 | 5,05 | 73,1 | 63,5 | 86,8 | 33,23 |
| TW+PVoGt Flex20% | 52,36 | 20 | 38,28 | 18,04 | 3,96 | 73,1 | 65,5 | 89,7 | 34,32 |
| TW+PVoGt Flex30% | 52,36 | 30 | 38,28 | 17,18 | 3,10 | 73,1 | 67,2 | 91,9 | 35,18 |

| Szenario | Annual Demand [GWh] | Flexible Demand [%] | RES-E Production [GWh] | Import [GWh] | Export [GWh] | Share of Annual Demand covered [%] | Share of demand directly supplied [%] | Direct utili-sation rate [%] | Direct use [GWh] |
|---|---|---|---|---|---|---|---|---|---|
| TW+PVpGt | 52,36 | 0 | 38,28 | 20,87 | 6,79 | 73,1 | 60,1 | 82,3 | 31,49 |
| TW+PVpGt Flex10% | 52,36 | 10 | 38,28 | 19,13 | 5,05 | 73,1 | 63,5 | 86,8 | 33,23 |
| TW+PVpGt Flex20% | 52,36 | 20 | 38,28 | 18,04 | 3,96 | 73,1 | 65,5 | 89,7 | 34,32 |
| TW+PVpGt Flex30% | 52,36 | 30 | 38,28 | 17,18 | 3,10 | 73,1 | 67,2 | 91,9 | 35,18 |
| TW+PVpGt | 52,36 | 0 | 50,34 | 46,76 | 5,64 | 55,0 | 48,9 | 88,8 | 44,70 |
| TW+PVpGt Flex10% | 52,36 | 10 | 50,34 | 44,07 | 2,95 | 55,0 | 51,8 | 94,1 | 47,39 |
| TW+PVpGt Flex20% | 52,36 | 20 | 50,34 | 43,02 | 1,90 | 55,0 | 53,0 | 96,2 | 48,44 |
| TW+PVpGt Flex30% | 52,36 | 30 | 50,34 | 42,34 | 1,23 | 55,0 | 53,7 | 97,6 | 49,11 |
| TW-PVpGt | 52,36 | 0 | 43,14 | 51,79 | 3,46 | 47,2 | 43,4 | 92,0 | 39,68 |
| TW-PVpGtFlex 10% | 52,36 | 10 | 43,14 | 49,57 | 1,25 | 47,2 | 45,8 | 97,1 | 41,89 |
| TW-PVpGtFlex 20% | 52,36 | 20 | 43,14 | 49,05 | 0,73 | 47,2 | 46,4 | 98,3 | 42,41 |
| TW-PVpGtFlex 30% | 52,36 | 30 | 43,14 | 48,74 | 0,41 | 47,2 | 46,7 | 99,0 | 42,73 |
| MW+PVoGt | 91,46 | 0 | 50,34 | 46,76 | 5,64 | 55,0 | 48,9 | 88,8 | 44,70 |
| MW+PVoGt Flex10% | 91,46 | 10 | 50,34 | 44,07 | 2,95 | 55,0 | 51,8 | 94,1 | 47,39 |
| MW+PVoGt Flex20% | 91,46 | 20 | 50,34 | 43,02 | 1,90 | 55,0 | 53,0 | 96,2 | 48,44 |
| MW+PVoGt Flex30% | 91,46 | 30 | 50,34 | 42,34 | 1,23 | 55,0 | 53,7 | 97,6 | 49,11 |
| MW+PVpGt | 91,46 | 0 | 43,14 | 51,79 | 3,46 | 47,2 | 43,4 | 92,0 | 39,68 |
| MW+PVpGt Flex10% | 91,46 | 10 | 43,14 | 49,57 | 1,25 | 47,2 | 45,8 | 97,1 | 41,89 |
| MW+PVpGt Flex20% | 91,46 | 20 | 43,14 | 49,05 | 0,73 | 47,2 | 46,4 | 98,3 | 42,41 |
| MW+PVpGt Flex30% | 91,46 | 30 | 43,14 | 48,74 | 0,41 | 47,2 | 46,7 | 99,0 | 42,73 |
| MW+PVpGt | 91,46 | 0 | 38,28 | 55,71 | 2,53 | 41,9 | 39,1 | 93,4 | 35,75 |
| MW+PVpGt Flex10% | 91,46 | 10 | 38,28 | 54,37 | 1,19 | 41,9 | 40,6 | 96,9 | 37,09 |
| MW+PVpGt Flex20% | 91,46 | 20 | 38,28 | 53,63 | 0,45 | 41,9 | 41,4 | 98,8 | 37,83 |
| MW+PVpGt Flex30% | 91,46 | 30 | 38,28 | 53,25 | 0,08 | 41,9 | 41,8 | 99,8 | 38,20 |
| MW-PVpGt | 91,46 | 0 | 31,08 | 61,24 | 0,86 | 34,0 | 33,0 | 97,2 | 30,22 |
| MW-PVpGtFlex 10% | 91,46 | 10 | 31,08 | 60,48 | 0,09 | 34,0 | 34,0 | 100,0 | 31,08 |
| MW-PVpGtFlex 20% | 91,46 | 20 | 31,08 | 60,38 | 0,00 | 34,0 | 34,0 | 100,0 | 31,08 |
| MW-PVpGtFlex 30% | 91,46 | 30 | 31,08 | 60,39 | 0,00 | 34,0 | 34,0 | 100,0 | 31,08 |
| CW+PVoGt | 144,66 | 0 | 50,34 | 96,33 | 2,01 | 34,8 | 33,4 | 96,0 | 48,33 |
| CW+PVpGt | 144,66 | 0 | 43,14 | 102,43 | 0,90 | 29,8 | 29,2 | 97,9 | 42,24 |
| CW-PVoGt | 144,66 | 0 | 38,28 | 107,21 | 0,83 | 26,5 | 25,9 | 97,8 | 37,45 |
| CW-PVpGt | 144,66 | 0 | 31,08 | 113,69 | 0,11 | 21,5 | 21,4 | 99,6 | 30,97 |