MSc Program
Renewable Energy in Central and Eastern Europe

100% renewable energy supply for the city of Vienna and its impact on households' energy costs

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

supervised by
ao.Univ.Prof. Dr. Reinhard Haas

MMag. Alexander Cizik
8706611

Vienna, July 2011

Affidavit

I, Alexander Cizik hereby declare

1. that I am the sole author of the present Master Thesis, “The city of Vienna based on 100% renewable energy and its impact on households energy costs”, 119 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.

Vienna, ________________ ______________________________

Date Signature

Abstract

As a master student of renewable energy living in Vienna, it is naturally interesting to know, if my own city would be able to base its energy system fully on renewable energy produced within or around the city. But the answer should be more than a theoretically yes or no. It should also give an indication on costs for the individual household and necessary steps to achieve this goal.

To reach a scenario of 100 % renewable energy I first analyzed the potentials to reduce energy demand in the main sectors households, service sector, industry and mobility. Thereafter the reduced demand split by energy carrier is compared to the potentials for renewable energy within the city and around it. Finally in a combing model the effect on costs for households for energy services are simulated in 2 scenarios.

The first important result is that it is indeed possible to supply Vienna with 100% renewable energy produced within the city, or in its surroundings by using only little resources of its neighboring state, Lower Austria. The second result was that especially some of the saving measures will strongly increase the costs for energy services of households.

The main conclusions are that there is a significant potential of renewable energy to be used within and around Vienna at reasonable costs. But to really reach a 100% renewable scenario, it will be necessary to support especially households in the area of energy demand saving for space heating and mobility.

Table of content

List of tables

List of figures

List of abbreviation and symbols

€c	*Euro cent*
GWhel	*giga watt hour unit of electrical energy*
kWhel	*kilo watt hour unit of electrical energy*
kWp/MWp	*kilo watt peak / mega watt peak*
LRMC	*long run marginal costs*
MWhel	*mega watt hour unit of electrical energy*
NPV	*net present value*
DM	*dry matter of a material*
oDM (OTS)	*organic dry matter of a material*
TWh	*tera watt hour*
TWhel	*tera watt hour unit of electrical energy*
WACC	*weighted average cost of capital*

1 Introduction

1.1 Motivation

There are several reasons why I have chosen this topic:

- Firstly, I conducted several projects to develop plans for regional energy systems. In these projects, there was always a calculation included, if there are enough renewable resources within the area to have 100% renewable local energy supply. Since these regions were rural areas, there was always plenty of space for biomass and wind installations. Under these circumstances it was fairly simple to find a 100% solution. But it is a much more challenging task to find a solution for a big city.
- Secondly, even though the potential for renewable energy was always there, the expectation was that it is too expensive to switch. Despite the fact that there was never a detailed calculation made, how prices would change for households.

1.2 Core question of the thesis

The core question of this master thesis is – can the city of Vienna supply itself with renewable energy produced within the city and in its surrounding areas. Secondly what will be the price effect on energy services for households, if Vienna is 100% supplied by renewable energy produced within Vienna and its surroundings? How would the energy carrier mix look like in a 100% scenario? In case Vienna uses also potential from its surroundings, in this case Lower Austria, will it leave enough resources for Lower Austria to cover their energy demand on a renewable basis.

Since there is certainly more than one solution to reach a 100% renewable supply, two different scenarios are developed. In these scenarios the following underlying questions are covered:

- Potential and costs to reduce energy demand on household levels

- Potential to reduce energy demand for office buildings and other parts of the commercial sector (on this part only rough and global assumptions are made based on existing literature and practical experiences).
- Potential and costs for renewable energy sources (solar, hydro, geothermal, eventually wind) within the city.
- Potential and costs for renewable sources around the city (wind and biogas).
- Costs and effects when changing mobility from fossil fuels to e-mobility.
- Effects of reduction of consumption, additional renewables and e-mobility on the overall load profile of Vienna

The thesis will only be based on existing proven and running technology. It is not part of the thesis to investigate how new technology could improve the situation.

1.3 Citation of main literature

For the structure of energy demand mainly data from Statistik Austria was taken, especially in the case of households. The most important basis is the energy flow chart of Vienna 2009 with supporting details. This was combined with data from Wien Energie, especially for the load profile of demands. Wien Energie is the dominating energy supplier of Vienna. In 2009 its district heating system covers 35% of the heat demand of Vienna. It provides almost 100% of the gas and over 90% of electricity consumed in Vienna.

For the current energy production and load curves, the data was provided by Wien Energie and compared with data from Statistik Austria.

For the costs and saving potentials of e-mobility a study of Price Waterhouse Coopers and own research was the basis.

For the costs and savings potential for households, different studies and own research of prices for energy efficient appliances and thermal insulation was done.

For the potential of renewables the following sources have been used:

- Wind: The result on a project to estimate the commercial potential of wind energy in Austria. The results are partly published on the web-site: www.windatlas.at. Additional information was provided by members of the project.
- Solar: Vienna City Administration, “Wiener Umweltgut Solarpotenzialkataster” compared with the result of the “Solarkataster” of the city of Graz, Styria. Additional information was provided by experts of MA42 of Vienna.
- Biogas: Data from Statistik Austria for the available areas, combined with the biogas calculation tool of Wellinger to calculate the CH4 yield per ha.
- Hydro: Data from Wikipedia about Hainburg and production data from the annual report of Wien Energie.
- Heat pumps/ambient heat: Own calculation based on a study of Regio Energy,
- Geothermal: Internal study of Wien Energie.

For the load curves, the model is based on expert estimates, data of existing plants and current demand.

For the costs of electricity generation an IEA study was taken. The costs for heat production were provided by experts of Wien Energie.

The calculation model was prepared by the author himself.

1.4 Methodology and basic assumptions

At the beginning it has to be stated that the creation of a model to provide the city of Vienna with 100% renewable energy and calculate the effect on household costs is a very complex task. It is based on many assumptions. Almost each individual major assumption is debatable and could be discussed in a master thesis of its own. To limit the scope many simplifications had to be made. The most important are:

- It is a static model. There is no time factor in the model. Increases or decreases of prices are not covered.

- For many assumptions only a few sources or a single source have been investigated.
- No change of behavior is considered. There is of course a huge potential to save energy through change of behavior, e.g. switching from cars to public transport or bikes. However this potential is very difficult to calculate and therefore it is not considered in this master thesis. The only minor exception is the reduction of standby losses in households, which is partly based on change of behavior.
- For electricity no changes to the grid or storage capacity is included in the price calculation.
- In general effects on mismatch between load profiles of demand and supply of electricity are only described but not considered otherwise.
- For heat process heat is always considered as base load and space heating demand as middle or peak load.
- Distribution losses of heat and electricity are not covered.
- In the cost calculation of households only the costs of household demand reduction and higher energy process, due to the renewable mix, are considered. No indirect cost effect because of higher costs for energy services of other sectors are considered.
- The costs for households are shown in two case studies of a typical household. One is living in an average apartment connected to the district heating system. The other is living in a single family home using gas for heating and warm water.

The outcome of this master thesis can therefore only give results in order of magnitude. It was not the goal of this work to give precise results, however it is my firm believe that in most cases a more detailed analysis would not produce better results. Because it will be based inevitable again on new assumptions that are open for debate. This master thesis can give good guidelines what are the crucial factors to reach the goal of 100% renewable energy in Vienna and how a possible path can look like.

1.5 Structure of the work

In the first part an analysis of the current structure of energy demand and supply of Vienna is done. A special focus is laid on the structure of the main energy services:

- space heating
- process heat
- power & light and
- mobility & transport.

In the second part the potentials and costs for reduction of energy demand per energy service is described. The focus is on households and private mobility. In case of mobility the switch to electrical cars is investigated. Also the effect on the mix of energy carriers is analyzed when the demand for energy services are reduced. In this chapter there also first assumptions made which (renewable) energy carrier is possible to provide the energy for the remaining demand of the energy service.

For all the energy saving measures of households there is a cost evaluation done. Investment costs are annualized using the capital recovery factor method. For households the underlying long term interest rate is 4%. Amortization times are depending on the respective investment item. In principal the investment horizon of a household is expected to be the useful lifetime of the goods.

The third part analyses the potential of renewable energy within Vienna and in its surroundings. The focus within the city borders are solar applications (PV and solar thermal), and geothermal. Around the city the focus is on biogas, hydro and wind. For biogas the assumption is made, that it is fed into the gas grid and used for the existing gas power plants or to replace natural gas use at the end user. In the third part also the costs of renewable energy is calculated. Investment costs are annualized using the LRMC method. In case of electricity and gas the costs are compared to current market prices of electricity. In the case of heat it is compared to the current tariffs of Wien Energie.

In the fourth part all the data analyzed before is combined. A comparison of potentials and remaining demand is made per energy service. Finally two scenarios are prepared. In these two scenarios consideration regarding load profiles and costs are made. The first scenario is based on the cheapest solution. The second scenario is based on the politically most accepted solution. The assumptions behind are, that energy saving is always more accepted than the building of new energy production plants, a new hydro plant on the Danube is not accepted and solar and geothermal production is more accepted than wind and biogas. In the fifth and final part the main conclusions are summarized.

2 Current status of energy demand and supply of Vienna

2.1 Overview of demand

The current situation of Vienna can be seen in a flow chart:

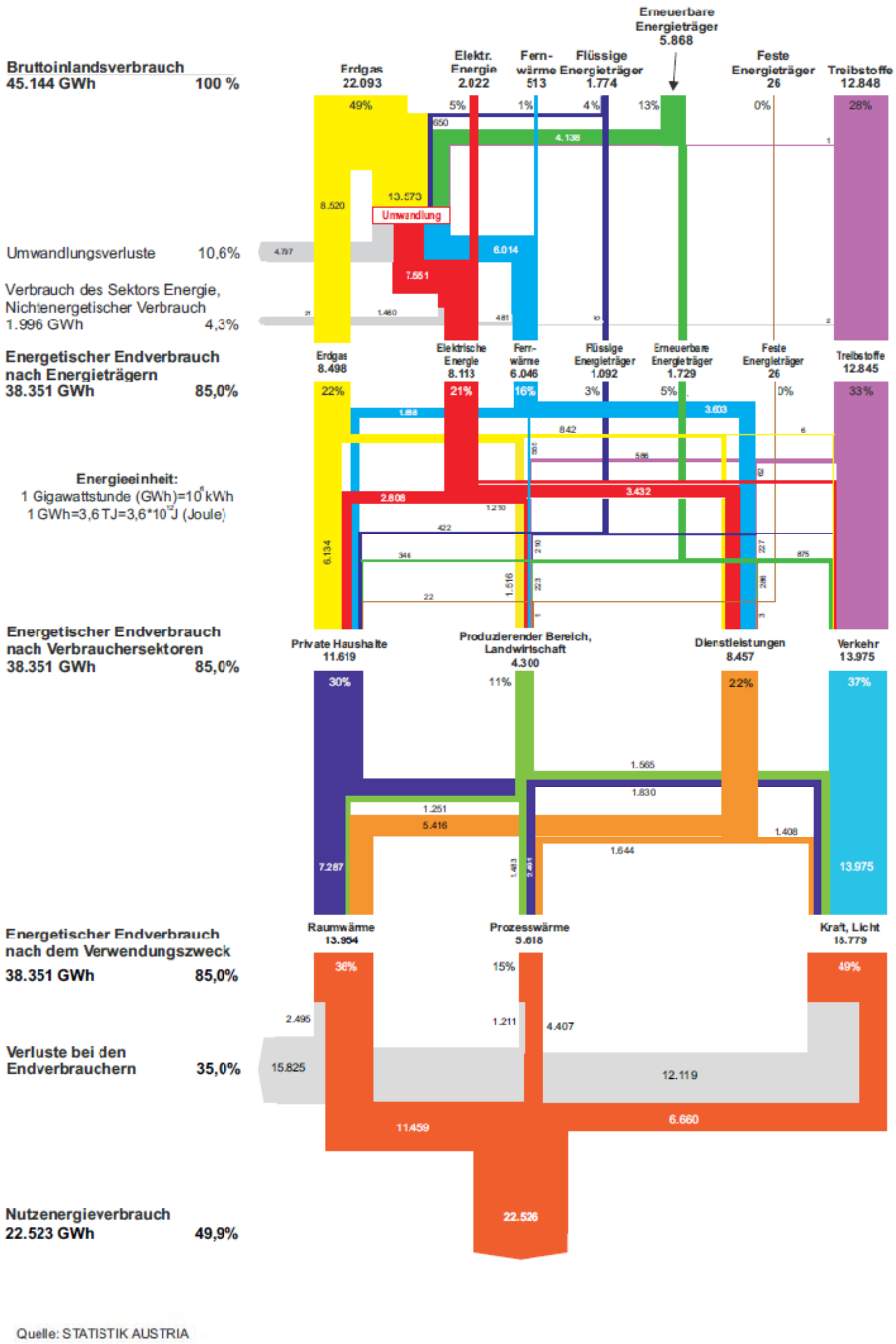


Figure 1: Energy flow chart Vienna (Source Statistik Austria 2009)

Total energy demand before losses and transformation of Vienna adds up to 45.144 GWh. Final energy demand currently is 38.351 GWh. All saving calculation are based on final energy demand.

2.1.1 Demand per sector

2.1.1.1 Demand of households

Households have a total share of 30% of energy demand. The dominating energy service is space heating. This is also the most important saving potential within this sector. A second important energy service part, mobility is not included, but shown under the sector “Verkehr”. Typically the share of energy consumption of mobility is around a third.[1] The potential of savings in this area is covered in a separate section about mobility. Only for the household sector calculations of cost effects are done.

2.1.1.2 Demand of industry and agriculture

Industry and agriculture play only a minor role in Vienna. With 11% its share of total consumption is rather low. Energy saving potentials are rather difficult to estimate in this sector, because processes between industries are very different and so are the saving potentials. Air pressure applications, for example, normally have a very high potential of savings, because of leakages or recovery of heat from the compressor machines. On the other hand industries with mostly electrical engines show a rather low potential for savings. Due to these complications only very conservative and simple assumptions are made regarding the saving potential per energy service.

2.1.1.3 Demand of services

The service industry on the other hand has a high share of energy consumption (22%). This sector comprises office buildings, shops, as well as public utilities like

[1] OÖ Energiesparverband Fürstenberger 2010

hospitals. In this sector there is still a significant potential for savings. For this sector a more detailed analysis is done for the potential of savings in the areas of power & light.

2.1.1.4 Demand of mobility and transport

With 37% it is the largest sector in Vienna. Currently the energy carrier of choice is fossil fuels with a share of 92%. There is of course a significant potential to reduce consumption simply by switching to smaller cars, or even public transport. But this would still mean that a substantial amount of fuels has to be switched to renewable sources. Therefore the underlying assumption of the model is a switch to electric cars, because the production of the additional electricity is most likely easier and more ecological than the production of additional biofuels.

2.1.2 Demand per energy service

This is an important distinction for the model, because it is also the basis to decide which energy carrier is needed, respectively which renewable energy source is needed. The 4 main categories which are analyzed are the following:

- Space heating
- Process heat
- Power&light
- Transport&mobility (in the chart part of power&light)

2.1.2.1 Space heating

Space heating is the largest energy service at the same level as transport&mobility. The total demand for space heating in 2009 in Vienna was 13.954 GWh. Fortunately is has also a significant reduction potential. But it comes at a price, as can be seen in the later chapters. The split of energy carriers in space heating can be seen below:

Table 1: Split of energy carrier in space heating (Source Statistik Austria 2009)

	Raumheizung
Summe alle Energieträger	13.954
Feste Energieträger	24
Flüssige Energieträger	714
Treibstoffe	0
Gasförmige Energieträger	5.732
Erneuerbare Energieträger	732
Fernwärme	5.426
Elektrische Energie	1.326

The two dominant energy carriers are district heating and gas both having a share of around 40%. Renewables are mostly biomass and biofuels. Also electricity plays an important part.

2.1.2.2 Process heat

Has a much smaller share than space heating with 5.618 GWh but its potential for reduction is also much smaller. On the other hand it can be partly produced through solar thermal installations. The split of current energy carriers is as follows.

Table 2: Split of energy carrier in process heat (Source Statistik Austria 2009)

	Prozeßwärme
Summe alle Energieträger	5.618
Feste Energieträger	2
Flüssige Energieträger	125
Treibstoffe	1
Gasförmige Energieträger	2.743
Erneuerbare Energieträger	123
Fernwärme	620
Elektrische Energie	2.004

In case of process heat the dominating energy carriers are gas and electricity. The part of process heat not only includes all forms of steam (20%) and warm water production, but also cooking devices.

2.1.2.3 Cooling

Is not separately shown in the graph. No comprehensive data for cooling are available, since no separate measurements of cooling devices are done. In a discussion with experts of Fernwärme Wien the estimate was that the current demand is around 200 GWh. In recent years the consumption for cooling becomes more and more important. Firstly, because in modern office buildings the installation of air condition is becoming a standard. Secondly, modern office buildings are more and more based on glass facades, which allow huge solar gains. Unfortunately architectural “beauty” consideration often prevail energy efficiency requirements.

2.1.2.4 Power & light

Light & power comprises all energy consumption for light and electrical appliances. It also includes appliances as dish washers, which use a big part of its energy to produce process heat. Nevertheless it is registered under power & light.

The saving potential for light & power is covered in the section of households. Light in the private commercial sector, as well as different industrial power appliances are not covered specifically, but part of a general assumption of saving potentials for electricity.

The general assumption is, that this energy service can only be provided with electricity, despite the fact that part of it is also pure heat.

The total demand for power & light excluding the mobility services was 4.804 GWh.

2.1.2.5 Mobility & transport

Mobility & transport has a total consumption of 13.975 GWh. 92% of it is provided for by fossil fuels. The rest is mostly based on renewable, the majority is addition of biofuels.

Since more biofuels are not an option the only possible energy carrier remains electricity. Biogas could also be an option but in this model it is used for other energy services or to produce electricity.

2.1.3 Demand per energy carrier

2.1.3.1 Current situation

The biggest primary energy carrier currently is natural gas with a share of almost 50%. Second is oil with 28% used mainly for mobility&transport and only third a variety of renewables with 13%. The mix of renewable can be seen below:

Table 3: Split of renewable energy production in Vienna (Source Statistik Austria and Wien Energie 2009)

Schlüssel erneuerbare	**2009**
Summe alle Energieträger	45.144
Feste Energieträger	26
Flüssige Energieträger	1.774
Treibstoffe	12.848
Gasförmige Energieträger	22.093
Erneuerbare Energieträger	5.868
Brennholz	*344*
Biogene Brenn- und Treibstoffe	*2.092*
Wasserkraft	*1.154*
Umgebungswärme etc.	*119*
Brennbare Abfälle	*2.148*
Wind und Photovoltaik	*11*
Fernwärme	513
Elektrische Energie	2.022

The biggest source is waste, closely followed by bio fuels and biomass. Third is hydro, mostly coming from the plant of Freudenau (see also the chapter of production).

61% of natural gas is used to produce electricity and heat for the district heating system. Other sources for district heating are waste incineration, biomass from one large biomass combined cycle plant and ambient heat from industrial production.

2.1.3.2 Potential for (renewable) energy carrier

This model is based on the following assumption which renewable energy carrier can be used to provide different energy services:

Table 4: Potential of renewable energy carrier per energy service

Energy service	Space heating	Process heat	Cooling	Power&light	Transport&mobility
Possible energy carrier	District heating biogas, geothermal, electricity (heat pumps)	District heating biogas, geothermal, electricity (heat pumps) solar thermal (max. 2/3)	electricity, district heating, geothermal	electricity	electricity

2.1.4 Load curve of demand

The data for electricity are based on an estimate of current electricity supply of Wien Energie in Vienna. On the other hand the load curves for heating are based on data of the district heating system, which covers currently only around a third of the cities heat demand. Nevertheless the load curves of the district heating system are assumed to be the same as for the entire city.

For electricity the load curve in a typical winter month (January) is 1,17 of the average demand (1,35 during the day and 0,99 during the night). In summer (July) the current load curve is 1,04 (1,21 during the day and 0,87 during the night). Based on current final electricity demand of 8.113 GWh the following typical load curve can be derived.

Table 5: Current electricity load factors of demand

Current status MW	Average load	Day	Night
Summer	963	1.121	806
Winter	1.084	1.250	917

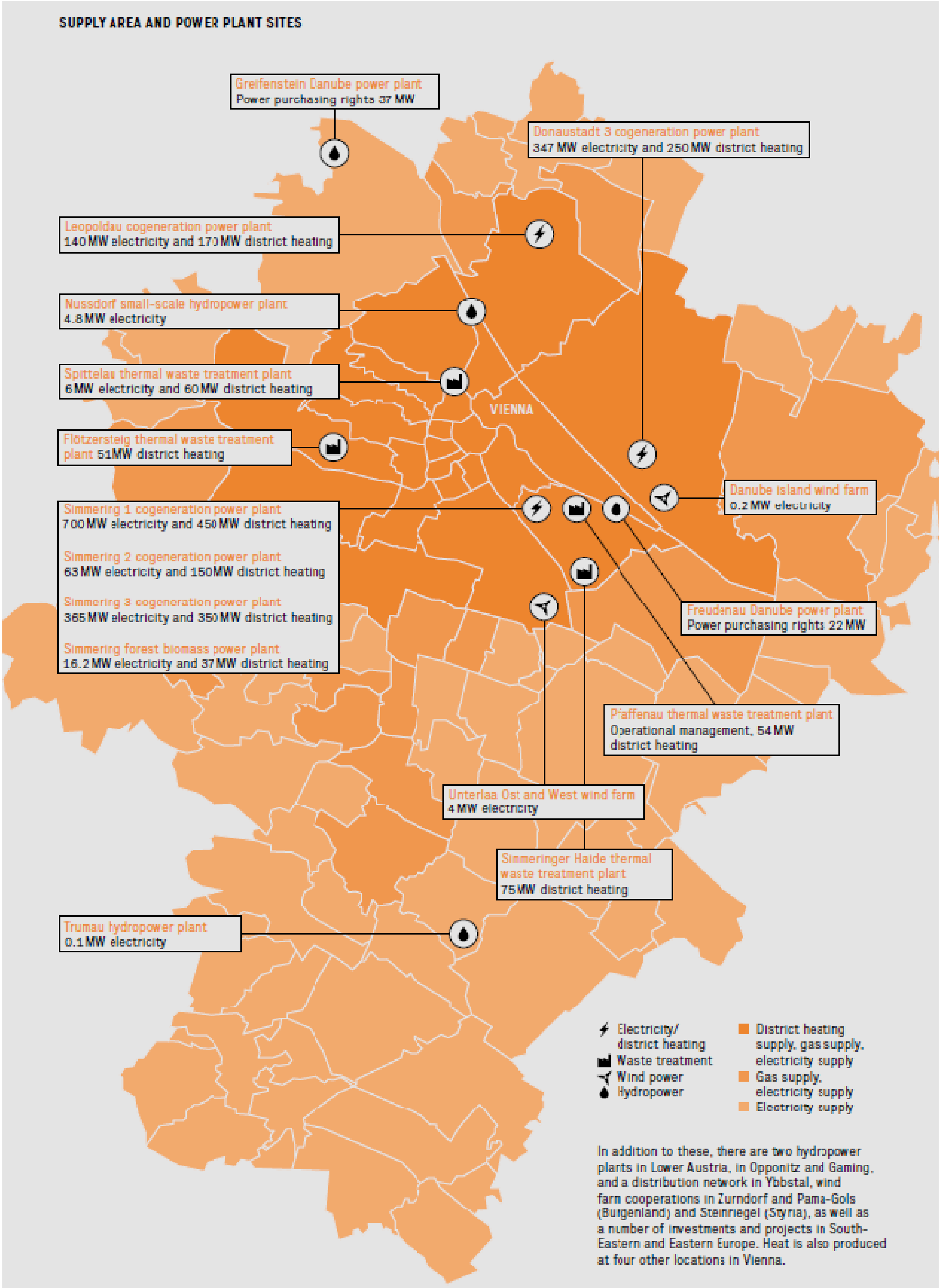


Figure 2: Supply area and production sites of Wien Energie (Source annual report 2009/2010)

For heat the load profile can be split into three categories. Base load that is needed all year round, mostly for process heat, within the district heating system is around 240 MW. Thereof 50 MW are losses in the distribution network. The Vienna district heating system currently covers around a third of the market. Excluding the network losses for the entire area of Vienna the base load can be estimated being around 620 MW. This figure can be compared with the consumption number for process heat form the energy flow chart. Assuming that process heat is consumed constantly over the year the base load according to the flow chart would be 640 MW. Since within process heat also other heat applications as cooking for example are included, 620 MW can be assumed for the warm water production.

Average (middle) load in winter is around 1300 MW in the district heating system and estimated 3.800 MW for the entire city.

Peak load is 2400 MW in the district heating system, which would lead to around 7200 MW for the entire city. Fortunately only 2-3% of total demand is peak load demand.[2]

2.2 Energy supply and own production of the city of Vienna

Two describe the current energy supply two sources have been used. On the one hand the energy flow chart (see above in chapter 2.1) and on the other hand data provided by Wien Energie. The current production of Wien Energie can be seen in the table below:

---

[2] All data provided by experts from Fernwärme Wien

Table 6: Energy production of Wien Energie (Source annual report 2009/2010)

ELECTRICITY PRODUCTION

in MWh	2009/10	±%	2008/09	2007/08
Thermal power stations	6,587,005	20.5	5,466,339	4,604,183
Hydroelectric power stations	447,268	-1.7	454,822	474,808
Wind turbines	307	-5.8	326	305
Biomass power plants	162,049	23.0	131,786	150,380
Waste incineration	4,513	-16.1	5,381	11,865
Total electricity production	**7,201,143**	**18.9**	**6,058,654**	**5,241,541**
Hydropower plants incl. partnerships	42,970	72.1	24,969	8,296
Wind farms incl. partnerships	111,127	10.1	100,932	78,732

District heating, local heating, district cooling

HEAT PRODUCTION

in MWh	2009/10	±%	2008/09	2007/08
Waste incineration	1,448,916	-4.0	1,510,063	1,470,047
Cogeneration	3,881,312	22.3	3,173,119	3,353,347
Peak load boilers	212,887	-18.0	259,635	239,605
Forest biomass power station	99,962	12.4	88,940	91,009
Total from all networks	**5,643,077**	**12.1**	**5,031,757**	**5,154,008**
Heating centres	73,154	19.8	61,083	61,805
Total district heating production	**5,761,231**	**13.1**	**5,092,840**	**5,215,813**

2.2.1 Renewables

The split of energy carriers according to Statistik Austria was shown above with a total renewable consumption before transformation of 5.868 GWh. Thereof 4.138 GWh were used to produce heat and electricity in different power plants. The main part was biomass and biofuels. Below are some details to the production plants of renewable energy within Vienna.

2.2.1.1 Electricity

The biggest renewable source is hydro. In the table above the production of Wien Energie is shown, but it gives no clear indication about the hydro electricity produced within Vienna. Since this thesis is about the city of Vienna and its surrounding, the production of the two hydro plants Freudenau and Nussdorf located within Vienna is taken.

The long term average of Freudenau is 1050 GWh and ofNussdorf 25 GWh.[3]

For wind the same is applied. Only production within Vienna or in its surroundings is included. According to the “windatlas” of IG-Wind there are the following plants installed in Vienna:

- Donauinsel 200 kW
- Freudenau 600 kW
- Unterlaa 4 MW
- Breitenlee 2,55 MW

The total installed capacity is therefore 7,35 MW. Assuming around 2000 full load hours there is currently less than 15 GWh production of electricity from wind, which is almost nothing. In the statistics for 2009 only 11 GWh were shown including PV.

A major biomass power plant is within the city at Simmering, but the biomass itself comes mostly from outside. The current electricity production based of biomass of Wien Energie is 162 GWh. Another 4,5 GWh are produced through waste incineration.

2.2.1.2 Production of heat

There are currently four waste incineration plants in Vienna to produce base load heat for the city. Waste incineration is normally only partly classified as renewable. For this model the total waste incineration is taken, since there is currently no realistic alternative to remove the waste. The total heat production out of waste incineration is 1.450 MWh. In addition there are 100 GWh heat produced in the biomass plant. So the total renewable heat production from Wien Energie is 1550 MWh.

[3] Data from Wikipedia „Donaukraftwerke“

2.2.1.3 Production of cold

According to experts from Wien Energie the short term potential for remote cooling is 200 MWth with 1000 full load hours. Thereof more than 50% is adsorption cooling. The efficiency rate (COP) of adsorption cooling is around 0,8. For compressor based cooling the efficiency rate is around 4,5.

The production of cold is not a renewable source by itself, but similar to heat pumps it increases the efficiency and in case of adsorption cooling is a possibility to use excess heat in summer.

2.2.2 Fossil fuel based

The biggest energy carrier is natural gas with 22.093 GWh. Thereof 60% are used to produce electricity in gas power plants, the rest is sold through the gas net.

The electricity output from the three caloric power plants was 6.587 GWh in 2009/2010. Total installed capacity is 1615 MW.

Most of the gas sold is used to provide space and process heat. Of the 8.500 GWh gas around 7.000 GWh are consumed by households and the service sector. The assumption behind is that this is 100% used for warm water and space heating[4] and is 100% replaceable by solar thermal, heat pumps, district heating and other. For the industrial part of 1.516 GWh the assumption is that a third of it (500 GWh) can not as easily be replaced because of special applications. The only renewable substitution therefore would be biogas or electricity.

The second largest group of energy carrier are fossil fuels with 12.845 GWh car fuels and 1092 GWh other fossil fuels. As described later the will be replaced by electricity.

The remaining part of coal and other is neglectable.

[4] Strom- und Gastagebuch Statistik Austria 2008

2.2.3 Load curve of the production

To show the load curve a typical summer and winter month is taken on average. Of course especially for renewables as wind and solar installations there is a strong fluctuation within the month. In both cases this means, that if a big share of energy production is based on these technologies, storage capacity is needed. In case of electricity the grid can, to a certain extent, provide the necessary storage function. Also electric cars with intelligent loading systems can act as an additional puffer to balance load differences between supply and demand.

2.2.3.1 Current capacity and load curve of heat

In the case of heating it is much more difficult, because there is no regional grid to balance supply and demand. In the current situation the heating system is mostly based on gas and district heating. Gas is similar to electricity provided by a transnational grid with integrated storage capacities. District heating is balanced through a mix of different cogeneration and pure heating plants, providing base, middle and peak load, depending on demand. Below the mix of Vienna can be seen. Waste incineration with 240 MW is used as base load, cogeneration plants will be used for middle load (1575 MW) and six pure heating plants are installed to provide peak load (1450 MW).

Table 7: Overview of district heating plants in Vienna (Source annual report Wien Energie 2009/2010)

INSTALLED DISTRICT HEATING OUTPUT

in MW	2009/10
Waste incineration	240
Cogeneration	1,575
Peak load boilers	1,450
Waste industrial heat	6
Total from all networks	3,271
Heating centres	52

The current district heating system covers 33% of the low temperature heating market (space heating and warm water). According to experts from Fernwärme Wien the maximum extension would be 70%.

2.2.3.2 Current capacity and load curve of electricity

Below is the installed capacity of own plants in Vienna, without the hydro plants because they are not fully owned. Hydro and waste incineration is generally used as base load. Whereas the gas and biomass plants are used for middle and peak load. All cogeneration plants can switch between condensation and cogeneration operation, except for Leopoldau. According to Wien Energie the plant Donaustadt 3 is the most efficient with a total efficiency of 86% (347 MWel and 250 MWth)[5]. As can be seen later there is some potential for biogas around Vienna, which theoretically could be used in one of the existing cogeneration plants. For this model the most efficient – Donaustadt 3 is used.

[5] Annual report Wien Energie 200/2010

Table 8: Installed electricity capacity Wien Energie own plants (Source annual report 2009/2010)

INSTALLED ELECTRICAL OUTPUT[1] in MW	2009/10
Simmering 1 cogeneration power plant	
Condensation operation	820
Cogeneration operation	700
Simmering 2 cogeneration power plant	
Condensation operation	65
Cogeneration operation	63
Simmering 3 cogeneration power plant	
Condensation operation	420
Cogeneration operation	365
Forest biomass power plant at Simmering	
Condensation operation	24.5
Cogeneration operation	16.2
Donaustadt 3 cogeneration power plant	
Condensation operation	395
Cogeneration operation	347
Leopoldau cogeneration power plant	
Condensation operation	100
Cogeneration operation	140
Spittelau waste treatment plant	6
Total condensation operation	1,824.5
Total cogeneration operation	1,631.2

The real load distribution between summer and winter is strongly influenced by the demand for heat for the district heating system.

The load summer/winter load curve of hydro and wind was discussed with experts and the following was the assumption:

Table 9: Load curve hydro and wind (Source Wien Energie experts and Wikipedia)

Wind		Vienna
Vienna		**Donauinsel + Unterlaa**
Installed capacity	*MW*	4,2
Average yearly production	*GWh/a*	6,1
Load summer		0,13
Load winter		0,19
Hydro		
		Freudenau
Installed capacity	*MW*	172
Average yearly production	*GWh/a*	1052
Load summer		0,85
Load winter		0,55

The estimate was that on average there is no difference between day and night. Hydro and wind will play a major role in the future renewable model. For the load curve these estimates are taken for all plants. For hydro this is very realistic, because the only additional potential plant is on the same river as Freudenau, only 50 km away. For wind this is only a approximation because the future wind mills could be placed all over Lower Austria an area with an extension of 150 km each direction.

For solar plants no real data was available in Vienna, but from a plant in Germany, This data was taken and adjusted by the overall higher radiation in Vienna, compared to central Germany.

3 Energy saving potential and costs

3.1 Structure of households

Since households play a special part, the detailed structure of households and its energy demand is investigated first.

In Vienna there are currently 845.000 (771.000 in 2001) households with an average size of 1,99 (1,98 in 2001) persons.[6] The increase of households was 9,6% in 10 years, while the average size remained the same. The average size of living space per household was 74,4 m2.[7] This results in a total heated space of 63 Mio m2. This corresponds roughly with a figure of a study of Energieagentur[8] which estimated 66 Mio m2. In the same study Energieagentur estimated that there are 958.082 apartments (including single family houses) in the city. The explanation of the higher figure could derive from second homes, that are not registered in the statistical data.

Dividing the consumption figures of the energy flow chart[9] by the number of households (statistical data) this results in the following:

Electricity consumption per household: 3.320 kWh per year.

Space heating demand per household: 8620 kWh per year, or 116 kWh/m2a. According to the Energieagentur data the respective figures would be 7659 kWh/a and 111 kWh/m2a.

Total consumption per household (excl. mobility and transport): 13.660 kWh per year

In the following chapters the saving potential and the related costs will be estimated.

---

[6] Statistik Austria Bevölkerung 2011
[7] Statistik Austria Mikrozensus 2009
[8] Studie Energieagentur 2011
[9] Statistik Austria Energieflussbild 2009

3.2 Saving potential and costs for space heating

3.2.1 Households

3.2.1.1 Structure of buildings in Vienna

Table 10: Age structure of existing dwellings in Vienna (Source Statistik Austria Mikrozensus 2009)

Tabelle 10: Bauperiode, Gemeindetyp, Nutzfläche (Schluss)
Construction period, commune type, floor space

Nutzfläche (Gruppen in m²)	Hauptwohnsitz-wohnungen insgesamt	Bauperiode							
		vor 1919	1919 bis 1944	1945 bis 1960	1961 bis 1970	1971 bis 1980	1981 bis 1990	1991 bis 2000	2001 und später
	Absolut (in 1.000)								
	Gemeinden mit 20.000 und mehr Einwohnern (ohne Wien)								
Zusammen	**638,1**	**60,2**	**61,3**	**92,6**	**114,9**	**102,5**	**66,5**	**85,0**	**55,1**
Bis unter 35	25,8	(3,3)	(3,1)	(4,3)	(6,7)	(3,4)	(1,7)	(2,3)	(0,9)
35 bis unter 45	44,8	(3,3)	(6,3)	(9,4)	(7,2)	(7,1)	(4,5)	(5,8)	(1,2)
45 bis unter 60	101,5	(8,0)	(12,8)	22,1	16,0	(11,7)	(8,2)	(14,2)	(8,4)
60 bis unter 70	78,0	(6,6)	(9,6)	(12,7)	17,8	(10,5)	(7,3)	(8,2)	(5,4)
70 bis unter 90	170,4	(12,8)	(11,3)	19,0	34,4	28,0	19,2	28,2	17,4
90 bis unter 110	88,9	(10,9)	(6,7)	(9,8)	(13,5)	18,5	(11,2)	(10,1)	(8,2)
110 bis unter 130	49,0	(5,1)	(5,0)	(4,9)	(8,7)	(9,2)	(6,6)	(5,1)	(4,3)
130 bis unter 150	35,0	(3,2)	(3,0)	(5,5)	(5,1)	(7,0)	(3,9)	(4,0)	(3,2)
150 und mehr	44,1	(7,0)	(3,4)	(4,7)	(5,7)	(7,0)	(3,8)	(6,4)	(6,1)
	Wien								
Zusammen	**838,4**	**238,1**	**96,7**	**99,5**	**129,8**	**86,6**	**65,4**	**73,0**	**49,4**
Bis unter 35	51,0	(21,9)	(8,9)	(6,8)	(7,1)	(2,3)	(1,3)	(1,9)	(0,8)
35 bis unter 45	85,0	28,0	(21,0)	(13,5)	(9,4)	(6,7)	(1,9)	(3,8)	(0,8)
45 bis unter 60	177,3	44,4	26,5	35,2	34,4	(11,9)	(8,0)	(8,6)	(8,3)
60 bis unter 70	113,1	25,1	(10,1)	(17,7)	27,4	(9,8)	(5,7)	(11,5)	(5,8)
70 bis unter 90	207,9	46,6	(15,1)	(17,8)	35,6	30,7	25,0	(21,2)	(15,9)
90 bis unter 110	101,7	32,3	(5,7)	(3,9)	(9,2)	(14,1)	(13,1)	(15,5)	(7,8)
110 bis unter 130	52,6	(19,5)	(4,2)	(1,5)	(3,3)	(6,9)	(5,5)	(6,0)	(5,6)
130 bis unter 150	(21,3)	(8,1)	(2,8)	(0,9)	(1,4)	(1,5)	(2,5)	(2,1)	(2,1)
150 und mehr	28,4	(12,1)	(2,3)	(2,2)	(1,9)	(2,8)	(2,5)	(2,4)	(2,4)

Q: STATISTIK AUSTRIA, Mikrozensus, Jahresdurchschnitt 2009.

As can be seen in Vienna there is a high percentage of buildings before 1919 (28%) compared to other bigger cities in Austria (9%). There is also a high percentage of buildings between 1960 and 1980 (26%), a period with a rater low thermal standard of buildings. This shows that there is a high potential for the reduction of heating consumption based on the age of building.

On the other hand Vienna has a low number of single or dual family homes (9%) compared to the rest of Austria (46,7%) – see table below. This should result in lower heating consumption per m2 compared to other parts of Austria.

Table 11: Number of dwellings per building in Austria (Statistik Austria Mikrozensus 2009)

Hauptwohnsitzwohnungen nach Gebäudegröße und Bundesland
Dwellings (main residences) by number of dwellings in the building and provinces

	Hauptwohnsitz-wohnungen insgesamt in 1.000	davon in Gebäuden mit .... Wohnungen				
		1	2	3 bis 9	10 bis 19	20 und mehr
		in %				
Österreich	**3.598,3**	**35,4**	**13,1**	**19,5**	**16,9**	**15,1**
Burgenland	112,0	71,3	12,9	9,3	5,1	1,4
Kärnten	238,2	42,6	19,5	21,9	10,5	5,5
Niederösterreich	664,7	55,2	13,7	16,6	9,8	4,6
Oberösterreich	582,1	37,8	20,4	22,3	13,6	6,0
Salzburg	223,5	29,9	19,3	27,8	13,5	9,5
Steiermark	500,9	45,3	12,6	20,2	13,5	8,4
Tirol	288,2	30,6	19,4	30,1	13,0	6,9
Vorarlberg	150,3	38,1	18,7	28,2	10,2	4,8
Wien	838,4	7,7	1,3	12,8	33,9	44,4

Q: Statistik Austria, Mikrozensus.

3.2.1.2 Reduction of space heat demand

The table above shows that the main impact to reduce the energy consumption in Vienna lies in multi dwelling buildings rather than single family homes. To estimate the size of heated space in buildings the following table was used.

Table 12: Average size of buildings based on legal status (Statistik Austria Mikrozensus 2009)

Übersicht 11
Durchschnittliche Nutzfläche der Hauptwohnsitzwohnungen nach Rechtsverhältnis und Bundesland
Average floor space of dwellings (main residences) by legal basis and provinces

	Hauptwohnsitz-wohnungen insgesamt	Rechtsverhältnis der Haushalte an der Wohnung					
		Hauseigentümer	Verwandte der Hauseigentümer	Wohnungs-eigentümer	Hauptmieter	Untermieter	Sonstige Rechts-verhältnisse
	Durchschnittliche Nutzfläche im m²						
Österreich	**98,5**	**135,0**	**92,6**	**82,7**	**68,5**	**68,1**	**83,4**
Burgenland	123,1	135,5	104,1	85,4	81,9	76,6	91,7
Kärnten	105,6	132,6	84,4	86,2	72,2	59,1	89,3
Niederösterreich	112,5	136,2	93,9	80,7	69,9	78,6	97,0
Oberösterreich	104,6	140,1	93,8	81,1	68,4	74,9	86,4
Salzburg	93,6	130,0	85,2	75,7	66,0	57,4	74,6
Steiermark	105,4	137,1	101,9	82,4	66,5	71,6	75,4
Tirol	99,1	125,8	90,7	85,4	72,2	74,7	84,5
Vorarlberg	101,3	126,9	84,1	85,6	71,6	71,4	84,0
Wien	74,4	135,7	78,5	84,7	67,4	60,8	73,4

Q: Statistik Austria, Mikrozensus

Since typically people who live in family houses are also the owner, the figure of 135,7m2 per family house was taken. According to Statistik Austria 7,7% or 65.000 households are living in single family houses. The total heated space of single family houses is therefore 8,8 Mio m2. This is 14% of the total heated space.

According to the Energieagentur study the space heating demand for all single family houses was 2.159 GWh in 2010 Per building the figure was 26.242 kWh. Divided by 135,7m2 this results in an average consumption of 193 kWh/m2a for family houses. For multi dwelling buildings the respective figure is 103 kWh/m2.

According to a study of Biermayr et al an improved but realistic scenario would be to reduce the heat demand of buildings down to 90 – 125 kWh/m2 for renovations completed until 2020 increasing to 50-55 kWh/m2 until 2050.[10] In a more ambitious scenario heat demand for renovated buildings could go down to 10 kWh/m2.

Unfortunately most studies concentrate on technical potential but disregard the investment costs needed. One reason could be that it is very difficult to get generalized figures, because each renovation is very much dependent on the individual circumstances. There are general figures for insulation/m2 of wall but this is only a fraction of the total renovation. For example costs to insulate the ground floor are very different if a basement is existing or not. Only one estimate could be found based on several case studies. These figures are very hard to generalize, but at least the give an indication of magnitude of costs. According to 4 case studies of Kapusta[11] the investment costs to reduce the energy consumption for heating of buildings are as follows:

For a single family house with 150m2 to reduce from 184 kWh/m2 down to 60 kWh/m2 the investment costs are 235 EUR/m2. To reduce a 119m2 family house from 285 kWh/m2 down to 35 kWh/m2 – 750 EUR/m2.

For multi dwelling buildings with 1323m2 to reduce from 161 kWh/m2 down to 44 kWhM2 – 296 EUR/m2. To reduce a 1414m2 building from 192 kWh/m2 down to 14 kWh/m2 – 640 EUR/m2.

The base consumption of the first case study fit to the current average consumption per family house. The other three cases start from higher consumption. According to the opinion of the author the starting point of a thermal renovation is not influencing the overall investment costs a lot, in case a low energy demand level shall be reached. For example it makes no difference in costs to insulate a house with no

[10] Biermayr et al Heizen 2050, Klima und Energie Fonds 2010
[11] Friedrich Kapusta, Klimaschutz und Sanierung, Energieinstitut der Wirtschaft 2010

current insulation or with a moderate insulation. The same applies for the exchange of windows. The important factor is the future level to be reached. To reach very low levels it is necessary to install a ventilation system with heat recuperation. Therefore the figures for prices and future levels of the cases of Kapusta are taken, despite the fact that the current level is often better. For the moderate and ambitious demand reduction scenario the lower reduction is used and for the high demand reduction scenario the higher reduction figure. Firstly it has to be mentioned that the high decrease of consumption is only achieved with high investment costs and because of practical reasons it is often very difficult to achieve e.g. 14 KWh/m2 in a historic building before 1914, which is also in accordance with the result of the study of Biermayr.

In case all multi dwelling buildings are reduced to 44 kWh /m2 and all single family homes are reduced to 60 kWh/m2 the resulting total demand for Vienna for heating of private homes would go down to 2907 GWh from 7287 GWh (-60%) see table below.

If the lower levels of Kapusta were taken the demand would be reduced down to 1066 GWh (-85%). This figure is taken for the high demand reduction scenario.

Table 13: Reduction of space heat demand households moderate and ambitious scenario

	Number	% of total	m2/house	Total m2	% of total	kWh/m2	Total GWh	Reduced kWh/m2	Total GWh
Family	65.065	7,7	135,7	8.829.321	14,0	193	1.704	60	530
Multi dwelling	779.935	92,3	69,3	54.038.680	86,0	103	5.583	44	2.378
Total	845.000		74,4	62.868.000			7.287		2.907

The resulting question is how this would influence different energy carriers. To get a feeling the table below shows the type of heating devices and energy carrier in Vienna.

Table 14: Share of different heat types in Vienna (Source Statistik Austria 2009)

Heizungen 2007/2008 nach Bundesländern, verwendetem Energieträger und Art der Heizung Ergebnisse für Wien							
		Heizungsart					
Energieträger	Wohnungen ("Haupt-wohn-sitze") insgesamt	Einzel-ofen	Gaskon-vektor	Elektro-heizung (fest ver-bunden)	Zentral- und gleich-wertige Heizung	Fern-wärme[1])	In %
Holz, Hackschnitzel, Pellets, Holzbriketts	15.259	11.513			3.745		1,8
Kohle, Koks, Briketts	1.172	1.172					0,1
Heizöl, Flüssiggas	25.929	7.962			17.967		3,1
Elektr. Strom	51.506	12.704		30.032	8.769		6,2
Erdgas	456.642		43.486		413.156		54,9
Solar, Wärmepumpen	1.649				1.649		0,2
Fernwärme	278.947					278.947	33,6
Zusammen	**831.103**	**33.351**	**43.486**	**30.032**	**445.287**	**278.947**	**100,0**
Q: STATISTIK AUSTRIA, Energiestatistik: MZ Energieeinsatz der Haushalte 2007/2008. Erstellt am: 08.06.2009. - 1) Hauszentralheizungen mit unbekanntem Brennstoff werden als Fernwärme definiert.							

The dominant energy carriers are natural gas (55%) and district heating (34%). In third place is electricity with 6%. The rest – in total 5% - can be neglected. For electricity as can be seen later, there are several options to produce it on a renewable basis. Also for the district heating part there are several renewable sources available to cover the lower demand. The data of Statistik Austria shows a similar picture with gas and district heating dominating.

Table 15: Current split of energy carriers for space heating of households (Source Statistik Austria 2009)

Summe alle Energieträger	7.287
Feste Energieträger	11
Flüssige Energieträger	388
Treibstoffe	0
Gasförmige Energieträger	4.736
Erneuerbare Energieträger	330
Fernwärme	1.336
Elektrische Energie	486

In case the 60% reduction of space heating demand is applied across the different types of heating devices/energy carrier, it is clear that there is still a substantial demand for natural gas remaining.

After a reduction of heating demand the load curve of total heat demand of a household changes significantly as can be seen below:

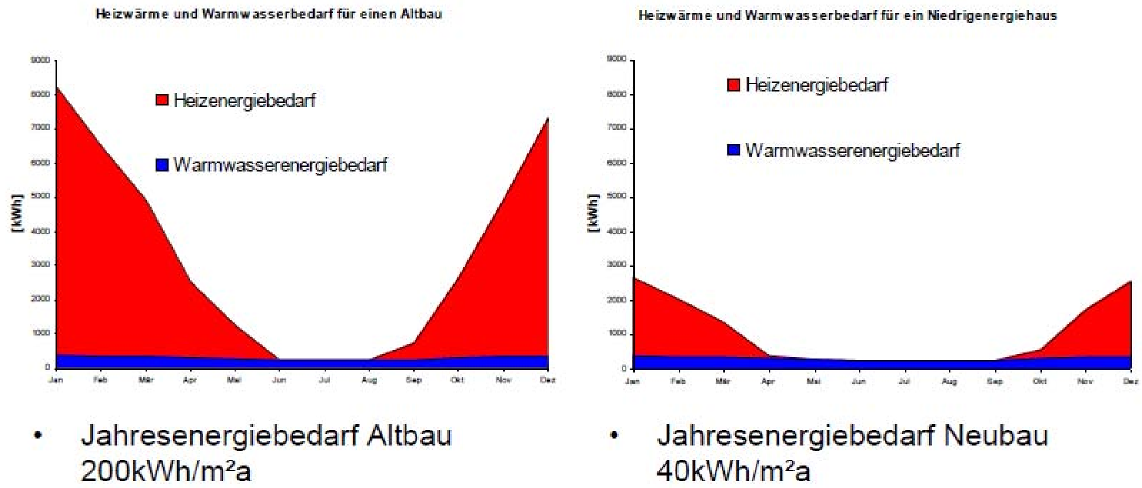


Figure 3: Load curve heat demand of households (Source Weiss – Eurem 2009)

3.2.1.3 Costs for households to reduce the space heating demand

Again the figures from Kapusta are taken. Of course the individual financial result of a thermal renovation can be very different. The lower the original thermal standard of a building the more cost effective a renovation would be, since simple measures, as e.g. insulating the top ceiling, are rather cheap but effective measures. On the other hand for a building which has already a high standard the measures to reduce it even further are normally rather expensive – e.g. the installation of a controlled ventilation system. Also the individual location and structure of a building will influence costs intensively. A building that is under a preservation order will be much more expensive to renovate, than a simple family house.

The investment costs per m2 of Kapusta for the lower reduction cases are 235 EUR/m2 for single family houses and 296 EUR/m2 for multi dwelling buildings. To compare it to annual savings the investment costs are transferred into an annuity using the capital recovery factor method. In both cases the amortization is calculated over 20 years with 4% interest rate. This results in annualized investment costs per m2 of 17,3 EUR/m2 for single family houses and 21,8 EUR/m2 for multi dwelling buildings in the ambitious and moderate demand scenario.

To calculate the savings it is assumed that the multi dwelling buildings are connected to the district heating system and the single family house uses natural gas. Both are the dominant heating systems in Vienna (see table below). The gas price is as of 27th of June 2011 was 7,1c/kWh[12] and for district heating 7,44c/kWh.[13] The savings per m2 of the single family home result into 8,8 EUR/m2 and for the multi dwelling building into 8,7 EUR/m2. This comparison is not 100% correct, because the district heating price also covers the device for the heat production, whereas an household using natural gas has to install the heater itself. But in the short run a reduction of consumption would not reduce this fixed costs, therefore only the change of variable costs (gas consumption) is taken.

Important however is the fact, that lower demand per household has possibly a negative impact on the revenue structure of the district heating system, because important parts of its cost structure are fixed costs of the network system. On the other hand most of the district heating system network is already written off. Since no data of the effect is available it is not considered.

So the total cost increase of the single family home is 8,5 EUR/m2a and for the multi dwelling building 13,1 EUR/m2a. A household with a single family house has a cost increase of 1.150 EUR per year and a household with an apartment in a multi-dwelling building 900 EUR per year. Of course over time these extra costs will decline because energy prices are rising, but even with a yearly energy price increase of 3% there is no break even in the next 20 years.

3.2.2 Service sector and industry

For the commercial part of space heating a reduction of only 50% is assumed which results in 2708 GWh for the service sector and 626 GWh for the industrial sector.

In a high demand reduction scenario space heating demand for the service sector and the industry demand reduction was estimated at 65%.

[12] e-control Tarifkalkulator Wien Energie Gas Optima
[13] Expert of Wien Energie current average en consumer price

3.3 Saving potential and costs for process heat

3.3.1 Households and the service sector

For process heat assumptions are much harder to make, since there are various processes behind. In households the most important process heat is the warm water demand. A reduction is not so easily achieved, since it depends on the individual behavior. Therefore in this model no changes of process heat demand are assumed. Much better are the possibilities to produce process heat with solar thermal installations. Usual estimates show, that up to 2/3 of warm water can be covered by solar panels.[14]

The same assumptions are made for the service sector, because normally it is also mostly hot water or cooking devices.

So the total potential for production of solar thermal process heat in the two sectors is 2729 GWh per year.

3.3.2 Industry

Normally, especially in industrial processes the biggest potential lies in the heat recovery from other processes, often combined with heat pumps to reach higher temperature levels. These heat pumps on the other hand increase the demand for electricity. Overall a conservative saving potential of 15% is assumed. For simplification no rise in electricity demand is included, because the individual solution can be vary substantially. In a more ambitious scenario the saving increases to 20%.

In the industrial sector, the picture for solar thermal potential is quite different, because much higher temperature levels are often required. The split for Austria can be seen below. The assumption for Vienna is, that only 30% of the industrial process heat demand can be supplied with solar thermal installations. Due to the seasonal

[14] Weiss

differences in reality only 2/3 of it or 20% of total are the realistic potential for solar thermal in the industrial sector.

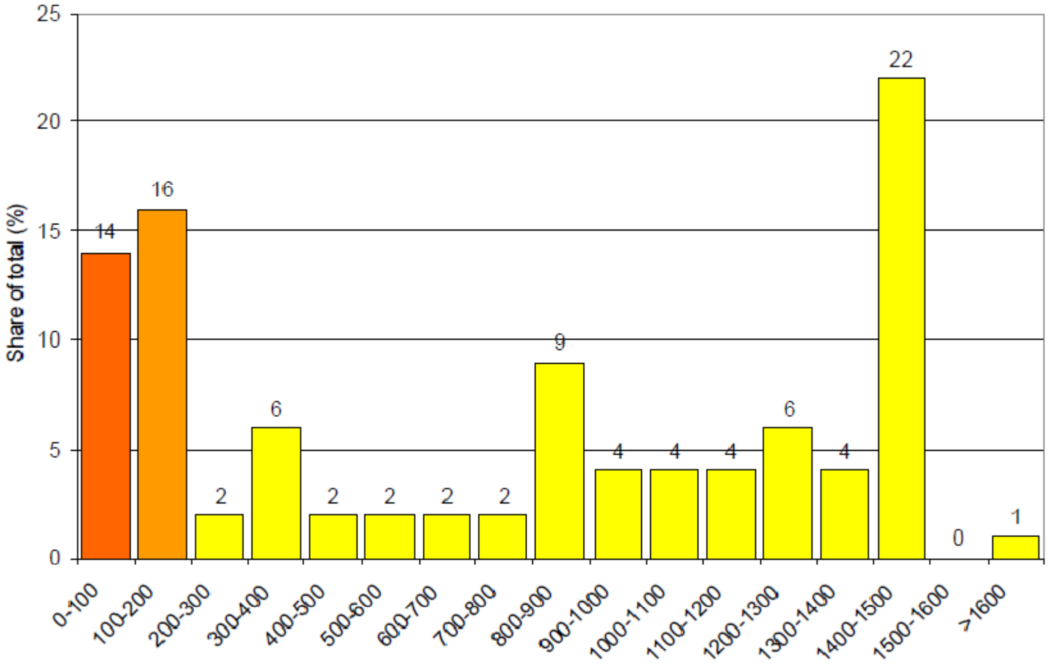


Figure 4: Share of different temperature levels in process heat in the industry of Austria (Source Weiss Potential of Solar Thermal 2010)

The additional potential for solar thermal of the industrial sector is around 200 GWh.

3.4 Saving potential and costs for light & power

3.4.1 Households – light and electrical appliances

There are many studies regarding the potential to reduce electricity consumption of households. See e.g. table below:

Table 16: Electricity saving potential of households (Source VKW Vorarlberg Kraftwerke AG 2009)

Jährlicher Stromverbrauch von Geräten im Haushalt in kWh pro Jahr	Durch-schnittl. Haushalt	Spar-Haushalt	Bemerkungen
Beleuchtung	285	115	
Kühlschrank	260	105	
Gefriergerät	330	170	
Elektroherd	400	350	
Waschmaschine	240	180	110 mit Warmwasseranschluss
Wäschetrockner	460	290	
Geschirrspüler	375	300	mit Kaltwasseranschluss!
Warmwasser (nur Anteil, im Winter mit Kesselbeheizung, im Sommer nur Elektro)	1100	900	200 mit Solaranlage
TV	360	140	
Pumpe	400	120	

Tab. 5: Hohe Spanne im jährlichen Stromverbrauch zwischen den sparsamen und durchschnittlichen Geräten [VKW Stromspartipps, im Internet Dezember 2007]

Unfortunately they are mostly technical and lacking an estimate of investment costs and age structure of the replaced appliances. Therefore an own calculation was done. All available data regarding the structure of electricity demand also includes heating and warm water. This part has already been covered in other sections. To avoid double counting it will be excluded.

3.4.1.1 Current structure of electricity consumption

The structure of electrical consumption of households in Austria shows the following picture:

Table 17: Structure of electricity consumption of households (Source Statistik Austria Strom- und Gastagebuch 2008)

Jahresstromverbrauch in kWh (alle Haushalte)	Anzahl der Personen im Haushalt							
	1 Person		2 Personen		3 Personen		Ab 4 Personen	
	Mittelwert	Median	Mittelwert	Median	Mittelwert	Median	Mittelwert	Median
Summe der Verbrauchskategorien	2.831	2.195	3.580	2.975	5.756	4.518	5.818	4.788
Kühlschrank	255	236	334	299	362	320	329	290
Gefriergerät	137	0	203	180	338	296	332	267
Herd und Backrohr	176	116	337	289	444	387	524	418
Waschmaschine	96	79	171	163	265	237	251	249
Wäschetrockner	19	0	38	0	91	0	176	0
Geschirrspüler	57	0	166	147	238	222	324	319
Küchen- und Haushaltsgeräte	82	73	172	150	197	159	226	198
Bürogeräte	69	22	86	19	141	65	120	68
Unterhaltungselektronik	122	104	179	155	255	191	235	187
Kommunikationsgeräte	18	0	34	35	33	35	33	35
Ladegeräte	8	1	19	4	24	5	26	7
Sonstige relevante Stromverbraucher (inkl. Ventilator, Klimagerät, Zusatzheizung)	188	19	117	36	168	93	168	69
Standby Bürogeräte	11	0	9	0	15	0	19	3
Standby Unterhaltungselektronik	96	66	117	56	181	164	152	101
Standby Herd und Backrohr	7	0	15	0	25	17	19	0
Standby Küchen- und Haushaltsgeräte	19	0	32	0	36	29	44	29
Beleuchtung	224	229	335	297	499	435	586	525
Warmwasserbereitung	590	0	579	0	928	0	1.090	0
Umwälzpumpen	150	0	235	216	276	330	345	322
Heizen	505	0	404	160	1.238	160	819	190

The average household of Vienna has 1,99 people and with an average electricity consumption of 3.320 kWh is very comparable to the average Austrian household in the range of two people. The slightly higher average consumption of 3.580 kWh (108%) is most likely caused by the much higher share of households living in apartments compared to the rest of Austria (see table below). From this figure the part of heating (space heating) and warm water (part of process heat) has to be seen separated because it has been covered already in another section. According to the statistic the remaining part of light & power, including cooking (which is by definition part of process heat, but is covered in this section), is 2400 kWh/a for a Viennese Household.

Table 18: Number of dwellings per building (Source Statistik Austria Mikrozensus 2009)

Persons in private dwellings by number of dwellings in the building and provinces

	Personen in Privatwohnungen insgesamt in 1.000	davon in Gebäuden mit ... Wohnungen				
		1	2	3 bis 9	10 bis 19	20 und mehr
		in %				
Österreich	**8.262,1**	**42,1**	**14,0**	**17,2**	**14,1**	**12,6**
Burgenland	281,2	71,8	14,5	8,7	3,9	1,1
Kärnten	555,4	50,5	19,3	18,0	8,1	4,0
Niederösterreich	1.589,3	59,9	15,1	14,1	7,5	3,5
Oberösterreich	1.390,4	45,0	20,5	18,8	11,0	4,6
Salzburg	521,7	36,7	19,8	24,6	11,2	7,7
Steiermark	1.195,3	53,2	13,3	16,4	10,4	6,7
Tirol	697,3	36,4	19,0	27,4	11,4	5,8
Vorarlberg	364,6	45,0	17,8	24,4	8,6	4,1
Wien	1.666,9	10,1	1,3	12,4	32,8	43,3

Q: Statistik Austria, Mikrozensus.

The saving potential will be focused on big appliances (fridge, freezer, stove, dish washer and washing machine) with a share of total consumption of 34% and light with a share of 9,5% The warm water and heating (34% together) part is already covered in the sections of process heat and space heating.

A complete change of all appliances, even in case they are only a few years old, would create a huge waste of grey energy and be very expensive for households. Therefore in the moderate and ambitious scenario it is assumed that only appliances older than 10 years are exchanged. In this case the relevant investment costs are only taken as the difference between a low energy appliance and a top efficient one.

3.4.1.2 Saving potential of big electrical appliances

As mentioned above an important factor is the age and energy efficiency of the current household appliances. According to a survey of Statistik Austria[15] 57% could not name the efficiency class of their fridge (60% for the freezer), 9% said A+ or A++ (14%), 25% said A (18%), 9% said B or C (9%).

Below the age structure of fridges can be seen from the same survey.

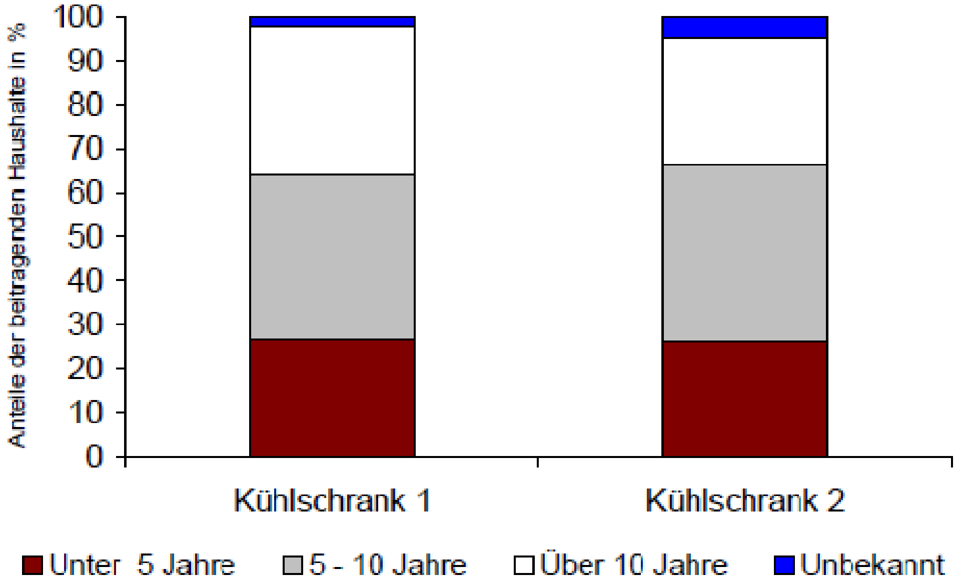


Figure 5: Age structure of refrigerators (Source Statistik Austria Strom- und Gastagebuch 2008)

Because of the high share of "not known" an assumption of the average energy efficiency of fridges and freezers hast to be made, which is class A. The top class currently has A+++ and is 60% more energy efficient than A. [16] The same applies for freezers. Around 35% are older than 10 years and will be exchanged.

In the categories washing machine and (dish washer) the current split is almost identical - class A 35% (33%), B or C 8% (8%) and 59% (59%) unknown. Only the

[15] Statistik Austria Strom- und Gastagebuch 2008
[16] Das neue Energie Label 2010 – Zentralverband Elektrotechnik- und Elektronikindustrie Deutschland

age structure shows that dish washers are on average newer than washing machines. Therefore it is assumed that the current average standard for washing machines and dish washer is A. The best standard for washing machines currently is A+++, with 32% savings compared to A and for dishwasher A++ with 21% savings. There are 26% of washing machines above 10 years and 20% of dish washers.

The estimate for stove and ovens is more difficult, since there are no data regarding energy classes available. The survey of Statistik Austria nevertheless states that only 1% have an induction cooker and the stoves are the oldest appliances in a typical household (42% are above 10 years).

According to Deutsche Energieagentur[17], induction stoves are 40% more efficient than new normal stoves. Considering the average age of existing stoves a reduction of 50% with an induction cooker seems feasible.

For all other appliances no changes are assumed, since the improvement of energy efficiency will be most likely neutralized by the increase of appliances.

3.4.1.3 Saving potential of light

In the case of light the survey of Statistik Austria shows that light bulbs are still the dominating source of light with 51% (see figure below).

[17] Web-site Deutsche Energieagentur/Haushaltsgeräte

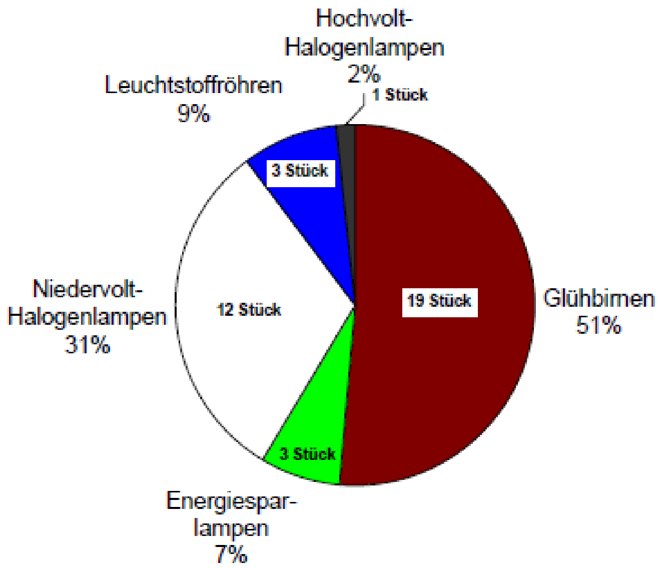


Figure 6: Type of household lights (Source Statistik Austria Strom- und Gastagebuch 2008)

They also have the biggest potential to reduce energy. In case they are replaced by energy saving light bulbs savings of 80% can be reached. For the other light types there are also saving potentials but they are harder to identify so they are left out. The efficiency of different types of lights are shown below in lm/W.

Table 19: Efficiency of light (Source Stromeffizienzpotentiale in Haushalten und Dienstleistungsbetrieben in Vorarlberg 2008)

Lichtausbeute (* mit elektronischem Vorschaltgerät)		
A	Leuchtstoffröhre T5 High Efficiency	95 lm/W
	Leuchtstoffröhre T5 High Output*	77 lm/W
	Kompaktleuchtstofflampe 11 Watt*	75 lm/W
	Sparlampe 11 Watt*	55 lm/W
B	Kompaktleuchtstofflampe 55 Watt*	67 lm/W
	Niedervolthalogenlampe IRC 50 W	23 lm/W
C	Niedervolthalogenlampe 50 W	18 lm/W
D	Hochvolthalogenlampe 300 W	18 lm/W
E	Glühlampe 75 W	12 lm/W
F	Globe-Lampe 100 W	10 lm/W
G	Soffiten-Lampe 60 W	7 lm/W

Tab. 23: Typische Lichtausbeute verschiedener Leuchtmittel in Lumen pro Watt [faktor Licht 2007]

For heat circulation pumps the saving potential is seen as around 80% in most studies[18].

The potential of warm water and heating are covered in a separate section. For heating the overall assumption of space heat demand reduction applies. For process heat no reduction for warm water are assumed.

3.4.1.4 Summary of saving potential and estimate of costs

In total a realistic saving potential of 24% can be reached. This would lead to a reduction of 440 GWh electricity demand in Vienna.

The total necessary costs have been again annualized and compared to the savings. The following assumptions are behind:

Amortization period: 12 years

Interest rate: 4%

Electricity price: 18,4 c/kWh[19]

For the change of light bulbs no investment costs are assumed, since they will have to be exchanged in near future to energy saving bulbs anyhow, since no other bulbs are available. Also for the reduction of standby no investment is assumed.

For all other calculations a correction factor of units is included to make savings and investment comparable. The savings are calculated based on the average electricity consumption for a device but the investment is based on 1 unit. There is never exact one 1 unit per household, e.g. on average in Vienna a household has 1,2 fridges. To make the 2 figures comparable this correction factor is included.

[18] Stromeffizienzpotentiale in Haushalten und Dienstleistungsbetrieben in Vorarlberg 2008 – Arena et al

[19] E-control 27.6.2011 Tarifkalkulator Wien Energie Optima

Table 20: Costs of electricity savings for households moderate and ambitious demand reduction scenario

	Current	% of total	Saving (%)	Correction	Result	Invest	Invest annuity	Cost saving	Result	Number of units/1
Summe	**3582**				**2726**					
Fridge	334	**9,3**	0,6	0,35	264	344,52	36,7	36,9	0,2	1,2
Freezer	203	**5,7**	0,6	0,35	160					
Stove	337	**9,4**	0,5	0,42	266	154	16,4	31,0	14,6	1,1
Washing machine	171	**4,8**	0,32	0,26	157	50,76	5,4	10,1	4,7	0,9
Dryer	38	1,1	0		38					
Dishwasher	166	**4,6**	0,21	0,2	159	150,92	16,1	6,4	-9,7	0,8
Other kitchen appliances	172	4,8	0		172					
Office Equipment	86	2,4	0		86					
Consumer Electronincs	179	5,0	0		179					
Communication	34	0,9	0		34					
Loading	19	0,5	0		19					
Other	117	3,3	0		117					
Standby Office	9	0,3	0,5	1	4,5	0		0,8	0,8	
Standby CE	117	3,3	0,5	1	58,5	0		10,8	10,8	
Standby Stove	15	0,4	0,5	1	7,5	0		1,4	1,4	
Standby Kitchen	32	0,9	0,5	1	16	0		2,9	2,9	
Light	335	**9,4**	0,8	0,5	201	0		24,7	24,7	
Warm water	579	**16,2**	0	1	579	0				
Pumps	235	**6,6**	0,8	1	47	400	42,6	57,7		0,6
Heating	*404*	***11,3***	*0,6*	*1*	*162*	*0*				
Total Austrian HH	**3582,0**	**100,0**			**2726,4**		**117,2**	**182,6**	**50,3**	
Saving in %					**24**					
Total excl. Heating/WW	**2599,0**				**1985,8**					
Saving in %					**24**					
Total Vienna HH excl. Heating/WW	**2406**		**Saving in kWh/a**	**568**	**1839**					

In this scenario households would actually save 50 EUR per years. In a second scenario, where all large appliances would be changed, the households would have increased costs of 126 EUR per year and the electricity saving would increase to 38% or 695 GWh (excluding space heating).

3.4.2 Service sector

The development of electricity consumption in Austria of the service sector can be seen below.

Table 21: Development of energy consumption in the service sector in Austria (Source Statistik Austria 2008)

Elektrische Energie	1970	1980	1991	1996	2001	2006	Quelle
Öffentliche und private Dienstleistungen in Österreich (GWh)	1.878	5.239	9.675 8.947	11.489 11.114	13.074 12.536	13.379	Stat.Austria EB Öst. 03

The figures show that after a steady increase till 2001 the increase of consumption leveled out after the year 2001.

Within the sector the most important industries in the light of energy consumption are:

- Retail and wholesale
- Hotels and restaurants
- Public service
- Defense
- Health care

The sectors together consume 60% of the entire service sector.[20]

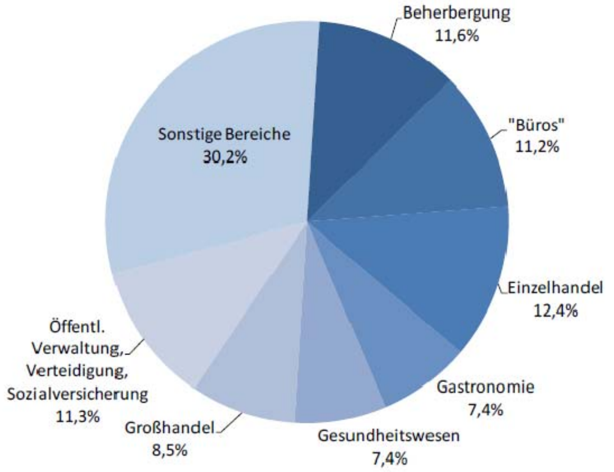


Abbildung 3: Anteil ausgewählter Bereiche am Endenergieverbrauch in %

Figure 7: Energy consumption share of different parts of the service sector (Source Statistik Austria Energieeinsatz im Dienstleistungssektor 2011)

In basically all sectors electricity is the most important energy used. See below the distribution for the entire sector:

[20] Statistik Austria 2011, Energieeinsatz im Dienstleistungssektor

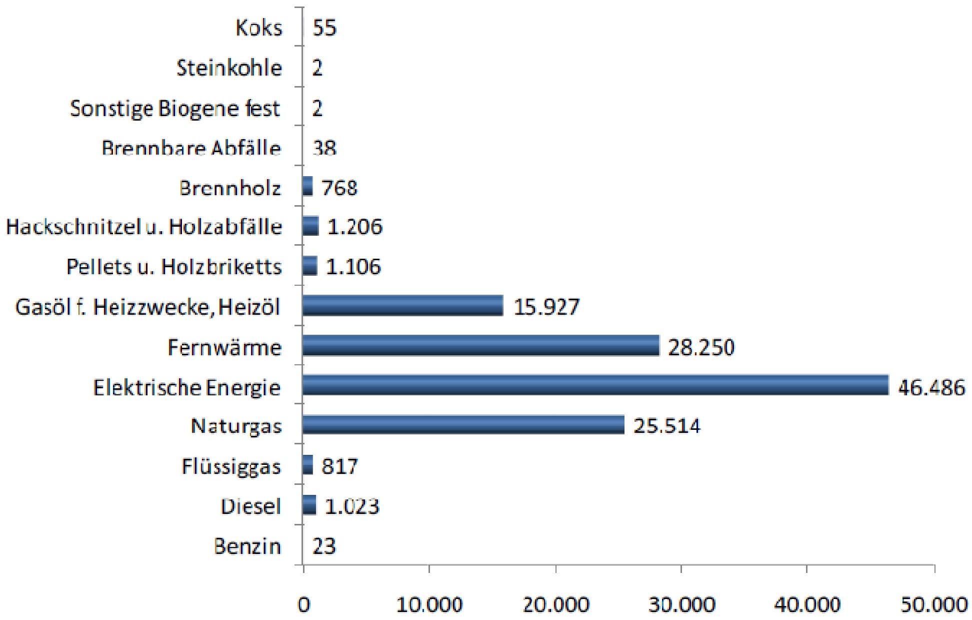


Abbildung 1: Energieverbrauch im Dienstleistungssektor 2008 in TJ

Figure 8: Distribution of energy consumption in the service sector (Source Statistik Austria Energieeinsatz im Dienstleistungssektor 2011)

In Vienna the share of electricity in the service sector is 40%.

The typical distribution of energy consumption of office buildings can be seen below. The figures are based on a building with 6.250m2.

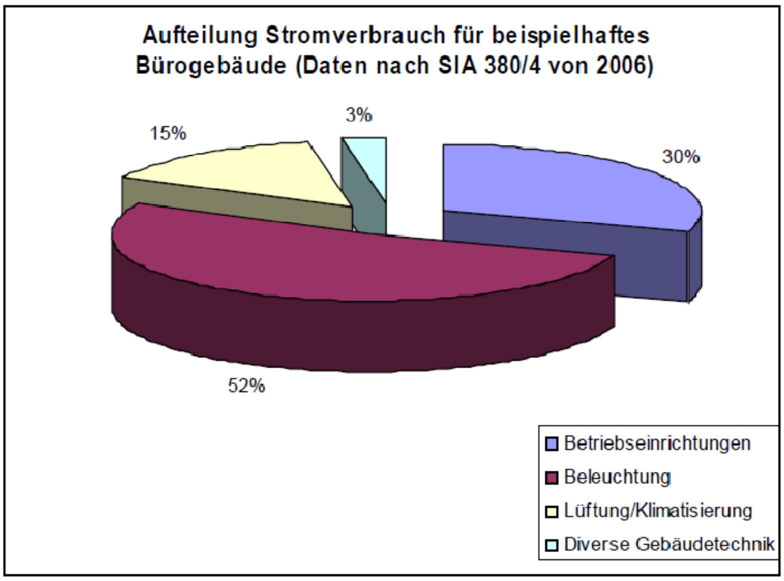


Abb. 5: Aufteilung des Stromverbrauchs für ein beispielhaftes Bürogebäude mit einer Nettogrundfläche von 6.250 m² [SIA 380/4 von 2006]

Figure 9: Share of energy consumption of a typical office building (Source Rath et al, Stromeffizienzpotentiale VbG 2008)

For public service building (a school) the distribution can be seen below:

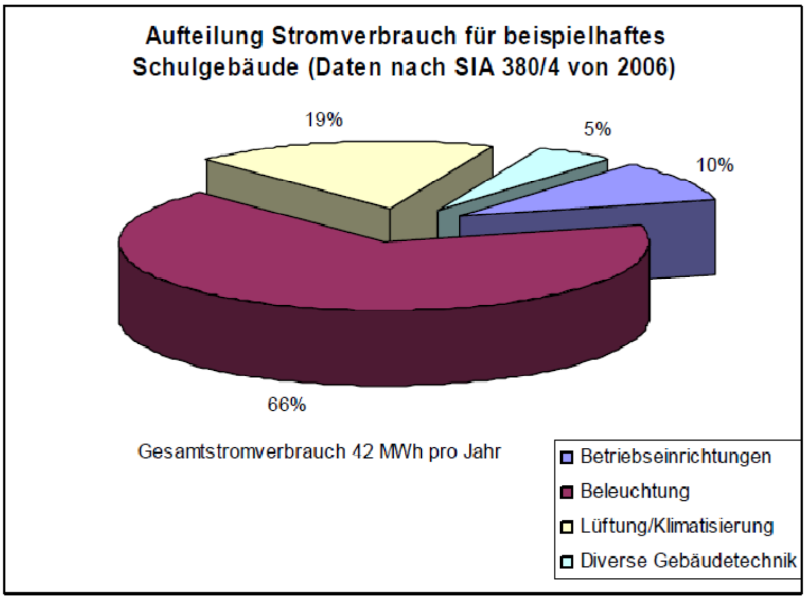


Abb. 6: Aufteilung des Stromverbrauchs für ein beispielhaftes Schulgebäude mit einer Nettogrundfläche von 1300 m² [SIA 380/4 von 2006]

Figure 10: Share of energy consumption of a typical school building (Source Stromeffizienzpotentiale VbG 2008)

In the same study a significant potential to reduce energy consumption was identified. The summary can be seen below in two tables.

Table 22: Potential to reduce energy demand in office buildings I (Source Stromeffizienzpotentiale VbG 2008)

Energiekennzahlen Bürogebäude (kWh/m²*a)	Bestand	Energie-optimiert
Beleuchtung	25	10
Klimatisierung	11	0
Lüftung	13	10
Wärme	125	40
Summe	174	60

Tab. 39: Energiekennzahlen für Bürogebäude im Bestand und für energieoptimierte Gebäude ohne Bürogeräte am Arbeitsplatz [Büro 2006]

Table 23: Potential to reduce energy demand in office buildings II (Source Stromeffizienzpotentiale VbG 2008)

Effizienzpotenziale in Dienstleistungsbetrieben	Verhaltens-bedingte Einspar-möglichkeiten	Technisches Sparpotenzial Bestgeräte ggü. Durchschnitt	Absehbare künftige Optimierungen	Substitutions-potenzial
Beleuchtung	10%	bei Komplettsanie-rung bis zu 80%	LED mit sehr hoher Effizienz	Tageslichtnutzung
Lüftung / Klimatisierung	10%	im Mittel 30%, incl. Systemoptimierung bis zu 75%	EC-Motoren in der Breite	durch bauliche Optimierung Minimierung von Klimatisierungs-bedarf
Umwälzpumpen	5 bis 10%	EC-Pumpen im Mittel 30%, incl. hydraul. Abgleich bis 60%	EC-Motoren in der Breite	-
Informations- und Kommunikationstechnik	10-20%	30-50%	sehr niedriger Stand-by-Verbrauch, automatische Schaltung in Stand-by, geringerer Betriebsstrom-verbrauch bei PC	-
Stand-by / Leerlaufverluste	80% durch vernünftige Nutzung und durch schaltbare Steckerleisten	mind. 60%	Minimierg. Stand-by-Verluste unter 1 Watt; Auto-Off nach wählbarer Stand-by-Zeit	-
Kaffeeautomaten / Kaltgetränkeautomaten	gering; durch Zeit-schaltuhr od. Memo-Switch erheblich	im Mittel 50%, bis zu 65% bei zusätz-licher Standort-optimierung	automatische Ab-schaltmöglichkeit integriert; Ausschal-ten der Beleuch-tung in längeren Nutzungspausen	-
Aufzüge	vor allem durch Treppen- statt Aufzugnutzung	im Mittel 25%	Minimierung der Verluste aus Stand-by, Regeltechnik, Beleuchtung, Antrieb	-
Elektrische Wassererwärmung	gering; durch Zeitschaltuhr od. Thermostop-Schalter erheblich	im Mittel 10%	bessere Wärme-dämmung der Wasserspeicher	Anschluss an das Heizsystem

Tab. 45: Effizienzpotenziale in Dienstleistungsbetrieben

In total the study of Vorarlberg estimates an electricity realistic saving potential of 37% in the service sector. The maximum saving potential is seen as 67%. The moderate and ambitious saving scenario is based on a reduction of 37% or 521 GWh. The high saving potential of the study would result in a reduction of 943 GWh.

3.4.3 Industry & agriculture

The share of energy demand of industry and agriculture is rather low in Vienna. In the case of industry energy saving measures are often a matter of short payback times. Often payback times below 3 years (e.g. supermarket chains) are expected. Nevertheless there is still a substantial potential. In my own experience with energy efficiency projects in the industry 10-15% can always be saved within the restrictive limits for payback times.

A 15% reduction across the board results in this model a reduction of 234 GWh electricity for light & power. In the high saving scenario the reduction is increased to 20% .

3.5 Saving potential and costs for transport & mobility – effects of e-mobility

3.5.1 General & transport data

For the transport sector a total switch to e-mobility is assumed. But only the private transport is analyzed in more detail. The reason is, that for heavy duty vehicles there are currently no serious models on the market. The main reason is the low efficiency of e-trucks and the enormous capacities of batteries needed. Trucks are also normally going long distances without brakes, so the restriction in distance becomes a real issue. On the other hand in Vienna the share of light duty vehicles is rather high, since a lot of deliveries are into the city with small trucks, so there can be a realistic potential for e-mobility in the foreseeable future.

For private transport in cities, electrical cars are a perfect fit, since the average distance per day is rather low[21]. There are also plenty of possibilities to install loading facilities. Further advantages are the lower noise and other direct emissions.

The total consumption of fuel for transport in Vienna is 12.259 GWh.[22] In the table below the transport of private households can be seen. In 2006 the total consumption of fuel was 528 Mio liter. This corresponds to around 5280 GWh or almost half of total consumption. Per car the consumption is 956l or 9560 kWh per year. Per 100 km driven the consumption is 75 kWh.

---

[21] Verkehr in Zahlen 2007 BMVIT
[22] Energieflussbild 2009

Table 24: Households consumption of fuels for transport (Source Statistik Austria 2008)

Energieeinsatz der Haushalte (Mikrozensus 2007/2008) - Fahrleistungen und Treibstoffeinsatz privater Pkw
Ergebnisse für Wien

Verwendeter Treibstoff	Anzahl Pkw	gefahrene Kilometer	Treibstoffverbrauch			Durchschn. Jahres-kilometer pro Pkw
			Insgesamt	pro Pkw	pro 100 km	
			in Liter			
Erster Pkw						
Benzin	238.119	2.727.339.788	220.859.651	928	8,1	11.454
Diesel	236.575	3.623.470.317	257.302.512	1.088	7,1	15.316
Sonstiger	3.444	51.223.941	4.596.916	1.335	9,0	14.874
Zusammen	478.138	6.402.034.045	482.759.078	1.010	7,5	13.390
Zweiter Pkw						
Benzin	43.120	327.271.949	26.929.657	625	8,2	7.590
Diesel	30.916	264.275.030	17.943.699	580	6,8	8.548
Sonstiger						
Zusammen	74.036	591.546.979	44.873.357	606	7,6	7.990
Insgesamt						
Benzin	**281.239**	**3.054.611.736**	**247.789.309**	**881**	**8,1**	**10.861**
Diesel	**267.490**	**3.887.745.347**	**275.246.211**	**1.029**	**7,1**	**14.534**
Sonstiger	**3.444**	**51.223.941**	**4.596.916**	**1.335**	**9,0**	**14.874**
Zusammen	**552.174**	**6.993.581.023**	**527.632.435**	**956**	**7,5**	**12.666**

Q: STATISTIK AUSTRIA, Energiestatistik: Mikrozensus Energieeinsatz der Haushalte 2007/2008. Erstellt am 30.12.2008.

Considering that Vienna has 845.000 households, there are 0,65 cars per household. The average distance driven is 12.666 km.

3.5.2 The efficiency gain of e-mobility and its effect on load curves

There are a vast number of studies regarding the efficiency of electric cars. The average expected consumption seems to be between 15 and 20 kWh/100km.[23] For this model in the high demand reduction scenario the more optimistic figure of 15 kWh/100 km is taken. This would result in a switch from 7,5 l fuel (75 kWh) to 15 kWh of electricity per 100 km (-80%). According to Haas[24] the average consumption of VLOTTE (an e-mobility pilot project in Austria with almost 100 e-cars) is around 22 kWh/100 km. This would result in a reduction of 70% This reduction is assumed for the moderate and ambitious demand reduction scenario.

If all private cars currently using fossil fuels or gas would switch to e-mobility, the total fuel consumption would decrease by 5 TWh and electricity consumption increase by 1484 GWh (18% of current electricity demand). In case all fossil powered vehicles could be switched with the same efficiency improvement 12.443 GWh fuel would turn into 3733 GWh electricity (46% of current demand). With a

[23] Green Power for electric cars 2010 Delft Kampman et al p. 16
[24] Personal conversation with Haas

higher efficiency of electricity (-80%) the additional demand of electricity is 2489 GWh (+30%).

The effect on load curves was analyzed by a Price Waterhouse Coopers study. It is based on the logical assumption that the loading of batteries will happen at night when the vehicles are parked at home. The figure above show the effects of 20% e-mobility in Austria.

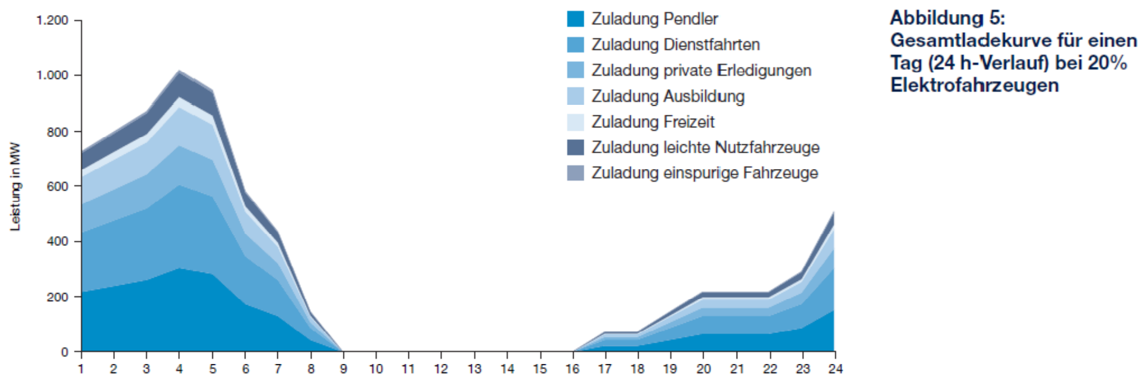


Figure 11: e-mobility and load curves (Source Price Waterhouse Coopers 2009)

3.5.3 Costs for the households

The first important factor is the difference in investment costs. For this 2 Mitsubishi models were compared, because Mitsubishi is one of the first to sell a standard e-car, the Mitsubishi Miev.

The Miev costs currently 35.900 including tax.

The comparable Mitsubishi Colt At Invite sells for 11.990.

The difference is therefore 23.910. Annualized over 15 years with 4% interest, results in yearly extra cost of 2548 EUR. The total comparison is shown below. Investment costs, consumption and price figures are taken from the homepage of Mitsubishi.[25] Fuel costs of 1,33 EUR per l are assumed. The electricity costs are again estimated with 18,4c/kWh. It is assumed that service & repair costs are smaller

[25] www.mitsubishi-motors.at

for the e-vehicle because there is e.g. no gear box. Also a difference in tax (NOVA) was included.

Table 25: Cost comparison e-car vs fuel driven car

EUR	Miev	Colt	Difference
Invest	35900	11990	
Annualised	3825	1278	2548
fuel cons kWh/100 km	10	55	
km driven	12666	12666	
Fuel costs	233	940	-707
tax		238	-238
Repairs	200	350	-150
Total costs/year	4258	2806	1452

The comparison shows that on an annual basis the e-car is 1452 Euros more expensive per year than a standard car. It has to be stated however that the calculated consumption of 10 kWh/100 km is based on data from Mitsubishi[26] and seems to be rather low. If the average consumption of Vlotte is taken (22 kWh/100km) the additional costs would rise to 1732 EUR, but compared to the average current consumption the rise would be only 1390 EUR. On the other hand also the consumption of the Mitsubishi Colt is taken from the same data of Mitsubishi. To remain comparable for the cost estimate the data from Mitsubishi is used for both cars. In the calculation of total demand for e-mobility the consumption of 15 and 22 kWh/100 km are used.

3.6 Summary of demand saving and its effects

For each of the energy services and sectors different reduction potentials were shown. For the model three demand scenarios were calculated. The moderate demand scenario will have more moderate demand reductions and only a partial switch to e-mobility. The ambitious scenario is a combination of moderate demand reduction and total switch to e-mobility. The high scenario combines high demand reduction with total switch to e-mobility. For the final model scenarios only the later two are used, because the first does not achieve 100% renewable energy supply.

[26] Mitsubishi Technical data and sales brochure 2011

3.6.1 Moderate demand reduction scenario

In the moderate scenario the following assumptions are behind:

- Space heating demand reduced by 65% for households and 50% for industry and service sector
- Process heat demand reduced by 15% in the industrial sector
- Light & power reduction of 24% by households, 37% by the service sector and 15% by the industrial sector
- Only private mobility is switched to e-mobility.

Following these assumptions the total energy demand goes down to 25 TWh from 38 TWh (-38%). The change of the split of energy carriers can be seen below:

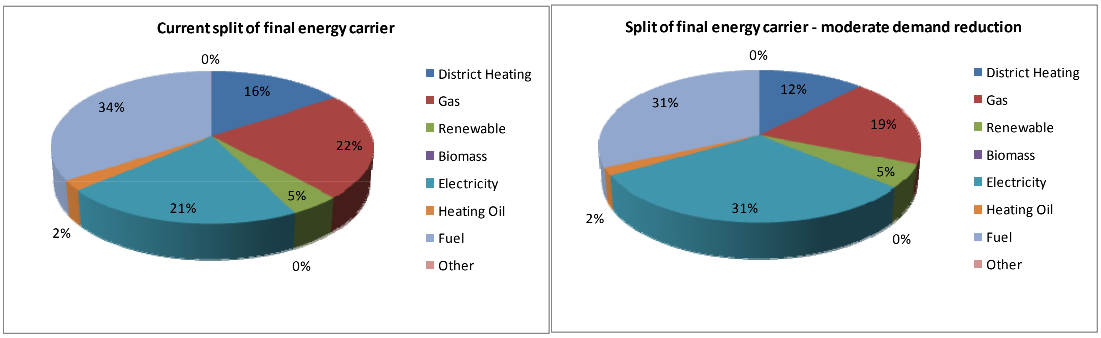


Figure 12: Split of energy carrier moderate demand reduction scenario

In this scenario fuel remains the dominating energy carrier, with electricity overtaking gas as the second most important.

3.6.2 Ambitious demand reduction scenario

In the ambitious scenario the following assumptions are behind:

- Same savings as in the moderate scenario
- Complete switch to e-mobility with 22 kWh/100 km consumption

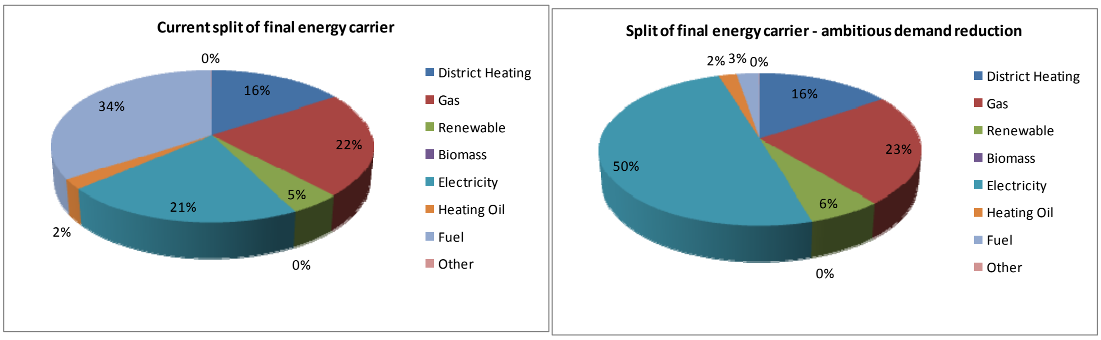


Figure 13: Split of energy carrier ambitious demand reduction scenario

In this scenario electricity becomes the dominating energy carrier with almost 50%. Gas remains second with 23%. Total demand is reduced to 20 GWh.

3.6.3 High demand reduction scenario

In the high scenario the following assumptions are behind:

- Space heating demand reduced by 85% for households and 65% for industry and service sector
- Process heat demand reduced by 20% in the industrial sector
- Light & power reduction of 38% by households, 67% by the service sector and 20% by the industrial sector
- Complete switch to e-mobility with 15 kWh/100 km

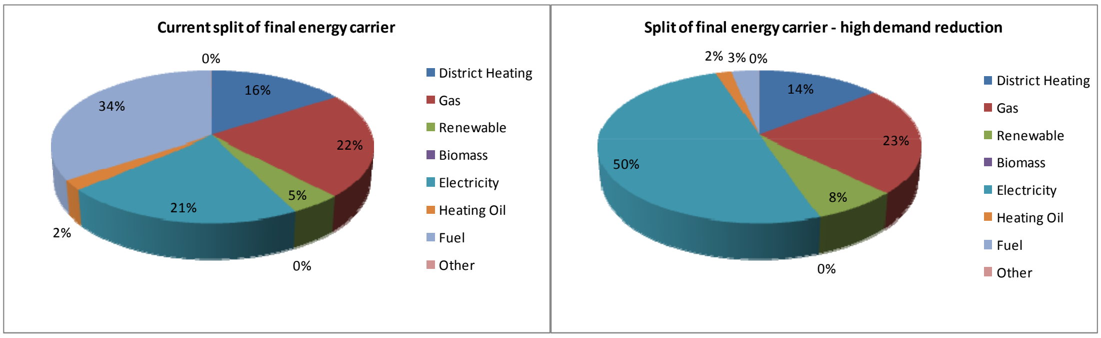


Figure 14: Split of energy carrier high demand reduction scenario

The shares are very similar to the previous scenario. Total demand goes down to 16 TWh.

3.6.4 Effect on split between energy services and sectors

Table 26: Split of final energy demand between energy services in different demand reduction scenarios (in GWh)

Demand per energy service	Space heat	process heat	Light & power	Mobility	Total
Current	13.954	5.618	4.797	13.981	**38.350**
% of total	36	15	13	36	**100**
moderate reduction	5.884	5.396	3.603	9.027	**23.909**
% of total	25	23	15	38	**100**
ambitious reduction	5.884	5.396	3.603	2.487	**17.370**
% of total	34	31	21	14	**100**
high reduction	3.427	5.321	2.846	2.487	**14.082**
% of total	24	38	20	18	**100**

In the moderate reduction scenario space heating is reducing its share, while all others are increasing their share. In the ambitious scenario the biggest effect is on mobility, because the entire mobility has changed to e-mobility. In the high scenario process heat becomes the most important energy service.

Table 27: Split of final energy demand between sectors in different demand reduction scenarios (in GWh)

Demand per sector in GWh	HH	Service	Industry	Mobility	Total
Current	11.608	8.468	4.293	13.981	**38.350**
% of total	30	22	11	36	100
moderate reduction	6.432	5.239	3.211	10.518	**25.400**
% of total	25	21	13	41	100
ambitious reduction	6.432	5.239	3.211	5.271	**20.153**
% of total	32	26	16	26	100
high reduction	4.719	4.004	2.871	4.027	**15.621**
% of total	30	26	18	26	100

In the moderate scenario households drop their share and mobility increases. In the ambitious scenario the share of mobility drops significantly and all other sectors increase their share. This picture does not change much in the high scenario.

3.6.5 Load curve and costs for households

The costs for households are as follows:

Table 28: Cost for households for demand reduction

in EUR/year	Moderate/Ambitious	High
Space heating investment costs	2343	7489
Space heating energy costs	-1195	-2409
Light & power investment costs	117	293
Light & power energy costs	-183	-183
e-mobility investment costs	2548	2548
e-mobility running costs (energy, repairs,tax)	-1095	-1095
Total	**2535**	**6643**

For space heating costs for households living in a family home were taken. The energy cost savings are based on current prices and heat production systems. This will change in the final model scenario in chapter 5. In case of light&power energy savings are identical, because in both cases the electricity costs of top efficient appliances to average current standard is compared. In the moderate/ambitious scenario only households with old appliances will change and therefore the difference between a new top efficient and a new average appliance is calculated in the investment costs. In the high scenario total costs of new appliances are considered.

The moderate and ambitious scenario are equal for household costs, because the only difference is the switch of the industrial and service sector to e-mobility.

In the first two scenarios yearly cost increase of households would be 2.535 EUR. The biggest share comes from e-mobility closely followed by space heating. In the high scenario, yearly costs increase by more than 6.000 EUR, because of the steep increase of costs for space heating demand reduction.

In all scenarios in can easily be seen that the demand reduction for light & power is by far the cheapest, even in the event when total investment costs for new appliances are included.

Regarding load curves the biggest effects are on the heat side, the reduction of heating demand in winter, because the biggest share of demand reduction is coming from space heating. The biggest effect on the electricity load profile is the switch to e-mobility that increases the demand during the night. A second major impact would be the extensive use of heat pumps because it would shift demand more in the time of winter. More details are analyzed in chapter 5 about the model scenarios.

4 Potentials of renewable energy

4.1 Overview

From the beginning it was clear, that within the city limit there is not enough space to produce all energy required. In this model first the maximum of renewable energy production within the city is analyzed and in a second step the potential in Lower Austria, the state surrounding Vienna for wind, hydro and biogas. For biogas only 5% of available farm land in Lower Austria is taken.

For wind and hydro it is checked, if after using this potential for Vienna, there is still enough potential remaining for the state of Lower Austria itself, to provide the state with 100% renewable electricity. The total electricity consumption of Lower Austria was 10.000 GWh in 2004 with a historic growth rate of 2,1%.[27] So consumption in 2010 would be around 11.300 GWh. According to a statement of Landesrat Pernkopf Lower Austria produces currently 89% of its consumption with own renewable sources (excl. mobility).[28] This would result in a production of 10.057 GWh and the remaining need of 1243 GWh to be produced by renewable sources. In case Lower Austria would also switch to e-mobility the demand increases to around 6000 GWh. As we will later see that can be easily covered with wind alone in Lower Austria.

The focus within the city limits is definitely the potential of solar installations. All cities have very little free land, but enormous areas of roofs available. As different studies show they can in total contribute significantly to the energy production of the city for PV as well as solar thermal applications. Of course in old cities as Vienna the structure of buildings has to be considered in respect to conservation obligations.

[27] Stromeffizienz - Potentiale in Niederösterreich 2006
[28] Press statement Öko News 18.2.2010

The second important potential is geothermal, because it is little connected with available space. Cities as Budapest cover a high percentage of their heat demand by geothermal sources.

The third possible option is another hydro power plant on the Danube river. The location would be outside of Vienna. In Austria this is a very sensitive political issue, because the river goes through protected wet lands. Nevertheless since hydro is a cheap and reliable source of renewable energy it is investigated.

Wind within Vienna has a very limited potential, but around Vienna there are a lot of possible locations.

Biogas at first sight is not a very promising option for Vienna. But considering that almost 100% of Vienna is connected to natural gas and natural gas currently provides 50% of primary energy it is worth a second look. Again the available land within Vienna is very limited, but Lower Austria, the state surrounding Vienna, has a lot of agricultural land and is crossed by many gas pipelines. So for this model it is assumed that biogas produced in Lower Austria will be fed into the gas grid.

Bio fuels are not an option, because their ecological value is very doubtful, except for ethanol based on sugar cane in Brazil.

Biomass is also not considered, because of the low energy density and the relatively long distances to transport it into the city.

4.2 Photovoltaic and solar thermal

4.2.1 Potential of optimal roof space

The usable roof space was calculated by the city of Vienna with the help of the "Solarkataster" a tool which is used already in several cities to estimate usable roof space for solar applications. This tool is based on a combination of geo information systems (GIS), true orthophotos and a digital surface model.

According to the information of the city of Vienna[29]the total roof space of Vienna is 52km2. Thereof are 21km2 that are very well placed with a global radiation of more than 1100 kWh/m2. Another 8 km2 with a global radiation between 800-1000 kWh/m2. Below the table showing the roof potential per district.

Table 29: Summary Solarkataster Wien (Source MA 41 Vienna)

District	SUM_SUNARE [m²]	%	SUM_SUNAR900 [m²]	%	SUM_SUNAR1100 [m²]	%
01	1.186.816	2	144.295	2	367.736	2
02	2.145.043	4	318.826	4	856.937	4
03	2.391.568	5	353.499	4	915.486	4
04	762.540	1	96.366	1	228.169	1
05	868.042	2	90.710	1	283.541	1
06	699.874	1	81.003	1	211.147	1
07	848.885	2	151.099	2	220.502	1
08	544.998	1	103.903	1	144.235	1
09	1.278.788	2	210.361	3	381.186	2
10	3.940.145	8	640.542	8	1.677.194	8
11	3.088.587	6	453.750	6	1.539.130	7
12	2.008.060	4	321.362	4	746.286	4
13	2.278.115	4	347.846	4	768.895	4
14	2.775.877	5	459.799	6	1.035.664	5
15	1.413.884	3	229.022	3	508.483	2
16	1.955.590	4	360.753	5	660.104	3
17	1.396.986	3	217.546	3	449.514	2
18	1.332.311	3	186.649	2	427.067	2
19	2.403.011	5	410.452	5	763.487	4
20	1.250.775	2	195.988	2	510.694	2
21	5.130.220	10	780.246	10	2.351.116	11
22	6.757.560	13	1.024.849	13	3.059.545	15
23	5.384.762	10	740.672	9	2.853.189	14
Total	**51.842.436**	**100**	**7.919.534**	**100**	**20.959.307**	**100**

[29] Dürauer Stefan, MA 41 Vermessungsamt

It is interesting to compare this figures with the city of Graz. Graz has also developed a "Solarkataster", very similar to the one in Vienna. The results were summarized in a report.[30]

The total roof area is 14 km2 (27% of Vienna). 6,3 Km2 (45%) have been identified as good or very good for solar applications. This is similar to the 56% of Vienna. The report also estimated that probably only 40% can be used, because of restriction due to statical issues or historic building protection issues.

Vienna with a large share of historic buildings, especially in the 1st district will also face similar problems. Therefore an adjustment of the theoretical figures above has been made. In the 1st district a reduction of 50% is assumed. In the districts 2-9, a reduction of 33% is assumed. In all other districts no reduction has been made. This results in the following:

Table 30: Adjusted Summary Solarkataster

District	SUM_SUNARE [m²]	Adjusted roof space	%	SUM_SUNAR900 [m²]	adjusted	%	SUM_SUNAR1100 [m²]	adjusted	%
01	1.186.816	593.408	1	144.295	72.148	1	367.736	183.868	1
02	2.145.043	1.437.179	3	318.826	213.613	3	856.937	574.148	3
03	2.391.568	1.602.351	3	353.499	236.844	3	915.486	613.376	3
04	762.540	510.902	1	96.366	64.565	1	228.169	152.873	1
05	868.042	581.588	1	90.710	60.775	1	283.541	189.972	1
06	699.874	468.916	1	81.003	54.272	1	211.147	141.469	1
07	848.885	568.753	1	151.099	101.236	1	220.502	147.736	1
08	544.998	365.148	1	103.903	69.615	1	144.235	96.638	0
09	1.278.788	856.788	2	210.361	140.942	2	381.186	255.394	1
10	3.940.145	3.940.145	8	640.542	640.542	9	1.677.194	1.677.194	9
11	3.088.587	3.088.587	6	453.750	453.750	6	1.539.130	1.539.130	8
12	2.008.060	2.008.060	4	321.362	321.362	4	746.286	746.286	4
13	2.278.115	2.278.115	5	347.846	347.846	5	768.895	768.895	4
14	2.775.877	2.775.877	6	459.799	459.799	6	1.035.664	1.035.664	5
15	1.413.884	1.413.884	3	229.022	229.022	3	508.483	508.483	3
16	1.955.590	1.955.590	4	360.753	360.753	5	660.104	660.104	3
17	1.396.986	1.396.986	3	217.546	217.546	3	449.514	449.514	2
18	1.332.311	1.332.311	3	186.649	186.649	3	427.067	427.067	2
19	2.403.011	2.403.011	5	410.452	410.452	6	763.487	763.487	4
20	1.250.775	1.250.775	3	195.988	195.988	3	510.694	510.694	3
21	5.130.220	5.130.220	11	780.246	780.246	11	2.351.116	2.351.116	12
22	6.757.560	6.757.560	14	1.024.849	1.024.849	14	3.059.545	3.059.545	16
23	5.384.762	5.384.762	11	740.672	740.672	10	2.853.189	2.853.189	14
Total	**51.842.436**	**48.100.914**	**100**	**7.919.534**	**7.383.484**	**100**	**20.959.307**	**19.705.842**	**100**

With this adjustment the roof potential with very good radiation is reduced by 6% and for the good radiation by 7%. The adjusted available roof space adds up to 27 Mio m2 for good or very good locations.

[30] Grazer Solar Dachkataster Kapfenbeger-Pock 2010

4.2.2 Production of energy PV and solar thermal

The total efficiency of the PV system is estimated as 12,3% (13,38% for the modules, 97% for the inclination and 95% for the inverter).[31] This results in a total production of 3.529 GWh electricity which are a respectable 43% of current total demand. A big issue of course will be that most production will happen in summer when demand is lower. More below in the section of load curves.

In case everything would be used to produce heat, the efficiency is somewhere between 40 and 60%:Selvicka estimates between 350 and 450kWh/m2a in Austria[32] Weiss expects around 300 – 500 kWh/m2a in European conditions[33]. With 400 kWh/m2a the total yield would be 11.337 GWh. This would cover almost 60% of total heat demand (space heating and process heat combined), but the big issue is again the seasonal load curve. Therefore as described in section 3 solar thermal applications will only be considered for process heat up to 100 degree. The maximum usable amount is 3022 GWh or 26,6%. In case the maximum potential is used this would reduce the available roof space by the according percentage. In this case only 2590 GWh electricity can be produced through PV installations.

Below the table for the 2 calculations:

Table 31: Calculation of solar yields in Vienna

District	SUM_SUNARE [m²]	Adjusted roof space	%	SUM_SUNAR900 [m²]	adjusted	%	SUM_SUNAR1100 [m²]	adjusted	%	PV production GWh	solar thermal production GWh
01	1.186.816	593.408	1	144.295	72.148	1	367.736	183.868	1	33,3	176
02	2.145.043	1.437.179	3	318.826	213.613	3	856.937	574.148	3	102,6	428
03	2.391.568	1.602.351	3	353.499	236.844	3	915.486	613.376	3	110,7	461
04	762.540	510.902	1	96.366	64.565	1	228.169	152.873	1	28,2	117
05	868.042	581.588	1	90.710	60.775	1	283.541	189.972	1	32,8	138
06	699.874	468.916	1	81.003	54.272	1	211.147	141.469	1	25,5	106
07	848.885	568.753	1	151.099	101.236	1	220.502	147.736	1	31,8	129
08	544.998	365.148	1	103.903	69.615	1	144.235	96.638	0	21,2	86
09	1.278.788	856.788	2	210.361	140.942	2	381.186	255.394	1	51,0	209
10	3.940.145	3.940.145	8	640.542	640.542	9	1.677.194	1.677.194	9	301,8	927
11	3.088.587	3.088.587	6	453.750	453.750	6	1.539.130	1.539.130	8	261,3	797
12	2.008.060	2.008.060	4	321.362	321.362	4	746.286	746.286	4	138,5	427
13	2.278.115	2.278.115	5	347.846	347.846	5	768.895	768.895	4	144,7	447
14	2.775.877	2.775.877	6	459.799	459.799	6	1.035.664	1.035.664	5	193,9	598
15	1.413.884	1.413.884	3	229.022	229.022	3	508.483	508.483	3	95,6	295
16	1.955.590	1.955.590	4	360.753	360.753	5	660.104	660.104	3	131,5	408
17	1.396.986	1.396.986	3	217.546	217.546	3	449.514	449.514	2	86,2	267
18	1.332.311	1.332.311	3	186.649	186.649	3	427.067	427.067	2	79,6	245
19	2.403.011	2.403.011	5	410.452	410.452	6	763.487	763.487	4	151,3	470
20	1.250.775	1.250.775	3	195.988	195.988	3	510.694	510.694	3	92,0	283
21	5.130.220	5.130.220	11	780.246	780.246	11	2.351.116	2.351.116	12	409,3	1.253
22	6.757.560	6.757.560	14	1.024.849	1.024.849	14	3.059.545	3.059.545	16	533,7	1.634
23	5.384.762	5.384.762	11	740.672	740.672	10	2.853.189	2.853.189	14	472,6	1.438
Total	**51.842.436**	**48.100.914**	**100**	**7.919.534**	**7.383.484**	**100**	**20.959.307**	**19.705.842**	**100**	**3.529**	**11.337**

[31] Solarverbund One stop shop Lösung für Photovoltaik 2009 EUREM A. Cizik
[32] Selvicka – Eurem presentation 2009
[33] Weiss Werner – MSC Presentation

4.2.3 Load curve of solar based energy

The typical seasonal distribution of sun light can be seen below:

Table 32: Sunlight distribution in Vienna kWh/m2 (Source Weiss Script MSC 2010)

	Jan	Feb	Mar	April	May	June	July	Aug	Sep	Oct	Nov	Dec	Year	Lat
Vienna, Austria	25.2	43	81.4	118.9	149.8	160.7	164.9	139.7	100.6	59.8	26.3	19.9	**1090**	48.2 N
Kampala, UG	174	164	170	153	151	142	141	151	155	163	154	164	**1882**	00.2 N
Johannesburg	215	185	183	144	135	119	132	158	189	200	197	218	**2076**	26.1 S

The table shows that in the summer half of the year (April to September) 77% of the total energy is produced. Through the day almost 100% of energy is produced in peak time. Spreading the potential yields over the year the following picture shows. In this table the assumption is that the total available roof is split between solar thermal and PV installations.

Table 33: Distribution of energy production from solar sources in GWh

Production	Jan	Feb	Mär	Apr	Mai	Jun	Jul	Aug	Sep	Okt	Nov	Dez	Total
Solar													
Global radiation	25,2	43	81,4	118,9	149,8	160,7	164,9	139,7	100,6	59,8	26,3	19,9	**1090**
% distribution	2,3	3,9	7,5	10,9	13,7	14,7	15,1	12,8	9,2	5,5	2,4	1,8	**100,0**
PV	60	102	193	282	356	382	392	332	239	142	62	47	**2588**
Solar thermal	70	119	226	330	415	446	457	387	279	166	73	55	**3022**

The load of course is 100% during the day. Below is a graph showing the load profile during a summer day:

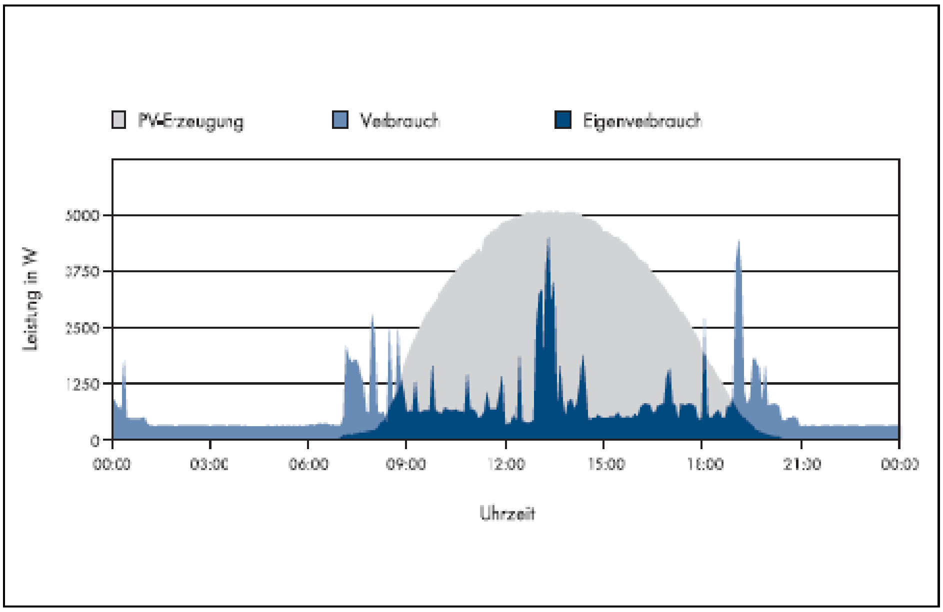


Abb. 1: Erzeugung, Verbrauch und Eigenverbrauch an einem wolkenlosen Sommertag (Vier-Personen-Haushalt und PV-Anlage mit 5 kW Peakleistung)

Figure 15: Solar load profile on a summer day (Source Gewerblicher Eigenverbrauch von Solarstrom – SMA 2010)

At noon on a summer day the plant reaches 100% of its capacity, during the night it is of course 0%. A load profile of one plant in Germany[34] shows an average capacity factor of 0,055 in winter and 0,168 in summer. During the day (8.00 -20.00) in summer it is on average 0,33 and 0,008 during night. In winter the figures are 0,1 during the day and almost 0 at night.

4.2.4 Costs of solar energy

4.2.4.1 Costs of electricity from PV

Investment costs of PV have declined rapidly in recent years. This was partly due to the famous learning curve and partly to market mechanisms, because enormous production capacities for PV modules have been added in recent years, especially in Asia. This has reduced the prices of PV modules drastically. And modules are still the most important cost factor of the PV system.

[34] Stadtwerke Unna Gmbh Lastprofil PV

To estimate the cost of a kWh from PV it is important to know the size of the plant. System investment costs are very different if it is a family house 5 kWp installation or a 1 MWp plant.

The cheapest (excl VAT) system price of a small 5 kWp installation is currently around 3350 EUR/kWp. For a large plant prices currently go down to 2100 – 2200 EUR/kWp (excl. VAT).

The yield per kWp in Vienna can be estimated with 975 kWh. In both cases a production period of 20 years and 4% interest rate is assumed. Maintenance costs are rather low with 1% of investment costs/year.

For the large plant this results in production costs (based on LRMC) of 19,2 €c/kWh. For the small plant costs go up to 30c/kWh. A household that uses the electricity itself would have to bear also the VAT. This increases the costs to 35 €c/kWh.

Based on available buildings probably only 10% single plants would have the size of 1 MW+. On the other hand there are many sites were many smaller plants could be realized in one project (state owned apprtemnt blocks "Gemeindebauten") The cost assumption is that 50% will be produced by small plants and 50% by large plants or larger projects combining many small plants, both feeding into the grid. Thus the average production costs of PV electricity in this model is 24,6 €c/kWh.

4.2.4.2 Costs of heat from solar thermal

Costs per kWh solar thermal are more difficult to estimate, because this depends very much on the individual situation, the size of the plant, the required temperature level and the use of the energy. For larger heat water applications up to 100 C the data from a master thesis about solar thermal installation was taken.[35] The costs of a family house installation are taken from sources of the internet and own experience.

The large plant has a collector size of 658 m2. The installed capacity is 460 kWth. Specific system investment costs are assumed to be 370 EUR/m2. Operating costs are 2% of the investment costs.

[35] Alexander Bauer 2010 -

In this thesis the yield per m2 was assumed to be 650 kWh/m2a. For conditions in Vienna this seems to be too high. As stated above the estimated yield is 400 kWh/m2a. Depreciation period and interest rate are 15 years and 4% respectively.

Total production per year add up to 263 MWhth. The specific production costs are 8,66c/kWhth for a large plant. For a small plant the investment costs per m2 are closer to 833 EUR[36] (excl. VAT) including all the equipment and installation. In this case the costs per kWhth for a 8m2 solar plant are 20 c/kWhth. The difference is very high, mostly because the individual investment for the storage, building and control system are quite high. Secondly for the individual household normally VAT has to be included in the costs as well since which would increase the price per kWhth to 24c.

4.3 Wind

4.3.1 Total wind potential

The total economic wind potential is based on a model calculation of the project windatlas. The assumptions behind are the following:

- No restricted area (natural protection area, residential area, etc.)
- Minimum distance to the next building 1.200m
- Specific investment costs of 550 EUR/m2 of rotator area
- 2 MW turbines
- Reasonable internal interest rate
- Feed in tariff of 9,7c and 12c

Table 34: Wind potential Austria (Source www.windatlas.at)

[36] Source: http://energieberatung.ibs-hlk.de/plansoltherm.htm

9,7 €Cent/kWh)	Leistung [MW]	Ertrag GWh/Jahr	Leistung (50% Auslastungsgrad)	Leistung (25% Auslastungsgrad)	Leistung (10% Auslastungsgrad)
Salzburg	32	69	16	8	3
Vorarlberg	31	67	16	8	3
Oberösterreich	368	833	184	92	37
Kärnten	564	1.294	282	141	56
Tirol	90	208	45	23	9
Steiermark	2.510	5.867	1.255	628	251
Niederösterreich	8.509	20.084	4.255	2.127	851
Burgenland	2.902	6.917	1.451	726	290
Wien	40	97	20	10	4
Gesamtpotential (inkl. Repow.)	**15.046**	**35.436**	**7.523**	**3.762**	**1.505**
12 €Cent/kWh					
Salzburg	256	474	128	64	26
Vorarlberg	165	315	83	41	17
Oberösterreich	1.493	2.912	747	373	149
Tirol	352	691	176	88	35
Kärnten	1.378	2.815	689	345	138
Wien	90	187	45	23	9
Niederösterreich	17.197	36.336	8.599	4.299	1.720
Steiermark	5.077	10.732	2.539	1.269	508
Burgenland	5.533	11.905	2.767	1.383	553
Gesamtpotential (inkl. Repow.)	**31.285**	**65.893**	**15.643**	**7.821**	**3.129**

As can be seen the potential in Vienna is rather low with just 187 GWh in case of a 12c feed in tariff. But in Lower Austria even with a lower feed in tariff the potential is 20.084 GWh. This production would cover the entire electricity consumption of Vienna and Lower Austria combined. Of course this is based on a model and often practical problems would impede the construction of wind mills as difficult terrain or lack of roads and grid connections. On the other hand it is based on 2 MW turbines, which are almost small for today's standards. So for this model it can be assumed that there is almost no limit for Vienna to use wind power sources in Lower Austria. For practical reason a share of 25% is assumed. For the lower tariff locations that results in a potential of 5000 GWh.

In all calculation there will be first used the larger potential of Vienna and thereafter the necessary potential of Lower Austria.

4.3.2 Load curve of wind energy

As shown in the chapter about current production the load factor in winter is 0,19 of the installed capacity and 0,13 in summer. No differences between day and night are assumed. It has to be registered however that the load factors in Lower Austria are higher in general. The average load factor over the year is normally above 0,2. Since no data from Lower Austria were available, the Viennese factors are adjusted to average 0,24 in winter and 0,18 in summer.

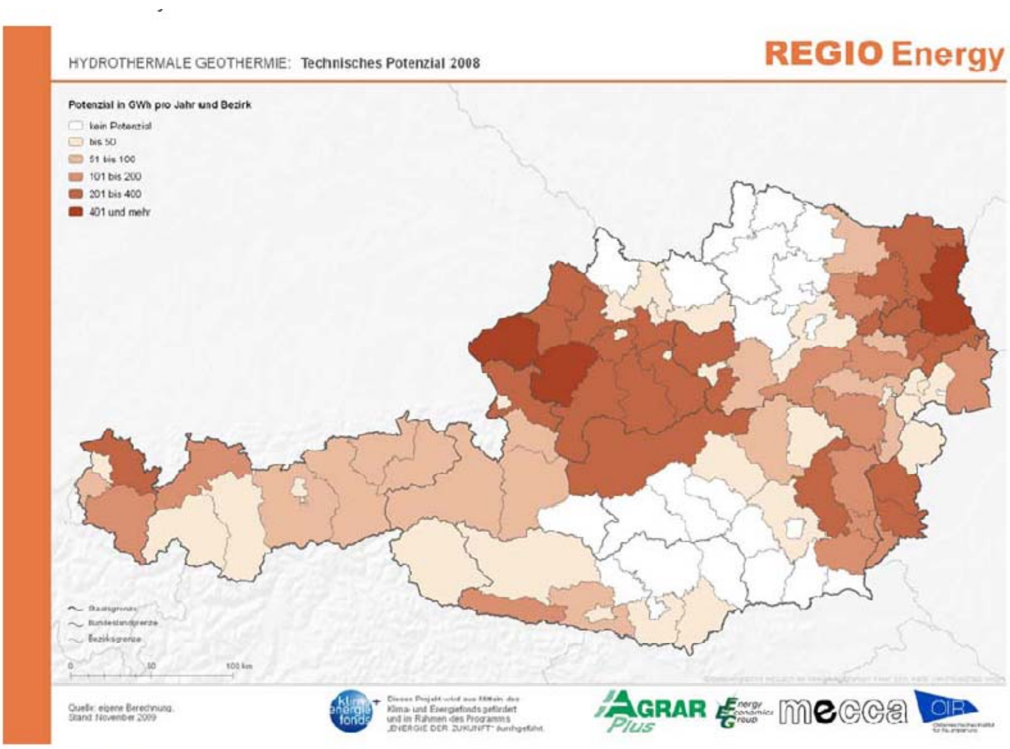
4.3.3 Costs of wind energy

The potential derived from windatlas is based on the assumption of different feed in tariffs. This defines that all plants within this potential are producing at LRMC equal or below the feed in tariff. Since the best locations are probably already taken the assumption is that all plants in the potential range of 9,7c/kWh have exactly this production costs. For plants that are additionally included in case the feed in tariff is 12c/kWh. As an weighted average - first all better locations are used that the worse locations - for the entire wind installed the assumption is 10,3 c/kWh.

4.4 Geothermal (Wien Energie)

4.4.1 Potential

The area around Vienna called the “Wiener Becken” is one of the bigger geothermal potentials in Austria. The map below shows the different zones in Austria:



Quelle: mecca

Figure 16: Geothermal potential Austria (Source Regio Energy 2008)

According to the Regio Energy study the total geothermal potential for Vienna is estimated to be 224 GWh.[37] An internal study of Wien Energie shows a much higher potential. According to internal studies of Wien Energie the potential is 300 MWth with 8000 full load hours. This results in a yearly production of 2400 GWh of heat. For this model the figures of Wien Energie are taken.

4.4.2 Load curve and costs

As stated above there is basically a year round production of heat with an installed capacity of 300 MWth. So the load factor is assumed to be 1 (300 MW) in winter and 0,9 (270 MW) in summer.

The investment costs according to Wien Energie experts are around 1,125 Mio per MW for a lifetime of 40 years. Operation costs are rather low. Assuming 1% the production costs per MWh would be very low at 7,3 EUR. According to the experts

[37] G. Stanzer Regio Energy 2008 page 100

the use of geothermal heat would therefore not increase the overall heat price significantly.

4.5 Heat pumps – ambient heat

4.5.1 Potential

As described above the geothermal potential can only be used via the district heating system. Since biomass is excluded and biogas is limited another option to provide space heating and process heat is the use of the ambient heat via heat pumps. Heat pumps use electricity to change the low ambient temperature into the necessary flow temperature. The level of the flow temperature and the type of heat pump determines the efficiency of the process. The level of flow temperature depends whether the heat distribution system is based on radiators (typical flow temperature 55-65 °C) or floor heating (around 35 °C) and on the level of required heat. Very well insulated houses require less flow temperature than buildings with a high energy demand.

The most efficient combination is water/water with a flow temperature of 35 C as can be seen below:

Table 35: Efficiency of heat pumps (Source Regio energy 2008)

Tabelle 2.8: Wärmepumpen – Annahmen zu den Jahresarbeitszahlen

System Heizungs-WP	Leistung	Jahr 2000 Vorlauftemp. 35 Grad C	Jahr 2000 Vorlauftemp. 55 Grad C	Jahr 2020 Vorlauftemp. 35 Grad C	Jahr 2020 Vorlauftemp. 55 Grad C
Luft/Wasser	8 kW	3,30	2,21	3,81	2,72
Wasser/Wasser	18 kW	4,73	2,78	5,44	3,49
Sole/Wasser	18 kW	4,03	2,41	4,55	2,92
Direktverdampfer	18 kW	4,60	2,97	5,15	3,53

Quelle: EEG

The same study sees the ambient heat potential of Vienna at 8.465 GWh.[38] The technically reduced potential with 6.860 GWh. In reality the study did assume a limitless potential and calculated the potential based on the demand of households, therefore an own calculation is done.

Firstly it is assumed that all houses are well insulated – see chapter efficiency of households. In this case a flow temperature of 35 °C could be sufficient. To maximize efficiency the mix of types is 75% sole/water and 25% water/water. 100% water/water would be even more efficient but water/water heat pumps are not always possible to install because of local groundwater conditions. Sole/water heat pumps are more often feasible for single family houses, either by using horizontal collectors or deep probes depending on the available area. The average efficiency is therefore 4,2 according to figures of the year 2000 (see above).

In case also warm water is included an important factor is the higher temperature level required of around 50 °C. For the warm water part probably not more than efficiency factor of 3 can be assumed. To produce the total 2491 GWh with heat pumps another 830 GWh would be necessary. Of course there is also the possibility to use solar heat for the warm water part, but in this case the household has to invest in two different heat production devices which is rather expensive.

The figures above are based on the assumption that heat pumps are used in individual buildings. There is also the possibility to feed into the district heating system. The efficiency of this process depends a lot on the temperature level of the input temperature and the grid temperature. In case the input temperature is high, by using

[38] Regio Energy 2008 page 130

for example excess heat of industrial processes and the grid temperature is comparable low, the process can be very efficient. On the other hand if ground temperature level has to be heated up to the current grid temperature the process would be very inefficient. Again for simplification heat pumps are seen as family house installations. Other possible solutions are larger plant separated from the grid.

4.5.2 Costs and load curve

The load curve will affect electricity and the production will mirror 100% the demand side of space heating and warm water. The heat demand for space hearing has to be divided by the efficiency factor of 4,2 and the demand for warm water by 3.

Based on own experience the costs for a heat pump installation sole/water would be at least around 15.000 EUR with ground collectors. In case a deep probe has to be drilled the costs would rise to 20.000 EUR. As an average investment costs of 17.500 EUR are taken. Again the question is if the underlying assumption is that an existing system is replaced before its end of the useful time span. In this case the full costs of the system are additional. If the assumption is that the system has to be replaced anyhow only the difference to the investment in a fossil boiler has to be calculated. As in the case of large household appliances only the costs compared to another system is taken. The replacement of an old gas boiler with a new condensing boiler costs around 7.000 EUR. The investment cost difference is therefore 10.500 EUR.

The comparison of LRMC has the following additional assumption:

- Yearly heat demand space heating (after insulation) and warm water 11.600 kWh
- Lifetime 20 years
- Interest rate 4%
- COP heat pump 4,2 (3)
- Efficiency gas boiler 95%
- Electricity price 18,4 c/kWh
- Gas price 7,1 c/kWh for current natural gas
- Gas price 16c/kWh for biogas (see calculation in the next chapter biogas)

- No price increases for both fuels

Comparing now the cost of 1 kWhth of a heat pump with 1 kWhth of a gas boiler the total installation costs have to be taken into consideration for both options.

Table 36: Comparing household costs of different heat production appliances

	heat pump	gas boiler	biogas boiler
Invest	17500	7000	7000
Annualised	1288	515	515
heat demand	11600	11600	11600
Thereof WW	3500	3500	3500
energy demand	3095	12211	12211
Fuel costs	570	867	1954
Total costs	1857	1382	2469
Costs per kwHth	0,160	0,119	0,213

The costs for heat from heat pumps is 4 €c more expensive per kWhth than the gas boiler with current gas prices. For the total year the difference of costs would be 475 EUR: In case the gas boiler is based on biogas the heat pump with current electricity prices becomes cheaper. Of course in a renewable Vienna also the electricity price will change depending on the mix of renewable. The final comparison will be made in the models in chapter 5.

A second cost factor of course is the heat distribution system. A building with a high temperature distribution system is impeding a high COP of the heat pump. Only low temperature heat systems as floor heating are allowing a high efficiency rate as was also stated by the Biermayr study.[39] To simplify the calculation no costs for the change of the heat distribution system are assumed.

[39] Biermayr et al, Heizen 2050, 2010

4.6 Biogas

4.6.1 Assumption and potential

For biogas several assumptions are made. First it is assumed that the biogas produced is not electrified at the biogas production site, but upgraded and fed into the gas grid. From there it is transported to Vienna and fired in the existing gas power plants in Vienna. This has several major advantages:

- the existing infrastructure can be used
- the efficiency of electricity production is much higher in the existing large gas power plants than in small scale installations
- the excess heat can be used in the existing district heating system

The second assumption is, that the biogas produced is based on 100% maize silage. This simplification is made to limit the scope of this work. Of course there are manifold other potential substrates but to investigate the optimal mix would mean a new master thesis in itself. But in case this option will be pursued in the future a detailed investigation could be very supportive, especially investigating the use of intermediate crops to limit the competition with the production of food, a general disadvantage of biogas from crops.

The third assumption is that not only within Vienna but also in Lower Austria plants will produce biogas for Vienna.

The first important question is how much land is available for the production of the necessary substrate for the biogas plant. The fourth assumption is that 5% of land currently used for the production of crops and 10% of unused land (Brachland) is available for our biogas production. In Vienna there are currently 4.590 ha used for crop production.[40] Below the share of farm land per crop and district in Lower Austria can be seen:

[40] Statistik Austria Anbau auf dem Ackerland 2009

Table 37: Agricultural land in Lower Austria (Source Bärnthaler et al Biogasgroßanlagen)

Bezirk	Ackerfläche	Getreide	Mais	Zuckerrüben	Kartoffel	Ölsaaten	Eiweiß-pflanzen	Gemüse	Obst	Brache	NAWARO	Energie-pflanzen
Amstetten	34.666	11.940	12.961	770	102	909	1.190	29	59	1.642	260	281
Baden/Mödling	25.296	13.953	1.491	1.547	71	1.659	939	242	96	2.618	39	89
Bruck/L.	45.411	25.347	3.738	3.747	211	3.959	1.229	24	38	4.389	706	555
Gänserndorf	84.797	47.655	2.881	7.330	3.471	4.570	2.618	5.152	261	7.138	830	58
Gmünd	17.406	9.858	195	0	1.855	164	924	1	3	384	32	31
Hollabrunn	60.099	35.320	2.109	4.560	1.717	3.260	1.843	164	238	6.296	1.113	226
Horn	46.246	25.551	3.125	174	684	3.689	2.371	84	97	2.354	1.963	221
Korneuburg	40.859	22.255	3.456	4.224	2.946	2.103	930	281	149	2.808	665	188
Krems	21.831	11.101	2.423	113	133	1.304	1.211	9	440	1.759	100	22
Lilienfeld	716	121	77	0	1	0	4	0	3	0	0	
Melk	30.229	12.192	8.533	693	92	621	697	68	47	1.188	177	741
Mistelbach	90.030	53.691	4.603	5.002	1.168	6.221	3.218	340	246	9.314	1.593	2
Neunkirchen	12.185	4.965	1.178	0	21	245	342	3	17	497	25	
St.Pölten	43.082	15.547	15.292	1.794	289	1.874	1.014	169	284	2.776	544	254
Scheibbs	10.661	4.290	2.878	161	15	129	161	20	18	361	25	8
Tulln	32.640	13.509	8.079	2.731	365	2.221	1.192	173	160	2.580	478	173
Waidhofen/T.	35.023	19.611	2.297	5	2.095	1.637	2.068	87	55	1.554	719	385
Waidhofen/Y.	1.199	333	291	0	6	28	15		5	18	3	
Wr. Neustadt	22.692	10.173	2.555	462	42	399	1.030	2	34	1.288	67	75
Zwettl	42.719	23.015	771	0	2.737	627	2.308	7	15	1.650	199	145
Summe	**697.788**	**360.427**	**78.933**	**33.313**	**18.021**	**35.619**	**25.304**	**6.855**	**2.265**	**50.614**	**9.538**	**3.454**

In total in Lower Austria there are 697.788 ha used for crops, whereof 50.614 ha are currently unused land. Using the above mentioned formula the available land for biogas in Vienna and Lower Austria would be:

- 5061 ha from unused land in Lower Austria
- 32 359 ha from crop land in Lower Austria
- 459 ha from crop land in Vienna

This adds up to 37.879 ha of land for biogas. To calculate the yield of methane the calculation tool of Wellinger is used.[41] Based on it, the yield of 1 ha land is approximately 18t oTS of maize. With this amount a daily production of 29 Nm3 of biogas or 15 Nm3 of CH4 can be produced. Since there is no electrical transformation on site, the assumption is that there are 355 days of production per year. This results in a total production per year of 201.705.675 Nm3 of CH4 or 2017 GWh of natural gas. This is only 9,13% of the current natural gas consumption, or 14,9% of the natural gas used for the existing power plants. To simply substitute the existing natural gas consumption by biogas, around 50% of the current agricultural

[41] Wellinger – MSC calculation tool

land of Lower Austria and Vienna would be necessary, which does not seem to be feasible.

4.6.2 Load curve and costs

As mentioned above the plant Donaustadt 3 is taken as a reference. If all biogas (2017 GWh) is used in this plant with a total capacity fuel of 700 MW (347 MWel, 250 MWth) the plant would run with around 2880 full load hours. The plant could produce 999 GWh of electricity and 720 GWh heat. As we will see later from the heat perspective, biogas is the only available source for medium and peak times in winter except for electricity. Therefore the assumed load factor is 0 in summer and 0,7 in winter.

Another option for biogas is to use it for pure peak load without the production of electricity.

For the costs several steps have to be considered. Firstly the costs to produce the biogas/methane itself, secondly the costs to upgrade it and feed it into the grid and thirdly the transport to Vienna and its transformation into electricity and heat.

The costs of biogas production depend strongly on the size of the plant and the feedstock costs. According to a Frauenhofer study of 2008[42] the costs vary between 5c/kWh and 6,8 c/kWh for the gas production. In addition depending on size and method of upgrading there are between 1,5 c/kWh and 2,5 c/kWh to include for the upgrading. So total costs would vary between 6,5 c/kWh and 9,5 c/kWh. In Austria costs for biogas production are rather higher than in Germany[43] so the upper side of 9,5c/kWh is assumed for the model.

One of the assumption in the model is, that biogas will be used to produce electricity in a combined heat and power plant. To calculate the effect on the electricity price

[42] Verbundprojekt Biogaseinspeisung – Fraunhofer 2008 page 22
[43] Kosten bestehender Biogasanlagen p.17ff Boku 2011

produced, data from an IEA/OECD study about electricity production costs were used.[44] Below are the data from one Austrian combined cycle power plant .

Table 38: Production costs of gas fired power plants (Source Projected costs of electricity – IEA 2010)

Table 3.7e: CHP: Levelised costs of electricity in US dollars per MWh													
Country	Technology	Net capacity	Overnight costs[1]	Investment costs[2]		Decommis-sioning costs		Fuel costs	Carbon costs	Heat credit	O&M costs[3]	LCOE	
				5%	10%	5%	10%					5%	10%
		MWe	USD/kWe	USD/kWe		USD/MWh		USD/MWh	USD/MWh	USD/MWh	USD/MWh	USD/MWh	
Austria	Natural Gas – CCGT	405	788	866	935	0.06	0.02	63.89	12.60	37.06	3.91	**50.79**	**56.07**
	Br Coal Turbine	150	3 690	4 131	4 620	0.27	0.09	11.30	15.42	32.23	9.60	**42.12**	**108.75**

The calculation of the IEA is a LRMC cost calculation, based on the following assumptions:

- 30 years life time
- Exchange rate to the EUR of 1,45
- Carbon price of 30 USD (20 EUR)
- Natural gas price of 20 EUR/MWh
- 5% discount rate
- 85% load factor (7446 hours)

As it can be seen above the fuel costs are the most important factor. The annualized costs for the investment is only 7,45 USD/MWh. The assumption of a load factor of 85% for a gas power plant is in practice not very realistic, since gas power plants are mostly used to produce medium and peak load electricity.

In a scenario were biogas would fuel the gas plant the following changes would result:

- The gas price rises to 9,5 c (+ 475%)
- No carbon price anymore
- The full load hours are reduced to 3000 or a load factor of 34% (-250%)

[44] Projected costs of electricity – IEA 2010

Assuming everything else stays the same and O&M costs are fully variable the new costs would look as follows:

New Electricity costs (USD) = Annualized investment costs at 3000 full load hours + O & M costs + fuel costs of biogas – heat revenues =18,25 + 3,91 + 303 – 37,06 = 288.

The costs of electricity would rise to 288 USD/MWh or 19,9 cEUR/kWh. At first glance this figure seems to be quite surprising, because it is slightly above the production costs of the most efficient small biogas plants with 500 kWel. The main difference however is, that upgrading costs are not included in the small biogas plants and they are running above 7000 full load hours. Without these additional costs, the production costs of the big plant would go down to 13,6c/kWh. For this model the costs of 19,9 c/kWh are taken.

The other option is that biogas will be used directly at the end user. In this case it has to be analyzed how the final gas price will be effected when the purchase price of the gas distribution company is increasing from 2 c/kWh (assuming the purchase price is the same as for the gas power plant) to 9,5c/kWh. According to e-control the share of energy costs are 44% of the total consumer price or 3,1c/kWh.[45] Assuming that all other costs stay the same, except for Vat and the increase is passed on to the consumer in absolute figures not relative figures (the absolute margin stays the same, the relative margin shrinks) the new costs are calculated as follows:

(Consumer price old/1,2+difference between purchase price gas company and purchase price old)*1,2=(7,1/1,2+9,5-2)+1,2= 16c/kWh gas.

[45] E-control – web-site Zusammensetzung des Gaspreises

4.7 Hydro

4.7.1 Potential

Within Vienna there is almost no additional hydro potential. In the Danube river there are already two plants within or close to the city – Greifenstein and Freudenau. The only realistic additional larger plant close to Vienna that was discussed in the last decades was Hainburg. Due to massive political protests of environmentalists in the 80s, the plant was never built. Since this study does not reflect political issues, the potential is included in one of the scenarios. It has to be considered that the area around Hainburg is now a national park, so the implementation would be very difficult.

On the other hand in the original plans the installed capacity was 351 MW[46], the largest plant on the Danube (see below). With typical full load hours a production of 2000 GWh could be possible.

[46] Wikipedia – Österreichische Donaukraftwerke

Table 39: Hydro power on the Danube (Source Wikipedia 2011)

Strom -km	Kraftwerk	Bundes - land	Leistung in MW	Regelarbeit in GWh/Jahr	Auslastung	Ausbau-wassermenge in m³/s	Stauraumlänge in km	Fertig-stellung
2203,3	Jochenstein	OÖ, Bayern	132,0	850,0	73 %	2050	27,0	1956
2162,7	Aschach	OÖ	287,4	1617,4	64 %	2040	40,0	1964
2146,1	Ottensheim-Wilhering	OÖ	179,0	1134,9	72 %	2250	16,0	1974
2119,5	Abwinden-Asten	OÖ	168,0	995,7	68 %	2475	27,0	1979
2094,5	Wallsee-Mitterkirchen	NÖ/OÖ	210,0	1318,8	72 %	2700	25,0	1968
2060,4	Ybbs-Persenbeug	NÖ	236,5	1335,9	64 %	2650	34,0	1959
2038,2	Melk	NÖ	187,0	1221,6	75 %	2700	22,5	1982
1980,5	Altenwörth	NÖ	328,0	1967,6	68 %	2700	30,0	1976
1949,2	Greifenstein	NÖ	293,0	1717,3	67 %	3150	31,0	1985
1932,8	Nußdorf	Wien	4,5	24,6	62 %	-	-	2005
1921,1	Freudenau	Wien	172,0	1052,0	70 %	3000	28,0	1998
	Gesamt		2197,4	13235,8	68 %		280,5	

The small hydro potential within and around Vienna is seen as very low, because of the flat terrain. Therefore no additional hydro potential is included.

4.7.2 Load curve and costs

As stated above the load curve is estimated based on the existing plants and its long term average load factros. The summer load factor is 0,85 and in winter 0,55. The existing two plants in Vienna together have a capacity of 97 MW in winter and 150

MW in summer. Hainburg would add another 193 MW in winter and 300 MW in summer.[47]

Since over 97% of electricity produced by hydro in Vienna is from a large hydro plant, the production costs of large hydro are relevant. Based on LRMC the average for large hydro is around 7c/kWh according to Weissensteiner.[48] One of the most important factors influencing the costs is the interest rate, because of the high share of investment. In a study of the IEA different scenarios are calculated.[49] In the scenario of 5%, which is also the base on the calculation for wind and PV the LRMC costs are around 5c/kWh. For this model the later is taken.

4.8 Summary of the potentials of renewable energy

The total potentials within and around the city can be seen below. Waste incineration is considered 100% renewable and the current final energy produced by the biomass power plant is included as part of the city, even though most of the biomass is coming from outside of Vienna. Biogas is fully transformed to electricity and heat. Solar is split between PV and solar thermal.

Table 40: Overview potential of renewable in GWh (figures in red are current production)

	Inside Vienna		Surroundings		Total	
GWh	**Electricity**	**Heat**	**Electricity**	**Heat**	**Electricity**	**Heat**
Waste	5	1500			5	1.500
Biomass	162	100			162	100
Geothermal		2400			-	2.400
Biogas			999	720	999	720
Solar	2588	3022			2.588	3.022
Wind	187		5000		5.187	-
Hydro	1075		2000		3.075	-
Total	4.017	7.022	7.999	720	12.016	7.742

Within the city borders there is a total potential of 11.000 GWh of renewable energy, roughly split 1/2 between electricity and heat. In case parts of Lower Austria is included the potential for electricity increases strongly, but heat remains almost the

[47] Data from Wien Energie experts
[48] Weissensteiner MCS script cost of electricity
[49] IEA Projected costs of electricity

same. Comparing these figures with the reduced demand figures it shows that even in the high saving scenario the demand for heat (8.781 GWh) can not be fully covered with the available resources for heat. But the total amount of available renewable heat resources is enough to provide the current heat demand of the district heating system (6.046 GWh). It has to be remembered however that only 4.600 GWh are also available in winter. The rest comes from solar thermal installations that are only available in summer. This leaves two solutions: Either decrease demand further, or use electricity as an energy carrier for heat. As described in chapter 4.5 this could be efficiently done by the use of heat pumps.

4.9 Costs of renewable energy

Summarizing the results of the previous chapters the following ranking according to costs can be done. In case of electricity in the table below only pure production costs are shown, because the final costs for the household depend on the mix of sources. In case of heat the final household costs including the investment at the building are included. For district heating the mix of current biomass with waste and geothermal is assumed, including the cost for a network with lower density of demand.

Table 41: Costs of renewable energy

c/kwH production costs	Electricity	Heat
Hydro	5	
Wind	10,3	
Biogas	19,9	
PV	30	
Large solar thermal		8,7
Heat pump (current electr. mix)		15,5
Small solar thermal		20
Biogas boiler		21,3

All investment costs calculated without VAT

In case of electricity the cheapest source is hydro, thereafter wind and finally biogas and PV. In case of heat, large solar thermal installations and heat pumps are the cheapest, but heat pumps are only renewable in case the used electricity is based on renewable energy. Geothermal would be by far the cheapest heat source with production costs below 1c/kWh, based on the investment cost estimates of Wien Energie.

5 Model and scenarios

5.1 Summary of the results of the previous chapters

5.2 Description of the model

The model is combining all the information previously analyzed. It is combing saving measures with the use of the potential for renewable energy. Some parts are always taken for granted; other parts are more flexible based on the different scenarios. The fix parts are:

- Change of fuel based mobility to e-mobility
- Electricity savings for households by replacing old appliances
- Renewable energy carrier which are consumed already today will be fully included, even though they are not always from within the city (e.g. biomass)
- Geothermal sources will always be used, because of the large remaining demand for heat
- Process heat is always seen as base load heat and on the supply side base load heat is waste, geothermal, solar thermal and biomass. Even though today for economic reasons biomass is used for middle load. The difference of definition does not really change the cases, since biomass only contributes 100 GWh per year.

In a first step the demand reduction is taken per energy service/sector and the result per energy carrier is calculated. Based on the demand reduction the resulting heat and electricity demand is analyzed and compared to the renewable potential. Then different assumptions are made which renewable energy carrier can be used. In case of heat the differentiation between base, middle and peak load is already considered during the allocation of potentials. In case of electricity this differentiation is not done in a first step, because the assumption is that the grid can balance mismatches of supply and demand. But in the analysis of loads the mismatch of demand and supply in the case of electricity is analyzed.

For the costs for households the following is included:

- Costs for the reduction of energy demand
- Costs for the supply with renewable energy produced in Vienna:
    - For electricity the difference between production costs of the new renewable mix with current wholesale market prices plus network costs and taxes. For network costs no changes are assumed. In case of taxes only the absolute VAT changes.
    - For heat the difference between current prices of district heating and gas and future costs of production of the new renewable mix.
- Costs for switching to e-mobility.

The following potential costs are not included:

- Indirect costs because of energy efficiency measures of other sectors
- Costs for change of heat distribution systems
- Costs because of reduced energy density of consumption in the district heating system
- Additional storage and network costs
- In case of district heating the additional costs per kWh because of the high fixed costs for the network and the lower demand because of savings.

In the load curve part the effect of changes of demand and supply on the summer/winter and peak/off peak load curve are briefly described.

There is no time factor in the model. The result of savings and substitution is only shown as a final result. Therefore also no increases or decreases of energy demand outside the models assumption are included - e.g. no increases because of higher population or decreases because of overall technical development. Only in the final conclusions in chapter 6 some aspects of the time are discussed.

5.3 Scenario A – the low cost solution

In this scenario only the lower savings are performed, because the assumption is that after a certain level the costs for extra saving increase almost exponentially. This can be seen for example in the two household space heating reduction cases. The basis for this model is the demand reduction scenario ambitious. On the production side for electricity the ranking is hydro, wind, biogas, PV. After calculating the new electricity mix, the ranking for heat can be done, because the price of ambient heat through heat pumps depends on the price of electricity.

5.3.1 Overall Demand side

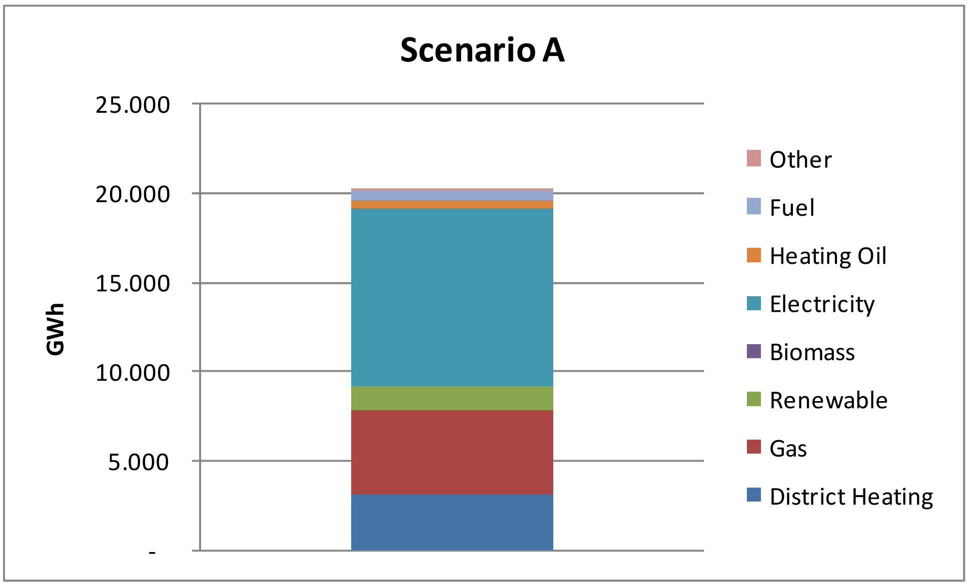


Figure 17: Overview of result of demand saving (in GWh final energy demand) ambitious demand reduction scenario

The total demand of final energy is reduced by 48%. If simply the demand is reduced the mix of energy carriers can be seen above. District heating and electricity are both currently only partly made by renewable primary energy carriers. In the next chapters the current demand structure is combined with the renewable sources available to create a mix where all energy is based on primary renewable energy from Vienna and its surroundings.

5.3.2 Electricity mix after demand reduction

The new demand for electricity is 10 TWh. The already existing renewable production based on waste, biomass and hydro is 1.242 GWh. According to the price ranking hydro and wind are added. The hydro plant on the Danube brings another

2.000 GWh. Another 5000 GWh will be covered by wind. This leaves, before other changes, a shortage of 1800 GWh. The new electricity mix looks as follows without PV and biogas:

Table 42: Scenario A – Electricity mix before change of remaining fossil carriers

Model A electricity	GWh	%	Costs
Hydro	3.075	37,3	5
Wind	5000	60,7	10,3
Biomass	162	2,0	0
Waste	5	0,1	0
Total	8242	100,0	8,3
Demand	10028		21,1

The new production price was based on the mix of hydro and wind, because the other two only contribute 2%. Based on this production price the new consumer electricity price is calculated. First the new production price is compared to wholesale base load price. The EEX base future is currently at 6c/kWh.[50] So the purchasing price for the distributor would rise by only 2,3c per kWh. As for the consumer gas price the absolute increase is added and all other parts of the electricity price remain unchanged except for the VAT. Starting from the current price of 18,4c the price would increase to 21,1c/kWh.

5.3.3 Process heat

The new energy carrier mix of process heat can be seen below:

Table 43: Process heat demand per energy carrier scenario A

Demand ambitious reduction	HH	Service	Industry	
District Heating	552	23	38	**613**
Gas	1.398	131	1.032	**2.561**
Renewable	16	21	73	**110**
Biomass	-	-	-	**-**
Electricity	491	1.455	49	**1.995**
Heating Oil	34	12	67	**113**
Fuel	-	-	1	**1**
Other	-	2	-	**2**
Total current demand	**2.491**	**1.644**	**1.261**	**5.396**

[50] Source: http://www.e-control.at/de/marktteilnehmer/strom/strommarkt/preise/grosshandelspreise 8/2011

Process heat demand after demand reduction is 5.396 GWh, thereof 1.261 GWh come from the industrial sector. The whole part of process heat can be seen as base load demand, because it is needed around the year. Since the district heating system can only reach 70% of the consumers the maximum potential for district heating is 3700 GWh. Before the use of solar thermal is considered the fix sources for base load heat are used. The combined potential of geothermal, waste and biomass is 4.000 GWh. This corresponds also roughly with the reach of the district heating system. 110 GWh are already produced by renewable sources. The remaining part of 1.286 GWh, is currently produced by electricity (most likely direct use) and to simplify matters there is no change. The overall electricity demand for heat is then reduced from currently 1.995 GWh to 1.286 GWh (-709 GWh).

5.3.4 Light & power and mobility

The remaining demand for light & power is 3.603 GWh. Thereof 3.046 GWh are currently covered by electricity, the rest of 557 GWh by different fossil fuels or gas. This theoretically can be replaced either by gas or electricity. To simplify the model it is fully replaced by electricity.

The demand of e-mobility was already considered in the starting point.

5.3.5 Space heating

Table 44: Space heat demand per energy carrier scenario A

Demand ambitious reduction	HH	Service	Industry	
District Heating	468	1.790	255	**2.513**
Gas	1.658	348	151	**2.156**
Renewable	116	133	69	**317**
Biomass	-	-	-	**-**
Electricity	170	330	90	**590**
Heating Oil	136	102	61	**299**
Fuel	-	-	-	**-**
Other	4	6	-	**10**
Total current demand	**2.550**	**2.708**	**626**	**5.884**

In this scenario total space heating demand is 5.884 GWh. 317 GWh are produced by direct renewable final energy carriers. This leaves 5.567 GWh. Since this demand is entirely seasonal the only realistic options are biogas or electricity with heat pumps. According to the assumption of electrification of biogas the full use of biogas in a combined cycle power plant, would produce 720 GWh of heat at winter time. On the other hand biogas is an excellent source of peak load heat, especially in the district heating system. According to experts of Wien Energie the peak load heat demand is around 2,5% of total heat demand. The necessary demand on biogas for peak load heat would be: Total heat demand * 2,5%*0,7 (maximum reach of district heating system) = 200 GWh. This is only 10% of the total biogas potential and leaves 648 GWh to be used from a CC power plant as excess heat potential.

This reduces the remaining space heating demand to 4.719 GWh heat. Thereof again 590 GWh are already covered by electricity and will not change. The remaining 4129 GWh could be provided by heat pumps, increasing electricity demand by 984 GWh. Since wind potentials are exhausted the next source has to be used, which is biogas and PV. Since most of the base load heat is provided through the district heating system, in this scenario it seems to be a realistic possibility that part of the heat pumps are connected to the district heating system.

5.3.6 Electricity mix after substituting remaining fossil based energy

After the first round of simulation the following has changed. To replace remaining fossil fuel based energy in space heating and light & power additional electricity was used. The electricity demand in total has increased by 830 GWh. Since hydro and wind are already exhausted biogas and PV are used. The result on production price can be seen below:

Table 45: Scenario A – Final electricity mix

Model A electricity	GWh	%	Costs
Hydro	3.075	28,3	5
Wind	5.000	46,0	10,3
Biomass	162	1,5	0
Waste	5	0,0	0
Biogas	899	8,3	19,9
PV	1.717	15,8	24
Total	10.858	100,0	11,8
Demand	10.858		25,3

The production price in this mix is around 12c. Using this production price in the calculation of the consumer electricity price, the price rises to 25,3c/kWhel.

In this model scenario 46% of electricity comes from wind. The rest comes from hydro, PV and biogas. In this scenario the city has a remaining potential of around 2.000 GWh electricity from PV, which in combination with heat pumps, can also provide heat. Also not all the biogas potential had to be used.

The heat production mix in GWh looks as follows:

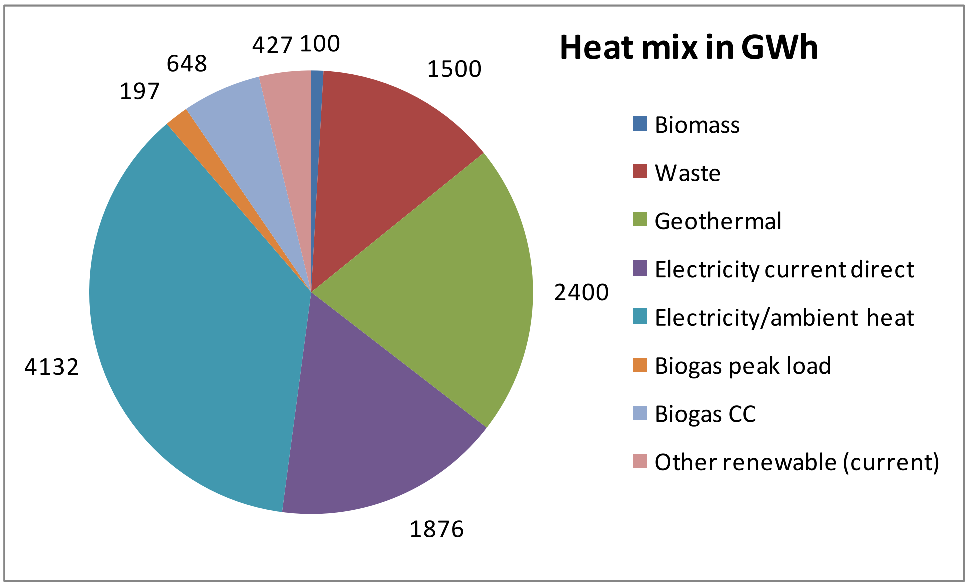


Figure 18: Heat production mix Model scenario A

The dominant source is electricity using heat pumps. This surprising result is caused by the lack of potentials to produce sufficient middle load. Waste and geothermal are used to cover the base load. Biogas covers the peak load. The lack of solar thermal is on the hand caused by the already mentioned high supply by other base load sources on the other hand it has the disadvantage, that it always needs a second heating system. The calculation is however not 100% fair to the solar thermal system, because in cases where a biomass boiler is an option and the necessary input temperature is high it can be more economically than a heat pump system. But in this model no biomass resources were available and the high thermal standard of buildings plays into the hand of heating pumps as the more logical option. In the second scenario also solar heat will be included.

5.4 Scenario B – the "politically most accepted" solution

In the second scenario the author makes several assumptions out of his own experience regarding the acceptance of different measures. In general the less a measure can be seen the more accepted it is. This gives energy saving measures an advantage over new energy plants. Solar installations on roofs are also more popular than for example wind mills. Hydro on the Danube has been and still is an extremely sensitive issue and can be excluded altogether. Biogas in general seems to be more popular than wind, because it is less visible. On the other hand it emits odors and the feedstock is in competition with food production. Geothermal is not critically because it happens underground. So for this scenario the following is used as a base:

- Demand reduction scenario high
- Current renewable production stays as in the other scenario
- Heat ranking: Geothermal, heat pumps, solar heat (heat pumps and solar is seen as equally popular, but the former is also usable for middle load)
- Electricity ranking: PV, biogas, wind

5.4.1 Overall demand side

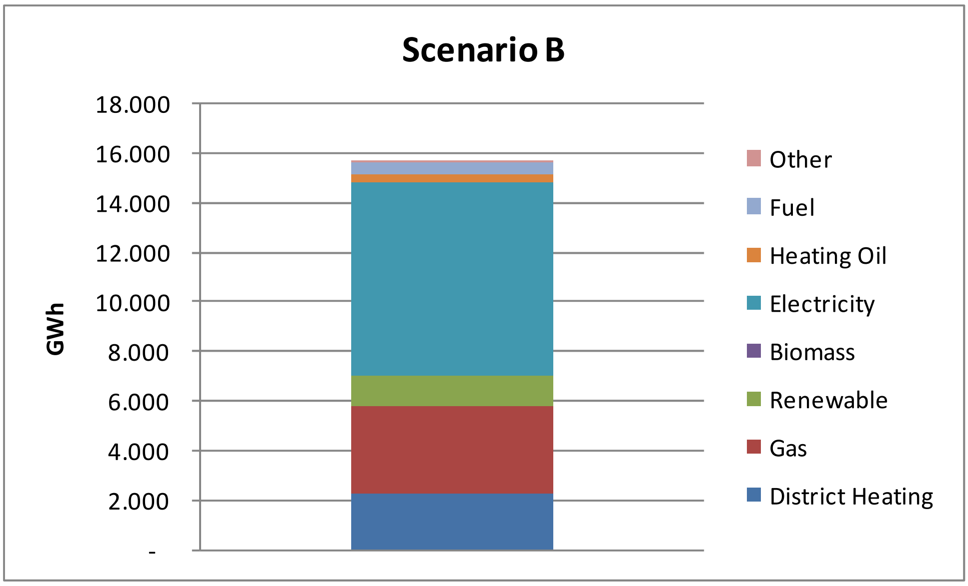


Figure 19: Overview of result of demand saving (in GWh final energy demand) scenario B

In this scenario demand is reduced by 58% down to 16 TWh. The biggest energy carrier with more than 50% is now electricity. Again the remaining demand is compared to production.

5.4.2 Electricity mix after demand reduction

The new demand for electricity is 7.857 GWh. The already existing renewable production based on waste, biomass and hydro is again 1.242 GWh. According to the new ranking maximum of PV and biogas and wind are added. The new electricity mix looks as follows:

Table 46: Scenario B - Electricity mix before change of remaining fossil carriers

Model B electricity	GWh	%	Costs
Hydro	1.075	13,7	5
Wind	2.087	26,6	10,3
Biomass	162	2,1	
PV	3.529	44,9	24
Biogas	999	12,7	19,9
Waste	5	0,1	
Total	7.857	100	17,1
Demand	7.857		31,7

In this scenario PV becomes the dominant renewable source for electricity. The new production price is 17,1c/kWh. Based on this production price the new consumer electricity price is again calculated. The price would increase to 31,7c/kWh. However at the moment all roofs are used for PV, which later changes.

5.4.3 Process heat

Table 47: Process heat demand per energy carrier scenario B

Demand hard reduction	HH	Service	Industry	
District Heating	552	23	36	**611**
Gas	1.398	131	971	**2.500**
Renewable	16	21	69	**106**
Biomass	-	-	-	**-**
Electricity	491	1.455	46	**1.992**
Heating Oil	34	12	63	**109**
Fuel	-	-	1	**1**
Other	-	2	-	**2**
Total current demand	2.491	1.644	1.186	**5.321**

Process heat demand after demand reduction is 5321GWh, thereof 1.186 GWh come from the industrial sector. As before in model A the whole part of process heat can be seen as base load demand, because it is needed around the year. The combined potential of geothermal, waste and biomass is 4.000 GWh, this leaves a remaining part of 1.321 GWh. Thereof 106 are already produced by renewables. The potential for solar thermal is 20% of the industrial demand and 66% of the other sectors, on average 56%. 740 GWh of the remaining heat demand is produced by solar thermal the rest by the already used electricity (475 GWh). The potential for PV is reduced by only 5% to 3.352 GWh. Electricity consumption is reduced by 1.517 GWh.

5.4.4 Light & power and mobility

The remaining demand for light & power is 2.846 GWh. Thereof 2.346 are currently covered by electricity, the rest of 500 GWh by different fossil fuels or gas. This theoretically can be replaced either by gas or electricity. To simplify the model it is fully replaced by electricity.

The demand of e-mobility was already considered in the starting point.

5.4.5 Space heating

Table 48: Space heat demand per energy carrier scenario B

Demand hard reduction	HH	Service	Industry	
District Heating	200	1.253	179	**1.632**
Gas	710	243	106	**1.059**
Renewable	50	93	48	**190**
Biomass	-	-	-	**-**
Electricity	73	231	63	**367**
Heating Oil	58	71	43	**172**
Fuel	-	-	-	**-**
Other	2	4	-	**6**
Total current demand	1.093	1.896	438	**3.427**

In this scenario total space heating demand is 3.427 GWh. 190 GWh are produced by direct renewable final energy carriers. This leaves 3237 GWh. Using the same formula as above for peak load heat, 153 GWh of biogas is needed for peak load. Biogas from CC adds another 662 GWh and reduces the remaining demand to 2422 GWth. Subtracting the already used electricity leaves 2.054 GWh. Using heat pumps adds another 489 GWh demand of electricity.

5.4.6 Energy mix after substituting remaining fossil based energy

In total 533 GWh electricity were saved. The final electricity demand is now 7.324 GWh. Since wind is the last remaining source, the additional demand will be covered by wind.

Table 49: Scenario B: Final electricity mix

Model B electricity	GWh	%	Costs
Hydro	1.075	14,7	5
Wind	1.810	24,7	10,3
Biomass	162	2,2	0
Waste	5	0,1	0
Biogas	919	12,5	19,9
PV	3.353	45,8	24
Total	7.324	100,0	17,2
Demand	7.324		31,8

In this model scenario 45% of electricity comes finally from PV. Wind has a share of 24%. The rest comes from biogas and hydro. In this scenario the city has a remaining potential of around 3.200 GWh electricity from wind in Lower Austria. What is also remarkable is the fact that in this scenario only around a third of the electricity comes from outside the city, namely wind, biogas and biomass. The consumer price of electricity finally reaches 31,9c/kWh. The heat production comes almost entirely from within Vienna. The replacement of direct electricity with heat pumps could almost achieve a situation when all energy is produced within the city limits. In the scenario B geothermal is the most important source, followed by ambient heat and waste.

The heat mix looks as follows in GWh.

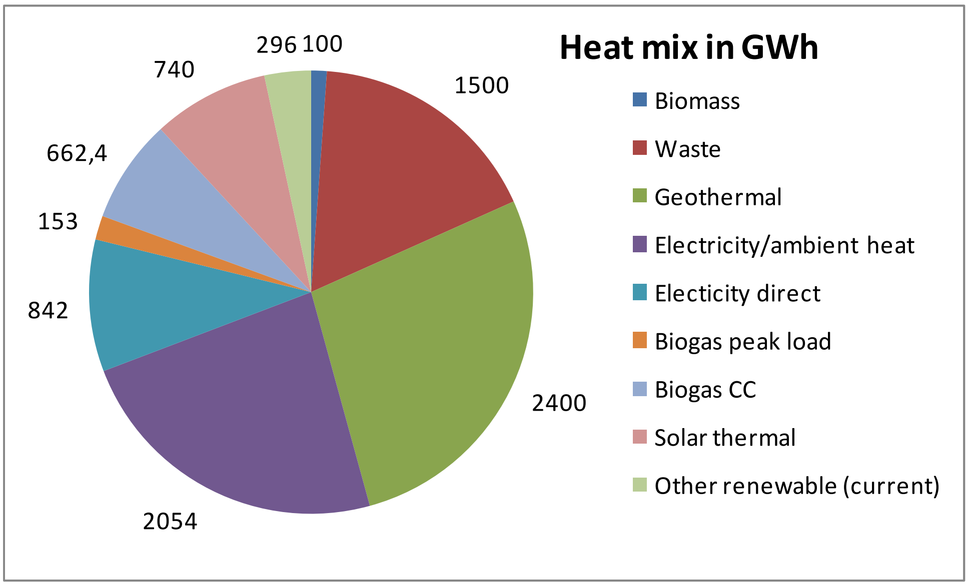


Figure 20: Heat production mix Model B

The heat mix is more distributed in model B. Geothermal is the most important source followed by waste and electricity. Solar thermal is fourth.

5.5 Comparison of the 2 scenarios

In the first table the different effects on demand reduction are analyzed:

Table 50: Comparison of demand reduction of the 2 scenarios

Demand in GWh	Current	Scenario A	Change %	Scenario B	Change %
Heat w/o elctricity	16.242	5.272		5.852	
Heat with electricity	3.330	1.876		842	
Heat with heat pumps*		4.132		2.054	
Total Heat incl. electricity	**19.572**	**11.280**	**-42**	**8.748**	**-55**
Electricity for heat pumps		984		489	
Total heat after use of heat pumps	**19.572**	**8.132**	**-58**	**7.183**	**-63**
Power & Light w/o electricity	678				
Power & Light with electricity	4.119	3.603		2.846	
Total Power & Light	**4.797**	**3.603**	**-25**	**2.846**	**-41**
Mobility w/o electricity	13.318	875		875	
Mobility with electricity	663	4.396		3.152	
Total Mobility	**13.981**	**5.271**	**-62**	**4.027**	**-71**
Total Electricity	**8.112**	**10.859**	**34**	**7.329**	**-10**
Total energy demand	**38.350**	**17.006**	**-56**	**14.056**	**-63**

In total the demand looks very similar, but looking at the individual energy services the real demand reduction is much higher in scenario B. In scenario A the much higher use of heat pumps reduces the total energy demand, but increases the demand on electricity substantially. This will have effects on the load curves in winter as can be seen in the following chapters.

In scenario B also the electricity demand also drops in total.

Also the production mix is different. Below are two figures comparing the production mix of heat and electricity.

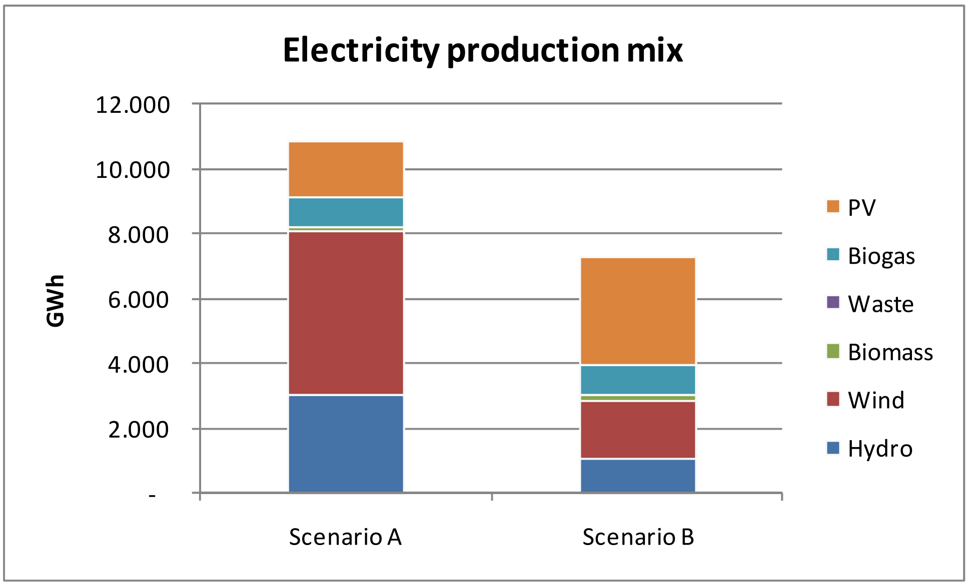


Figure 21: Electricity production mix of the 2 scenarios

In scenario A wind is the dominant energy carrier. Hydro also plays an important role. In scenario B, PV is the most important source.

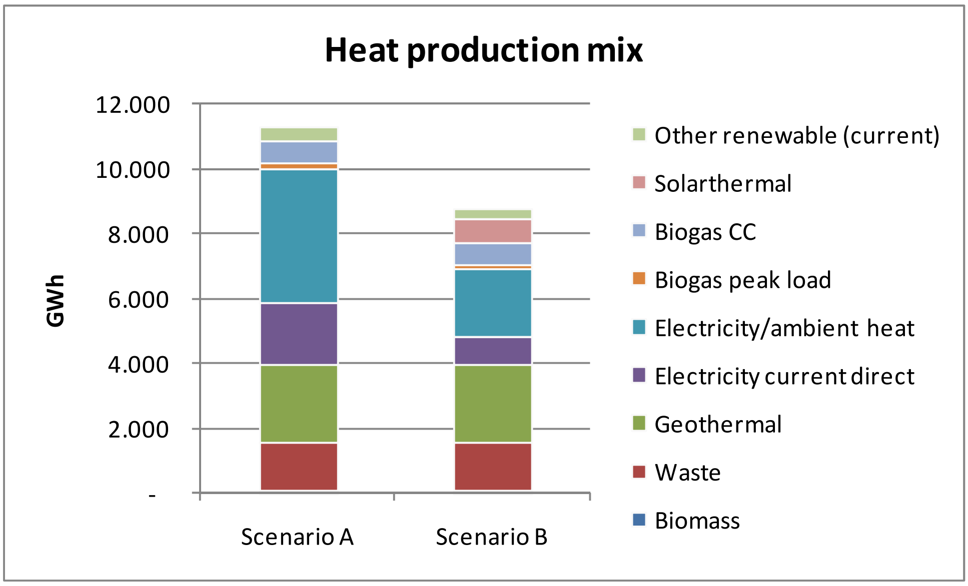


Figure 22: Heat production mix of the 2 scenarios

In scenario A heat pumps (and therefore finally electricity) are the most important sources. In scenario B geothermal is and waste are the most important factors.

5.6 Costs for the households

Combining all the factors calculated above the costs for households are estimated for both scenarios. For the comparison to current costs an important factor is if the investment costs for new equipment are compared to no investment at all or to an investment into an alternative. In case of the reduction of space heating demand the comparison is made to no investment at all, because a building has a very long useful life even without investments into the facade or windows. In case of the electrical appliances the differences is between the scenarios. In the ambitious scenario the investment costs for new, most efficient, appliances are compared to lesser efficient appliances. In the high scenario the costs are compared to no investments. In case of e-mobility the comparison is always between an alternative, fossil fuel driven, vehicle, because of the relatively short lifetime of a vehicle. In case of the change of the heat system the comparison is done to no investment, but additional information is given regarding the costs of a normal gas boiler. In the table below there are two master cases presented of an average household of Vienna. One household is living in an apartment, using district heating. The other is a single family house originally heating with gas. All other factors are kept equal. The effect of both scenarios are shown. It also shown what would be the cost effect if the energy price remains the same.

Table 51: Summary of household costs with 100% renewable energy

EUR/year	Familiy house					Multi dwelling building				
	Current	Scen A	old price	Scen B	old price	Current	Scen A	old price	Scen B	old price
Heat demand investment		2.343	2.343	7.489	7.489		1.507	1.507	3.263	3.263
Change heat system invest		1.288	1.288	1.288	1.288					
Space Heat costs	2.656	491	357	360	208	531	227	227	72	72
Process heat costs	209	249	181	313	181	219	219	219	219	219
P&L demand investment		117	117	293	293		117	117	293	293
P&L costs	399	419	305	427	247	399	419	305	427	247
Mobility investment		2.548	2.548	2.548	2.548		2.548	2.548	2.548	2.548
Mobility costs	940	321	233	403	233	940	321	233	403	233
Total	**4.205**	**7.777**	**7.371**	**13.121**	**12.487**	**2.089**	**5.359**	**5.156**	**7.226**	**6.876**
Total in case new heat system	**4.720**									

5.6.1 Family house owner

In the scenario A total costs for a single family house would increase by 3.500 EUR per year for all energy services combined. The most important parts are the investment in the thermal optimization of the house and the change to e-mobility. The effect of price changes are rather small compared to the other factors.

In the scenario B total costs for a single family house would increase by 8.900 EUR. The huge difference comes primarily from the strong increase in costs of space heating demand reduction.

5.6.2 Multi dwelling resident

The costs for the household living in the apartment the increase of costs is smaller. 3.300 EUR in scenario A and 5.200 EUR in scenario B. The reason is that investments are lower and also no change of the district heating price is assumed.

In both cases the costs are quite high for a single household. On the other hand with the exception of biogas and biomass, that play a rather small role, all renewable energy produced is based on sources that do not depend on feedstock. In case the investment cost stay stable, a strong increase in energy prices would close the gap between current energy service costs and the costs for renewables at least in scenario A.

5.7 Effects on load curve

The following results are only showing a trend in the order of magnitude, because the available data and the assumptions made are very broad. A detailed analysis would have exceeded the scope of this work.

5.7.1 Electricity

5.7.1.1 Scenario A

In scenario A the total capacity installed is 4,7 GW. With all capacity factors applied the total production load is 1,1 GW in winter and summer. Since only PV shows a significant difference between day and night, the load in summer during night would go down to approximately 850 MW and in winter down to approximately 1027 MW. The day load would be around 1200 MW in winter and 1400 MW in summer.

Table 52: Production load summer/winter in scenario A – average

Average in MW					
Source	**Full capacity**	**Cap Factor summer**	**Avg. Load summer**	**Cap Factor winter**	**Avg. Load winter**
Hydro	513	0,85	436	0,55	282
Wind	2.143	0,18	386	0,24	514
Biomass	20,25	0,90	18	1	20
Waste	0,625	0,90	1	1	1
Biogas	300	0,00	-	0,70	210
PV	1761	0,17	296	0,055	97
Total	4.737		1136		1124

For the demand side the assumption is that the pure reduction of demand does not change the load profile, as well as increases in light & power. The important factors are e-mobility and heat pumps. For e-mobility as described in the relevant chapter the assumption is that most of the demand is during the night with no differences between summer and winter. Heat pumps on the other hand will only add to the load in winter with no difference between day and night. Below the load profiles of demand for typical winter/summer day and night are shown.

Table 53: Scenario A – Demand load profile

Scenario A MW	Average load	Day	Night
Summer	930	648	1.211
Winter	1.636	1.359	1.913

Below the production load is compared to the demand load.

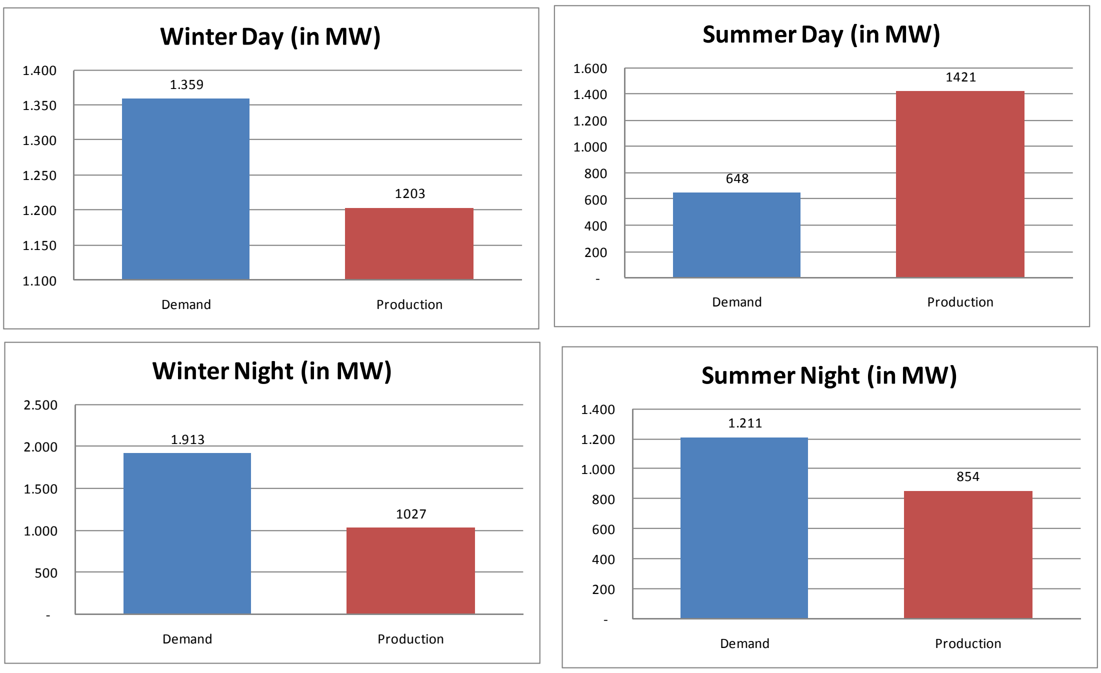


Figure 23: Comparison production and demand load for scenario A

The results show a significant shortfall in winter, especially at night. In this moment e-mobility, heat pumps and low hydro are combining their effects. During a summer day there is a substantial overcapacity. The problem at night could be improved by loading the cars also during the day, since most cars are only used during several hours per day. The problem during winter could only be solved by either reducing space heating demand further, using more biogas or investing in seasonal storage capacity, which is currently highly expensive.

Below the result is shown if PV is replaced by wind as source and e-mobility demand is equal between day and night. The additional wind form Lower Austria is around 1,7 TWh or 8% of the economic potential. It still leaves sufficient potential to cover demand in Lower Austria.

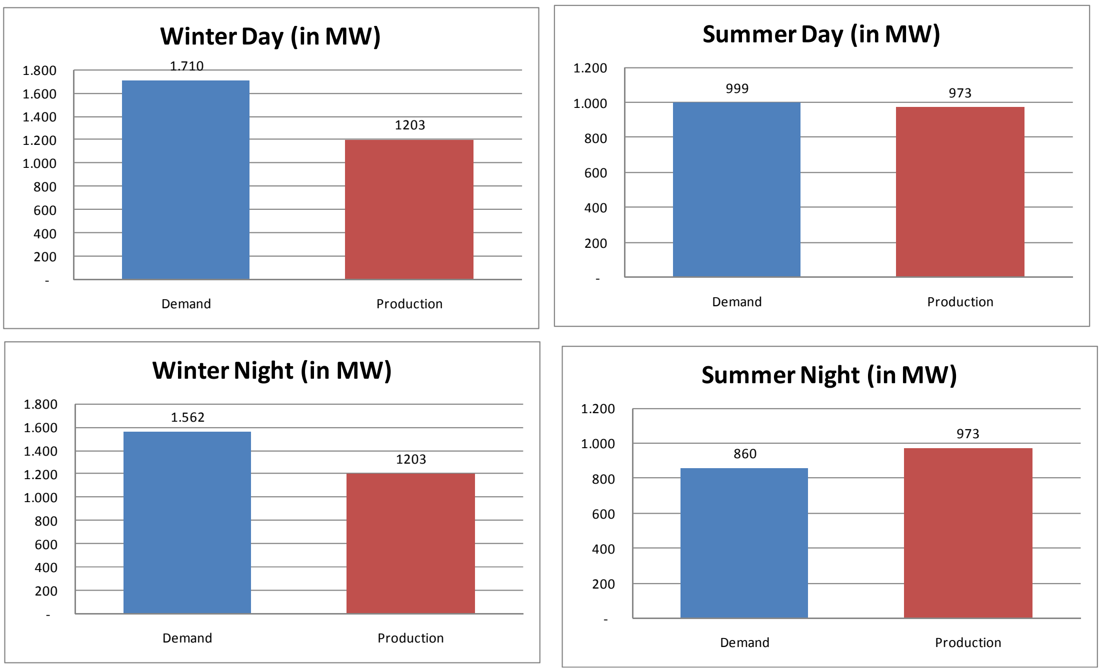


Figure 24: Comparison production and demand load for scenario A adapted

In this case during summer there is an almost perfect match, but in winter there is still a significant shortfall of production, especially during the day. The high demand in winter is mainly coming from space heating middle load. The only option to bridge the gap would be a strong increase of biogas or wind or decrease of space heat demand. In scenario B a stronger decrease of space heat demand is assumed.

5.7.1.2 Scenario B

In scenario B the total capacity installed is 4,7 GW. With all capacity factors applied the total production load in summer is 0,9 GW but in winter only 700 MW. In scenario B PV has a much more important share so there is an enormous difference between day and night in summer.

Table 54: Production load summer/winter in scenario B - average

Average					
Source (in MW)	**Full capacity MW**	**Cap Factor su**	**Avg. Load su**	**Cap Factor w**	**Avg. Load winter**
Hydro	179	0,85	152	0,55	99
Wind	776	0,18	140	0,24	186
Biomass	20,25	0,90	18	1	20
Waste	0,625	0,90	1	1	1
Biogas	306	0,00	-	0,70	214
PV	3439	0,17	578	0,055	189
Total	4.721		888		709

Table 55: Production load summer/winter in scenario B – during the day

Day					
Source (in MW)	**Full capacity MW**	**Cap Factor su**	**Avg. Load su**	**Cap Factor w**	**Avg. Load winter**
Hydro	179	0,85	152	0,55	99
Wind	776	0,18	140	0,24	186
Biomass	20,25	0,90	18	1	20
Waste	0,625	0,90	1	1	1
Biogas	306	0,00	-	0,70	214
PV	3439	0,33	1.135	0,1	344
Total	4.721		1445		864

Table 56: Production load summer/winter in scenario B – during the night

Night					
Source (in MW)	**Full capacity MW**	**Cap Factor su**	**Avg. Load su**	**Cap Factor w**	**Avg. Load winter**
Hydro	179	0,85	152	0,55	99
Wind	776	0,18	140	0,24	186
Biomass	20,25	0,90	18	1	20
Waste	0,625	0,90	1	1	1
Biogas	306	0,00	-	0,70	214
PV	3439	0,01	28	0	0
Total	4.721		338		520

Again the demand profile is shown and the comparison between production and demand.

Table 57: Scenario B – Demand load profile

Scenario B MW	**Average load**	**Day**	**Night**
Summer	700	569	831
Winter	1.056	929	1.183

Below the production load is compared to the demand load for scenario B.

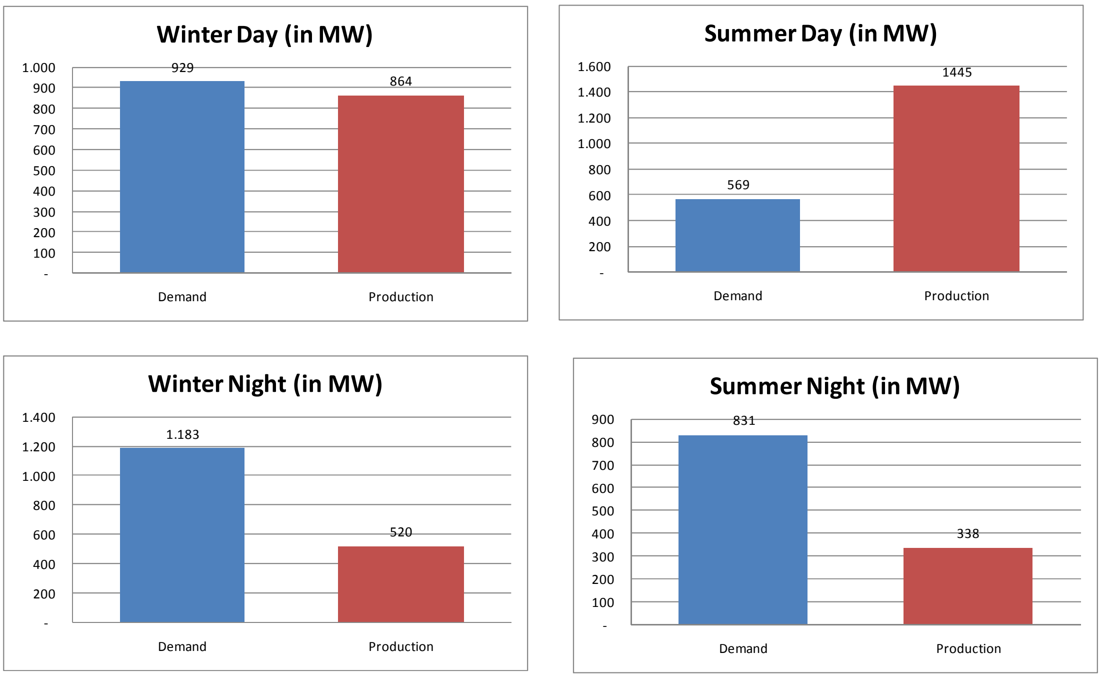


Figure 25: Comparison production and demand load for scenario B

In scenario B there is a huge lack of capacity during the night because of the high share of PV. On the other hand in summer during the day there is a huge over capacity. In general the loads during the day are well covered.

Again the effects of more wind and more loading during the day are included.

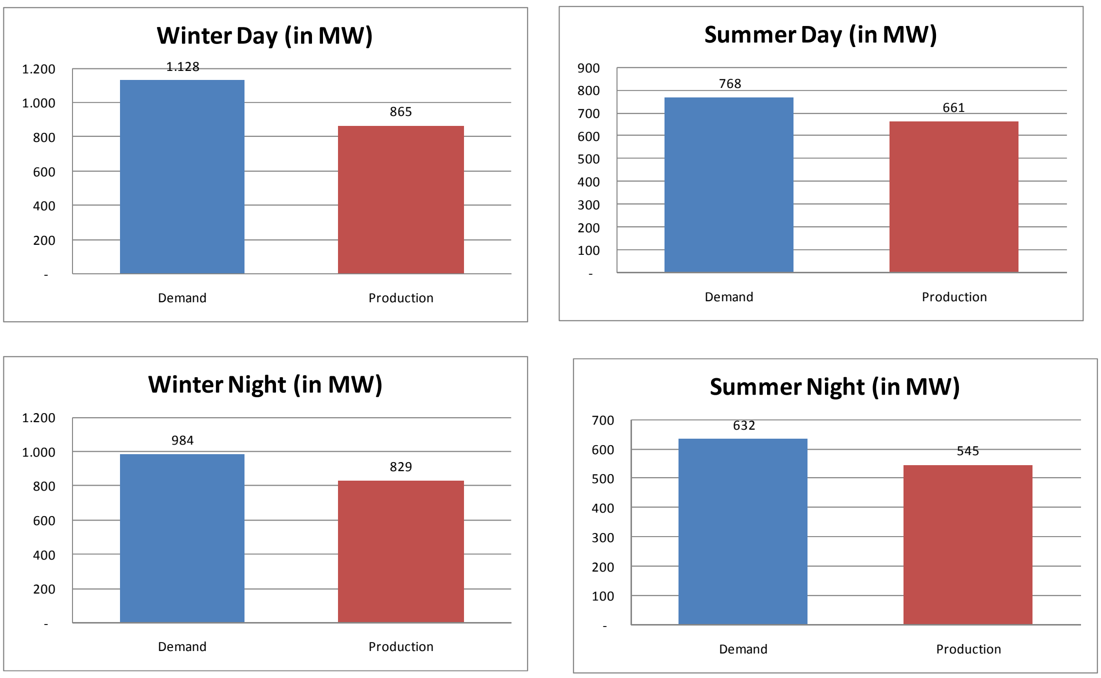


Figure 26: Comparison production and demand load for scenario B adapted

In this case now PV has almost vanished and was replaced by wind. Wind again produces now almost 5000 GWh. The load is now better balanced, but in winter there is still a shortfall of capacity.

5.7.2 Heat

The biggest impact on the demand side is the strong decrease of space heat demand, that leads to a leveling of demand through the year. As mentioned before that fits well to the existing potential, that is mostly base load heat. There is no substantial difference between the scenarios because in both cases the production mix is quite similar. Again the current split of base, peak and middle load is shown.

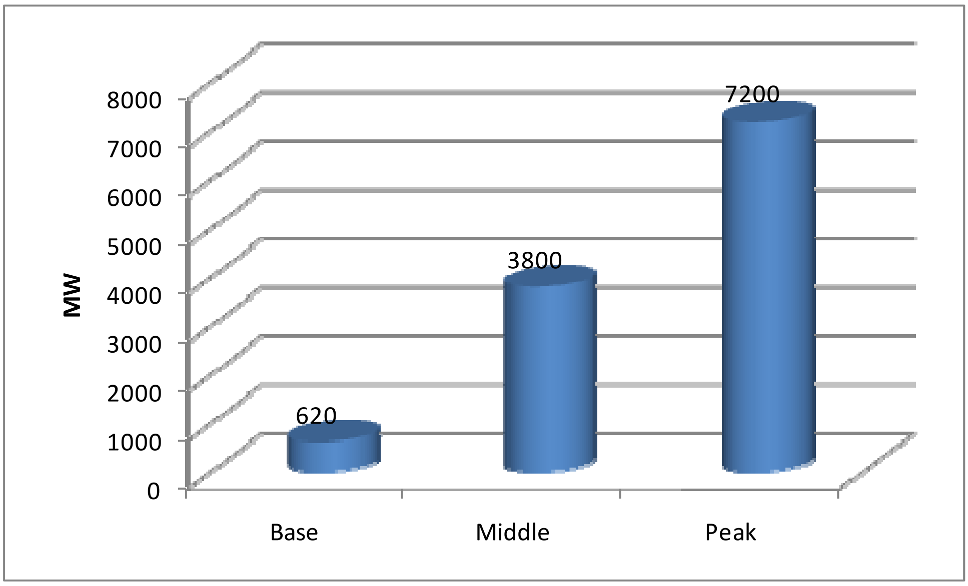


Figure 27: Current heat demand load split

5.7.2.1 Scenario A

First question is in this case how to derive to the model loads. The easiest way is to reduce the current load by the respective reduction of energy demand. Process heat, including warm water, can be seen as the base load heat. The overall reduction was only 4%. Space heating reduction on the other hand was overall 58%. This now changes the picture.

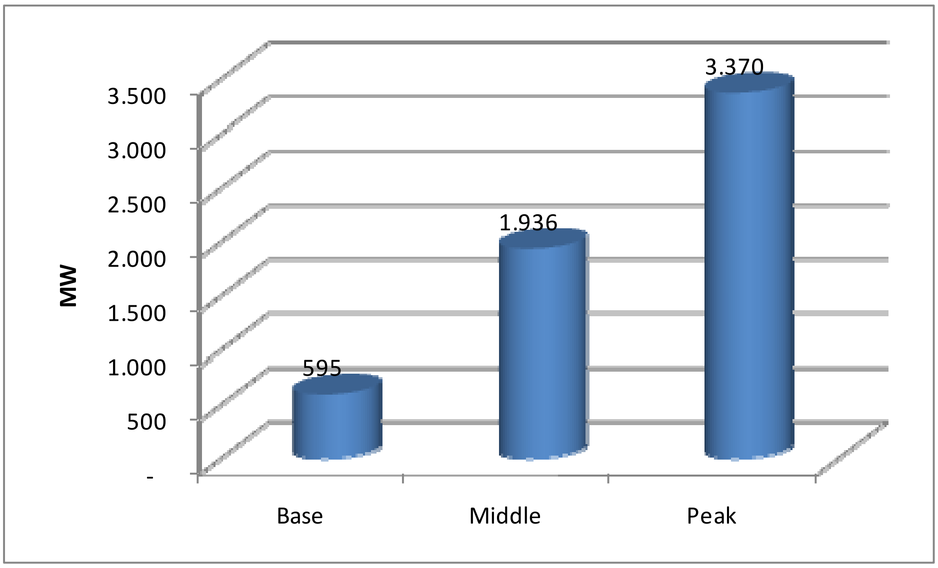


Figure 28: Heat demand load split scenario A

Base load almost did not change, but middle and peak load changed quite strongly. As described above base load will be provided mostly by waste and geothermal. Both together have a load of around 540 MW. The rest will be provided by individual electrical heater. Peak load on the other hand is provided by a few biogas peak load boilers in the district heating system. In the other parts its electricity either directly used or via heat pumps. This has the advantage that existing peak load plants can be used. Middle load is mostly provided by heat pumps and the heat output of the biomass and biogas plant.

5.7.2.2 Scenario B

In scenario B the heat reduction was larger and results in the following loads.

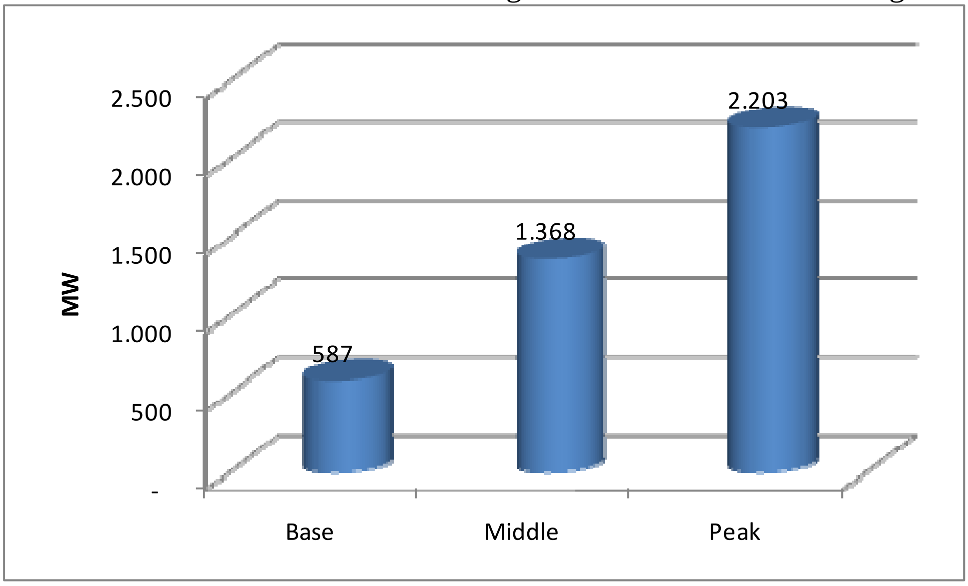


Figure 29: Heat demand load split scenario B

The situation for base load heat has not changed much. The main difference is on the supply side where electricity was replaced by solar thermal installations. Middle load is now around 2,5 times base load and again the relevant resources are biomass and biogas heat output together with heat pumps. For peak load only the needed capacity of the biogas peak load boiler was reduced.

6 Conclusions

Three main conclusions stick out:

It is not possible to provide Vienna 100% with renewable energy produced just within the city borders (the maximum in this model is 70%)., based on a calculation of total energy production. But by using just small parts of the potential of the surrounding areas it becomes possible. But to achieve this goal strong reductions of demand in all energy services have to be reached. It is however practically impossible to balance load of demand and supply without using the grid. The reason is that middle load heat always depends at least partly on electricity. Therefore in all scenarios there is a lack of capacity in winter. The only way to bridge the gap would be a further reduction of space heat demand, or an increase of use of biogas or biomass. Sources that are not easily available around the city.

The costs for households a very steep. Especially the costs for thermal installation of buildings and the switch to e-mobility would increase the costs strongly. Depending on the scenario and the distinction between family house owners and people living in multi dwelling houses the increase per year would be between 3000 and 9000 EUR.

Below is a table showing the necessary demand reduction in both scenarios.

Table 58: Demand reduction overview scenario A and B

Demand in GWh	Current	Scenario A	Change %	Scenario B	Change %
Heat w/o elctricity	16.242	5.272		5.852	
Heat with electricity	3.330	1.876		842	
Heat with heat pumps*		4.132		2.054	
Total Heat incl. electricity	**19.572**	**11.280**	**-42**	**8.748**	**-55**
Electricity for heat pumps		984		489	
Total heat after use of heat pumps	**19.572**	**8.132**	**-58**	**7.183**	**-63**
Power & Light w/o electricity	678				
Power & Light with electricity	4.119	3.603		2.846	
Total Power & Light	**4.797**	**3.603**	**-25**	**2.846**	**-41**
Mobility w/o electricity	13.318	875		875	
Mobility with electricity	663	4.396		3.152	
Total Mobility	**13.981**	**5.271**	**-62**	**4.027**	**-71**
Total Electricity	**8.112**	**10.859**	**34**	**7.329**	**-10**
Total energy demand	**38.350**	**17.006**	**-56**	**14.056**	**-63**

* In the current demand there is also a small part of heat produced by heat pumps, but no data is available. Most of the heat produced by electricity currently is warm water heated by electrical boilers and electrical heaters.

In scenario A the total reduction of demand of final energy is 21,3 TWh or 56% of current demand. The biggest drop is in mobility (-62%). Due to e-mobility and the use of heat pumps the demand for electricity almost rises by 34%.

In scenario B the total reduction is 24 TWh or 63%. The steep decline is mostly based on more optimistic assumptions on the efficiency gain of e-mobility and a lower level of space heat demand due to better thermal renovations. The electricity demand stays almost the same, because compared to scenario A less electricity is used for heating and also e-mobility is more efficient.

In this model, as mentioned above, there is no specific time line. Just looking at the saving overview it is clear that at the current pace this scenario will take a very long time. The current thermal renovation rate of buildings in Austria is around 1% with the political goal to reach 3%. To renovate all buildings this would last around 30 years and still not achieve the goal, because the current renovation standard is far below the levels assumed here. 100% coverage of e-mobility also seems a long way ahead, despite the obvious advantages, especially in urban areas as Vienna.

Apart from the very optimistic demand saving assumptions, the biggest problem of scenario B is the mismatch of demand and supply load curves of electricity. The high share of PV produces a significant surplus during a summer day, but a high deficit at night, especially in winter. The situation improves in case cars are loaded during the day instead of the night and more wind is used instead of PV.

On the other hand in scenario B it is almost possible to produce the energy within the city borders.

Of course every single assumption is disputable as in any modeling of a future scenario. Most assumptions are technically easy to achieve but quite cost intensive, especially on the demand side. the major exception is the full switch to e-mobility. This seems to be rather farfetched, at least for the non-private transport. On the production side in scenario A the high number of windmills is the biggest challenge with 1000 – 2500 additional wind mills depending on the size. On the other hand only 25% of today’s economic potential of Lower Austria is used. In scenario B the high share of PV makes it rather theoretical, because the enormous load differences are only manageable with a very smart grid and additional grid infrastructure and storage capacity. Political consideration apart, hydro is the much easier option for the production.

A total switch to renewables comes at steep costs for the households, but less through the increase of energy production costs, but because of the high costs for reduction of demand, primarily in the area of space heating demand and mobility.

A switch to renewable energy is not possible without the balance of the grid in case of electricity. The strong dependence on heat from heat pumps would add significantly to the electricity demand in winter, but in total more production in summer is added, especially through PV. E-mobility on the other hand is rather neutral but could increase demand too much during the night, especially when the production system is based on PV. For heat, where no regional network is available, at least on a model basis it is possible to supply base as well as peak load on a renewable basis. But only through electricity that again needs the grid for balancing.

In general electricity plays a very important role in these models, because neither is there sufficient alternative heat supply, mainly for middle load, nor a real alternative to e-mobility. Of course a total switch to e-mobility is currently rather theoretical, especially for the non-private transport.

As stated above the grid plays an important role to balance loads. In this thesis it was however not included how much additional storage capacity the grid would need to fulfill this balancing role. Especially solar and wind require substantial storage capacity.

Further conclusions are:

For the heat sector the main conclusion is the high importance of savings in the area of space heat demand. Solar thermal has big potential but is fairly expensive and adds heat in times when other sources as geothermal and waste could cover base load demand anyhow. From the perspective of the author the combination PV and heat pumps is on the same cost level for family houses and has the advantage from a local point of view, to be able to use storage capacity in the overall electrical grid.

In the area of light & power the cheapest savings are to be achieved. In case of replacements of appliances it is economically to buy the most efficient appliances. Therefore it would be sensible to set strict efficiency standards for new appliances as it was done for light bulbs.

In the sector of mobility, e-mobility has a big potential to contribute significantly to the switch to renewable energy. Main advantages are two factors:

- High potential for renewable electricity compared to biofuels
- Flexible loading times could support the balancing of the grid

The third major factor often stated is higher efficiency. Most publications expect a significant improvement, but some are more skeptical, especially regarding losses during loading and losses due to self depletion of batteries. Since no long term experiences exist the development has to be seen.

In the area of production the most important potentials are wind around Vienna, solar within the city and geothermal. Hydro on the Danube would also provide a cheap and significant resource but is politically highly controversial.

7 Acknowledgements

I want to thank Wien Energie for providing useful data and information regarding renewable heat potentials and structure of energy demand in Vienna, in particular Mr. Carlo Obersteiner for the coordination and feedback. Further Mr. Aarno Rapottnig for insides in heat demand and production in Vienna, Oswald Loibl for special insides into the demand structure and Gudrun Senk for enabling the support of Wien Energie.

I further want to thank Professor Haas for the supervision and constructive feedback and the staff of CEC for their overall help and support.

8 References

Bauer Alexander, „Solar heat in Austria, potential, regulatory framework and business environment", master thesis MSC Renewable energy CEE 2010

Bärnthaler J. et al: „Technologie, Logistik und Wirtschaftlichkeit von Biogas-Großanlagen auf Basis industrieller Abfälle", Energiesysteme der Zukunft 2008

Dürauer Stefan: „Solarpotential Wien", MA 47 email, 2011

Fürstenberger Karl: „Energiesparen beim Sanieren mit Förderung", OÖ Energiesparverband 2010

Haas Reinhard et al: „Städtisches Energieeffizienzprogramm", MA 27 Vienna 2007

Haider Bernhard, Smole Erwin et arme Consultants: "Auswirkungen von Elektrofahrzeugen auf die Stromwirtschaft", Price Waterhouse Coopers 2009

Kampmann Bettina et al: „Green power for electric cars", Delft 2010

Kapusta Friedrich: "Klimaschutz und thermische Sanierung", Presentation Energieinstitut der Wirtschaft, 2010

Krenn A. et al: „Austrian Windatlas and wind potential analysis", Energiewerkstatt presentation and web-site: www.windatlas.at, 2011

Pock-Kapfenberger Anneliese: „Grazer Solardachkataster", Bericht 2010

Pucharski Thomas: „Wissenswerte über die Fernwärme Wien, Kundenstruktur und Wärmeaufbringung", Presentation Wien Energie, 2009

Salvadores et al: „Projected costs of generating electricity", OECD/IEA 2010

G. Stanzer et al: „Regionale Szenarien erneuerbarer Energie – Potentiale in den Jahren 2012/2020“, Regio Energy 2008

Statistik Austria: „Energiestatistik: MZ Energieeinsatz der Haushalte 2007/2008“, 2009

Statistik Austria: „Strom- und Gastagebuch 2008“, 2009

Statistik Austria: „Energiestatistik: Mikrozensus Energieeinsatz der Haushalte 2007/2008“, 2008 und 2009

Statistik Austria: „Wohnen – Ergebnisse der Wohnungserhebung im Mikrozensus im Jahresdurchschnitt 2009“, 2009

Statistik Austria: „Anbau auf dem Ackerland“, 2009

Statistik Austria: „Energieeinsatz im Dienstleistungssektor“, 2011

Statistik Austria: „Österreichische Verkehrsstatistik“, 2009

Urban Wolfgang et al: „Verbundprojekt Biogaseinspeisung“, Frauenhofer Institut 2009

Urban Wolfgang et al: „Gasnetze der Zukunft“, Frauenhofer Institut 2010

Rath Ursula et al: „Stromeffizienzpotentiale in Haushalten und Dienstleistungsbetrieben in Vorarlberg“, Vorarlberger Landesregierung 2008

Weiss Werner: „Potential of solar thermal in Europe“,MSC Renewable energy CEE, 2010/2011

Weissensteiner: “Costs of electricity generation from renewable sources”, 2009 MSC script

Wellinger Arthur: „Gasertragsrechner“ MSC Renewable energy CEE, 2010/2011

Zentralverband Elektrotechnik- und Elektronikindustrie: „Das neue Energielabel“, Fachverband Consumer electronics 2010