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Gas and the electrification of heating & transport: scenarios for 2050

A case study for Austria

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24 May 2018

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1. Introduction

This report presents a 2050 scenario study of the implications of a possible gradual electrification of road transportation and domestic heating and cooking in Austria. The study is intended to derive the consequences of electrification for the electricity and gas sectors, for the CO_2 emissions associated with the residential, transport and electricity sectors and for the overall social costs.

Specifically, the study explores three possible electrification paths:

1. *Fossil Fuel* scenario: a business-as-usual electrification path, where electrification remains quite limited and in line with current practices, even by 2050;
2. *Full Electrification* scenario: a full electrification path as an extreme benchmark in which the residential sector and the road transport sector (in particular passenger cars and motorbikes), are virtually fully electrified by 2050;
3. *Hybrid Electrification* scenario: a path in which the extent of electrification in 2050 is intermediate.

These scenarios are not forecasts, and which scenario turns out to be closer to reality will depend both on the policy goals of the government and developments in the market. Of course, these may vary over time.

Instead, we provide a framework for analysing the consequences that electrification (to a greater or lesser extent) will have for aggregate electricity demand and therefore for the energy mix needed for power generation. It should be noted that throughout this study, we treat gas as a residual fuel for power generation and Power-to-Gas (PtG) as the first source of flexibility.

This study is a data-driven, quantitative exercise. The starting point for the projections to 2050 is the year 2016, a year for which we can obtain most of the necessary data from public sources. Historical data are used to determine the parameters for the year-to-year projections. The analysis takes into account the policy commitments of the government (where they exist) regarding the expansion of renewable electricity sources (hydro, biomass, wind and solar) and the phasing-out of fossil fuel and nuclear sources of power production. The model also accounts for the effect of innovation by including yearly increases in the energy efficiency of housing and cars, decreases in the losses of battery charging devices and improvements in the efficiency of electricity production technologies.

With the necessary data and policy commitments in place, the study proceeds through a number of logical steps:

1. First, it derives the increase in the power demand resulting from electrification of the residential and transport sectors.

2. It then calculates the energy mix which will be required by the power sector to meet this demand. These calculations take into account government commitments/policy objectives and also take gas as the resource of last resort.
3. We then study the reliability of the electricity sector, using PtG as the primary source of flexibility and gas as the secondary source.
4. Following this, we compute the CO_2 emissions of the three sectors involved in the study (the housing, transport and electricity sectors) and compare them to 1990 levels.
5. Finally, we compute the social costs of electrification. In computing these costs, we include the costs of retrofitting houses, the price premia of heat pumps and electric cars, the costs of quick charging posts, the costs of electricity grid expansion, the costs of gas network expansion (if necessary), the cost of PtG technology, the costs of gas-fired power plant capacity expansion to guarantee reliability of the power sector, the savings in fossil fuels (gas in houses and gasoline and diesel in transport), and the savings in CO_2 emissions (outside the European emission trading system (ETS)) and the costs of CO_2 emissions inside the ETS.

Through these steps, the model derives the consequences of electrification for each scenario.

As is the case with all scenario studies, we model some features of the energy markets and purposely leave some aspects outside the analysis. We do not explicitly model the price dynamics of the energy markets, nor the development of the carbon price within the EU ETS. These two assumptions reflect our objective of placing the focus on the impact of government policy on the electricity supply curve. By doing this, we intentionally put the emphasis on a case in which the merit order for electricity production is primarily determined by policy.

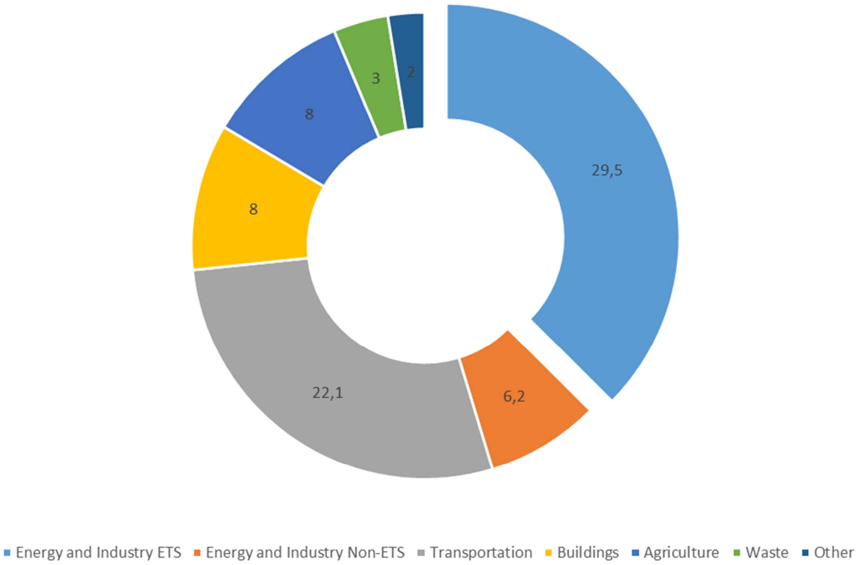
These aspects would not significantly alter the main qualitative results of our study. For example, a higher price of natural gas might lead gas-fired power plants to opt for biogas for power production; this would merely affect our calculations of CO_2 emissions but not the other conclusions in our study. Likewise, an increase in the carbon price within the EU ETS might result in a reduction in government support for renewables, thus the share of renewables would remain primarily determined by policy as we assume in our model. Finally, while we have included PtG and gas as the primary sources of seasonal flexibility, we have not included other potential sources such as demand response.

The results of this report should not be seen as a recommendation for a specific policy option. More modestly, we try to shed light on the challenges and choices policymakers and the energy sector will have to manage depending on the extent to which electrification occurs.

1.1 Background

In line with European climate policy, Austria's decarbonisation objective is to reduce CO_2 emissions by at least 80% in 2050, relative to 1990 levels. As a large share of emissions in Austria is not subject to the EU Emissions Trading Scheme (ETS), Austria has enacted a climate protection law ("Klimaschutzgesetz"). This act, amongst others, sets clearly defined emission caps for several relevant sectors not covered by the ETS. For instance, the transport, housing, and agriculture sector face maximum emission constraints at a yearly level, with yearly monitoring. Figure 1 depicts the share of emissions in Austria in 2015 by sector, and whether they are covered by the ETS or by the climate protection law.

Figure 1: CO_2 Emissions by sector in Austria, 2015



Source: Umweltbundesamt, 2017.

Overall emissions covered by the climate protection law amount to about 50 million tons (left part of circle in Figure 1).[1] Emissions covered by the ETS stem from the energy and industrial sector, and amount to about 30 million tons (right part of circle in Figure 1). Total emissions in Austria in 2015 thus were about 80 million tons, of which the largest share falls on the transport sector (about 20 million tons), followed by the housing and the agricultural sector (about 8 million tons each).[2] Since the dominant source of electricity generation is hydropower and thus low-carbon, the building and especially the transport sector are crucial for future decarbonisation efforts. To this end the following case study evaluates how the electrification of transport and heating impacts overall CO_2 emissions in Austria. The time horizon of this projection lasts, in line with policy goals, until the year 2050.

1.2 Scope

The data used in this study relate to market fundamentals in the Austrian electricity, heat, and transport sector. Data is used for two purposes. First it defines the starting level for the modelled projections, e.g. the current level of emissions and the amount of cars electrified.

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[1] See also the 2016 report on the climate protection law (Fortschrittsbericht nach §6 Klimaschutzgesetz 2016).

[2] See Umweltbundesamt, Treibhausgas-Bilanz 2015.

Second, data is used to determine the parameters for the projection of outcomes in future years, e.g. from the number of houses built in the past years, we draw parameters for the speed of electrification of housing in the future. Where possible, the study in addition relies on parameters established by the existing literature or as found by government agencies.[3]

What types of electrification does this study cover? Electrification of road transportation here refers to the year-by-year replacement of conventional gasoline and diesel vehicles (such as passenger cars or trucks) by the corresponding full electric versions. Electrification of domestic space and water heating, including cooking, refers to the substitution of natural gas boilers and gas stoves in the residential sector by heat pumps and electric stoves.

The outcome variables of the study, such as CO_2 emissions or the power generation mix, are projected towards 2050 on a yearly base and hence also allow for a discussion of outcomes vis-à-vis policy goals along the way. It should be noted that a precise forecast of all parameters is out of the scope of this study, and that the outcomes should be understood as a projection given the used parameters, rather than a forecast. As discussed later, some outcomes depend significantly on the chosen parameters. Where this is the case, outcomes are presented using a range of different parameters, or are interpreted highlighting the impact of modelling choices.

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[3] Input and feedback on the parameter choice and methodology from Christian Lebelhuber of E-Control is gratefully acknowledged. All errors remain with the author.

2. Method and scenarios

The methodological framework is adapted from the case study on the Netherlands by Moraga and Mulder (2018). The first block of the model calculates the impact of electrification on power demand. The model requires input data on the current stock of vehicles and houses, and their respective energy needs when electrified. Using estimates on the future development of the housing and vehicle stock until 2050, along with assumptions on the increase in the share of electrified houses and vehicles year by year, the model yields additional power demand arising from electrification.

For the speed of electrification, that is the increase in the share of electrified houses and vehicles per year, we then assume three scenarios: a business-as-usual scenario (FOSSIL FUEL, in short FF), a hybrid scenario (HYBRID, in short HY), and a full electrification scenario (FULL ELECTRIFICATION, in short FE). These three scenarios on the level of electrification will remain the central scenarios throughout all modelling blocks. That is, the levels of electrification in each sector constitute the main exogenous modelling choices.

The second modelling block then takes the power demand modelled in the first block and derives the required electricity supply. More specifically, the model calculates the resulting generation mix on the power supply side used to satisfy future power demand each year. The generation mix for each year is defined using a merit-order approach. Investment and market exit of technologies are exogenous and follow policy objectives, e.g. for increasing renewable generation.

The third modelling block determines the resulting gas demand. The higher the degree of electrification becomes, the more gas demand stems from the power market, and less from heating. This modelling block thus presents outcomes on the net impact of gas demand over the years.

Block four and five of the model, respectively, calculate the resulting net CO_2 emissions and infrastructure needs from electrification. Eventually, the last block of the model establishes a net-present value approach to electrification.

2.1 Scenario assumptions

The model runs separately for each of the three scenarios FOSSIL FUEL, HYBRID, and FULL ELECTRIFICATION. Table 1 summarises the parameters used in each scenario. The table depicts the assumptions on new houses and cars, as well as the degree to which the existing housing stock will be electrified each year.

Table 1: Assumptions on the speed of electrification

	Scenarios		
	Fossil Fuel	**Hybrid**	**Electrification**
Degree of electrification			
Housing			
New	**5%**	**50%**	**100%**
Existing stock (x1000)	**0**	**16**	**32**
Transport			
Passenger cars	**5%**	**40%**	**60%**
Vans	**0%**	**25%**	**35%**
Trucks	**0%**	**5%**	**60%**
Buses	**0%**	**25%**	**35%**

For FE, the most aggressive scenario, we assume that 100% of all new houses are built fully electrified, e.g. via the use of heat pumps. In addition, 32,000 houses, equal to about 1.5% of the current total stock of 2.2 million residential buildings in Austria, are electrified every year. This scenario reflects a very ambitious policy path. However, the parameters are chosen to yield fully electrified housing in 2050. Hence, the assumptions also depict the steep increase needed to fully electrify about 2.2 million houses.

The hybrid scenario HY assumes parameters to roughly result in half of all houses being electrified in 2050. In the FF business-as-usual scenario, the share of houses electrified remains insignificant in 2050.

Similar arguments hold for parameters in scenarios for the electrification of transport, likewise shown in Table 1. In the fully electrified scenario, passenger cars make up for almost the entire fleet in 2050. As illustrated later in more detail, we assume that the current stock of about 4.7 million passenger cars increases by 1% each year. This increase reflects the net increase of newly registered and retired cars. In line with previous years, we consider 300,000 newly registered cars per year (see Statistik Austria, 2016a). To reach a fully electrified passenger car sector in 2050, we then assume that about 60% of these newly registered cars will be fully electric. Hence, as for the housing sector, the share of electric passenger cars approaches 100% by design.

Also similar to the housing sector, the HY scenario in transport reflects a path that yields roughly half of the passenger cars being electrified in 2050. For comparison, in the business-as-usual scenario the share of electric passenger cars will grow to 8% only.

Policy assumptions on the power market are being kept constant in each scenario. In particular, renewable integration paths are identical across the scenarios. This modelling decision is made for a better comparison of impacts across the scenarios.

3. Electrification in road transport

3.1 Data and assumptions

All input data and assumptions here are derived from statistics published by the Austrian environmental agency (Umweltbundesamt) and the Austrian statistical office (Statistik Austria).

In detail, the data entail statistics for passenger cars, buses, vans, and trucks, as well as the annual average number of kilometres driven per year for each type.[4] Table 2 below summarises the data for the starting year of our model, the year 2016. According to Statistik Austria (2016b), in 2015 there were 4.7 million passenger cars registered in Austria, plus about 380,000 vans and light duty vehicles, about 100,000 trucks and heavy duty vehicles, and 9,000 buses.[5]

In addition, today, a total of 29,000 electric vehicles are already registered. This number includes fully electric vehicles and hybrid cars. Due to a lack of data on the share of electric vans, trucks, and buses, the model starts with zero electrification for these types. For calculating the electricity demand from transport, we also need to account for the kilometres driven and the efficiency of electric vehicles. On average, passenger cars drive around 14,300 km per year, while vans and trucks drive about 19,000 and 68,000, respectively.

Table 2: Input data for road transport

Variable	Value
Number of (x million)	
Passenger cars	4.7
Vans	0.38
Trucks	0.1
Buses	0.01
Of which electric (x 1000)	
Passenger cars	29
Vans	0
Trucks	0
Buses	0
Average distance per year (km)	
Passenger cars	14300
Vans	19100
Trucks	68100
Buses	50700

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[4] Vans comprise duty vehicles up to 3.5 tons. Trucks comprise duty vehicles above 3.5 tons. The categorisation was motivated by similar kilometres driven per year among the different types of duty vehicles. The driven kilometres then are averages.

[5] Heavy duty vehicles include „Sattelzugmaschinen, Arbeits- und Erntemaschinen".

The efficiencies of new vehicles, including the amount of new vehicles a year, are depicted in Table 3 below. While Table 2 reports historical data, Table 3 shows our key assumptions for the projections on the transport sector up to 2050. As shown, we assume an increase in the car stock of 1% each year and, based on data from 2014-15, it is assumed that 300,000 new cars will be sold every year.[6]

Data on the efficiency of electric vehicles and on losses when charging are published by the US Department of Energy.[7] The average performance of electric passenger cars in 2017 was 20kWh/100km. For the case of vans, trucks and buses we have less reliable data. Using the consumption of electricity for cars, we impute vans, trucks and buses consumption levels that are in proportion to what they consume of fossil fuels. For the case of vans, we factor an electricity consumption of 35 kWh/100kms, for trucks 70 kWh/100km, for buses 100kWh/100km, and for motorbikes and scooters 5 kWh/100km.

In this computation, we also take into account the electricity losses that occur while charging batteries of about 16%. Finally, to account for that fact that cars are becoming more fuel efficient, we assume their fuel consumption decreases by 1% per year. In a similar vein, we assume that there will be an annual improvement in battery charging efficiency of 0.5%.

Table 3: Assumptions on new vehicles

Variable	Value
Passenger cars	
Annual number of new cars (x 1000)	300
Performance electric (kWh/100km)	20
Vans	
Annual number of new vans (x 1000)	32
Performance electric (kWh/100km)	35
Trucks	
Annual number of new trucks (x 1000)	3.6
Performance electric (kWh/100km)	70
Buses	
Annual number of new buses (x 1000)	0.9
Performance electric (kWh/100km)	100
All vehicles	
Annual increase in number (%)	1%
Battery charging units	
Annual improvement in charging efficiency	0.5%

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[6] See Statistik Austria (2016a).
[7] See www.fueleconomy.gov.

3.2 Results

Before we discuss the impact of electrified transport on power demand, we graph the shares of electric vehicles in each scenario in 2050 (see Figure 2). Note again that the share of electrification of passenger cars, the most important driver in transport, is constructed to reach almost full electrification in 2050 by design. The amount of passenger cars grows by 1% net; every year 300,000 new cars (especially in the first years much more than 1% net growth) enter the stock. In the FE scenarios, all these 300,000 cars are fully electrified. This process yields almost 100% electrified passenger cars in 2050.

Despite the high shares of all types of electrified vehicles depicted in Figure 2, the power demand generated is highly concentrated on the passenger cars, as shown in Figure 3. This is in line with the mass of kilometres driven by the high stock of passenger cars. The additional electricity demand of above 20 TWh of all vehicles combined amounts to about a third of today's electricity load in Austria.

Figure 2: Shares of electrified vehicles in 2050

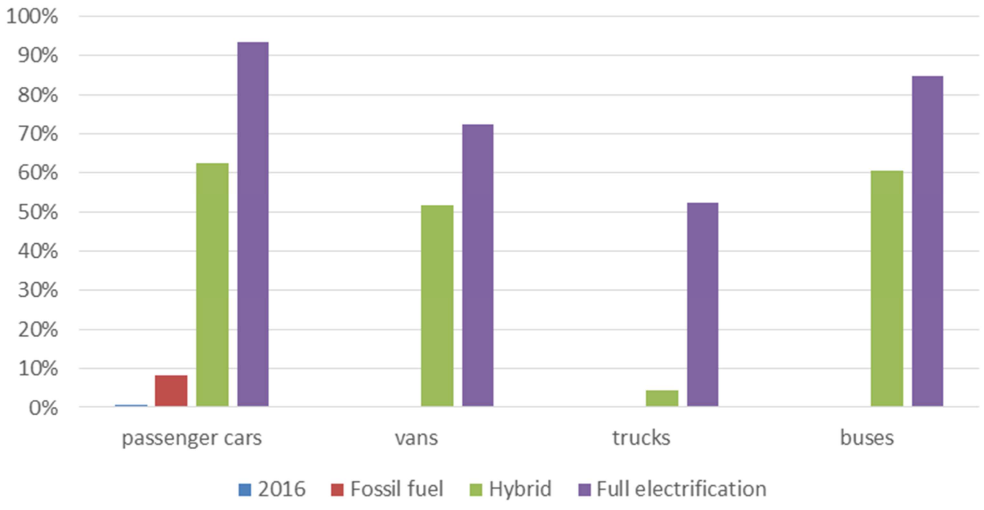
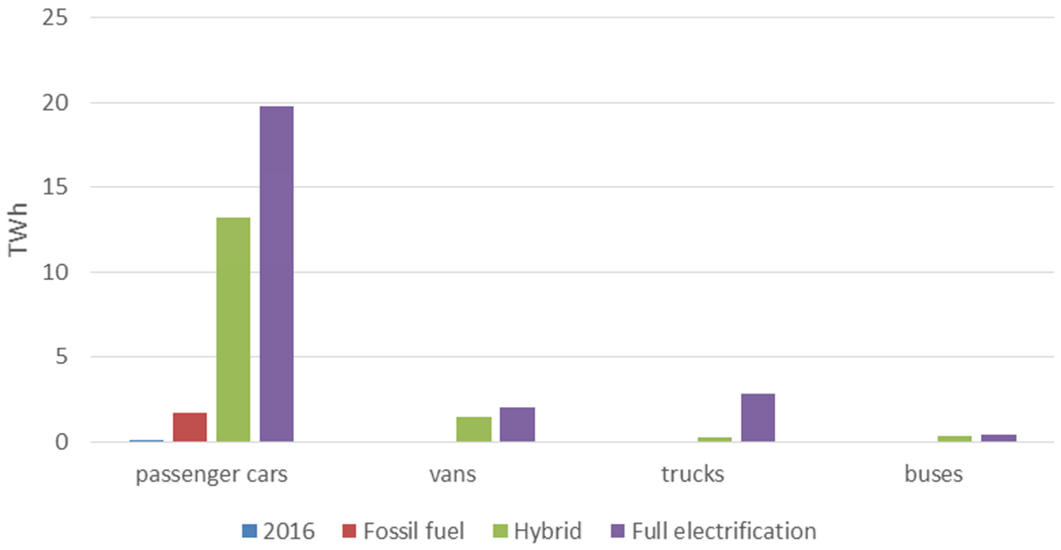


Figure 3: Power demand from electrified transport in 2050



4. Electrification in residential buildings

4.1 Data and assumptions

The second part of this modelling block to determine power demand from electrification relates to residential buildings. To determine this extra demand, we first gather data on the number of residential buildings in Austria, on the annual average consumption of natural gas for cooking, water heating and space heating.[8] Similar to the framework for transport, given a net growth rate of the housing stock and assumptions on the share of electrified buildings among new houses, the total housing stock becomes more and more electrified up to 2050.

Table 4 presents the input data on the stock of houses and the corresponding energy usage. Statistik Austria (2014) reports that 2.2 million buildings exist. The average building size of one household is 100 m^2. In 2015, the total gas consumption of a residential building equalled 8100 Petajoule or 1066m^3 gas.[9] Only 1% of gas is used for cooking.[10] Note that the differentiation between the different gas usage types is relevant for modelling power demand of electrifying each different type of gas application.

Table 4: Input data on residential buildings

Variable	Value
Number of houses (x million)	2.2
Number of houses electrified (x million)	0
Average size of houses in m2	100
Average gas consumption per house (m3)	1066
% of gas used for cooking	1%
% of gas used for hot water	16%
Average oil consumption per house (GJ)	50
CO2 emissions by households in 1990 (Mton)	13.2

To determine how the stock of houses develops up to 2050, we use historical and external forecast data. A report for the Austrian ministry of economic affairs estimates that the stock of houses will grow by 0.86% to 2020 and by 0.74% each year up to 2050.[11] For our projections we

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[8] Further, for the computation (in later sections) of saved emissions when electrifying, the model also needs data on oil consumption in houses with oil-fired heating.

[9] This number is constructed by considering around 18,000 GWh aggregate gas consumption of all households, divided by 2.2 million buildings. Note that the official statistics on buildings include more than just residential houses. As the gas consumption of 18,000 GWh relates to aggregate household consumption, but the number of houses relates to more than just residential homes, the assumed gas consumption of 1066m^3 may be slightly downward biased. Yet, this number is in line with household gas consumption in other countries.

[10] See Statistik Austria (2017), Energiestatistik: MZ Energieeinsatz der Haushalte.

[11] BMWA, Energieautarkie für Österreich?

set the growth rate to 0.8% throughout all years. From historical data, we observe that, roughly, each year 220,000 new houses have been added during recent years and thus use that value as the number of new houses per year. Together with our assumptions on the share of electrification in the different scenarios (see Table 1 above) we then obtain an electrification path up to 2050. The input on future total energy usage by household (measured in m^3 natural gas) is set to 1000 m^3. The coefficients of performance for heat pumps are set to 3 and 1 for space heating and warm water, respectively.

Table 5: Parameters for residential buildings

Variable	Value
Annual increase in number of houses (%)	0.8%
Annual number of new houses (x 1000)	45
Energy use for heating a new house (in m^3 gas)	1000
Annual increase in efficiency houses	1%
Coefficient of performance (COP) of heat pumps	
Space heating	3
Warm water	1
Annual increase in efficiency of heat pumps	1%
Autonomous increase in electricity use	0.5%

4.2 Results

Below we plot the resulting power demand from electrification of the housing sector. The additional demand for electricity is constructed as the sum of power needed for space and water heating – both in new fully electrified houses and in existing but renovated stock. The additional power demand likewise includes the power needed for cooking with electric stoves in new or renovated houses. Figure 4 depicts the projections results on the degree of electrification. As can be seen, given our assumptions the speed of electrification slightly decreased over the years, especially in the FE scenario. Due to our assumptions on the increase of electrified housing, a fully electrified housing stock will already be reached a few years before 2050.[12] Furthermore, the flat development of the business-as-usual scenario is a direct consequence of our assumption of zero electrification in existing houses and only 5% of electrified heating and water in newly constructed buildings.

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[12] Our assumptions are derived from data presented in a study by Forschungsgesellschaft für Wohnen, Bauen und Planen (2014).

Figure 4: Share of electrified houses by scenario, 2016 to 2050

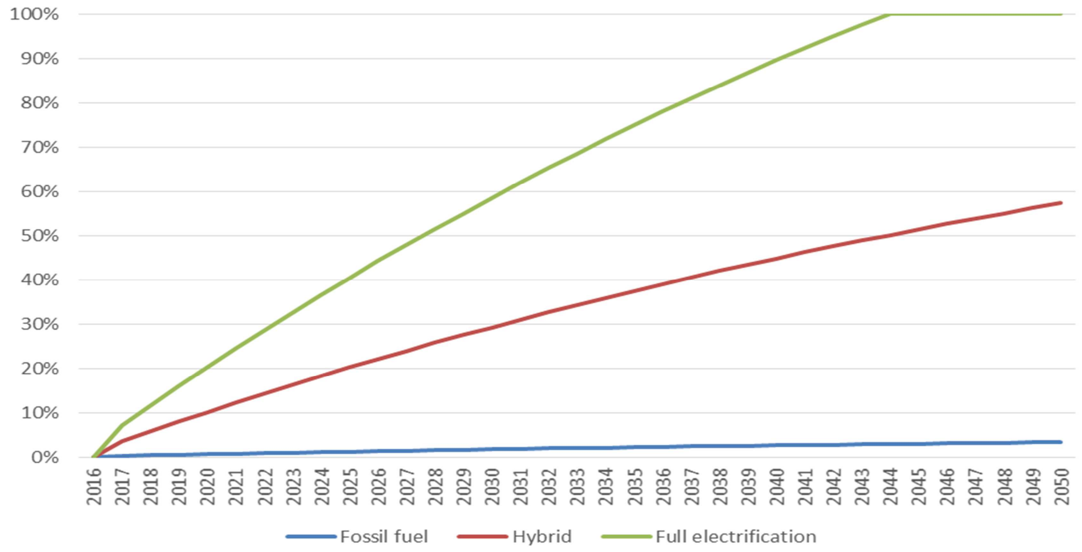
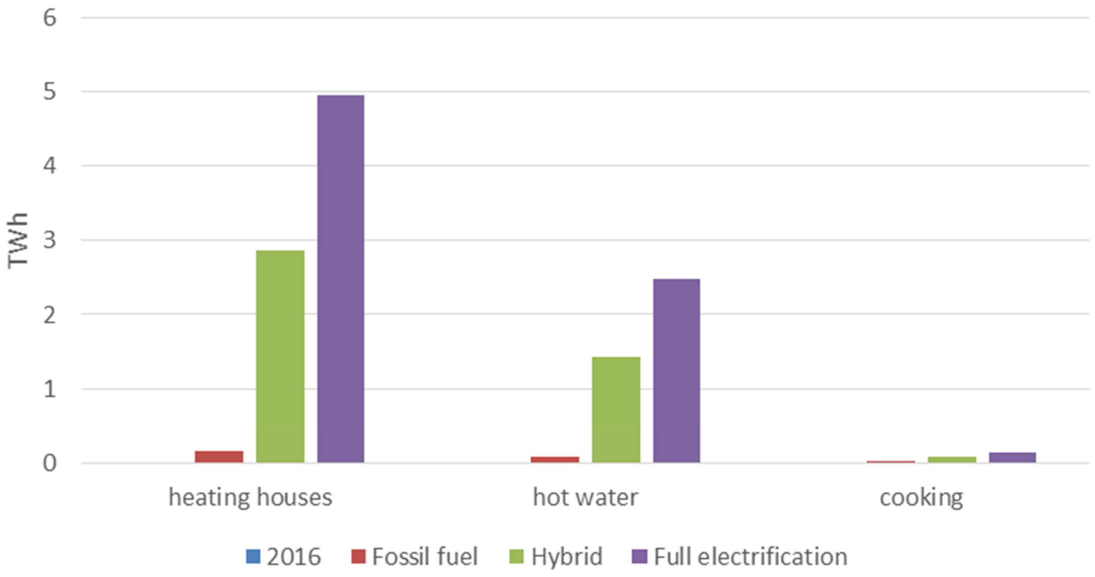


Figure 5 plots the resulting projected electricity demand from the housing sector in 2050. Most strikingly, under FULL ELECTRIFICATION, the total amount of electricity consumed by the housing sector increases by about 8 TWh, considering heating, hot water, and cooking combined. The increase is roughly halved in the HYBRID scenario, and insignificant in the business as usual scenario.

Figure 5: Household electricity demand by scenario and type, 2016 to 2050

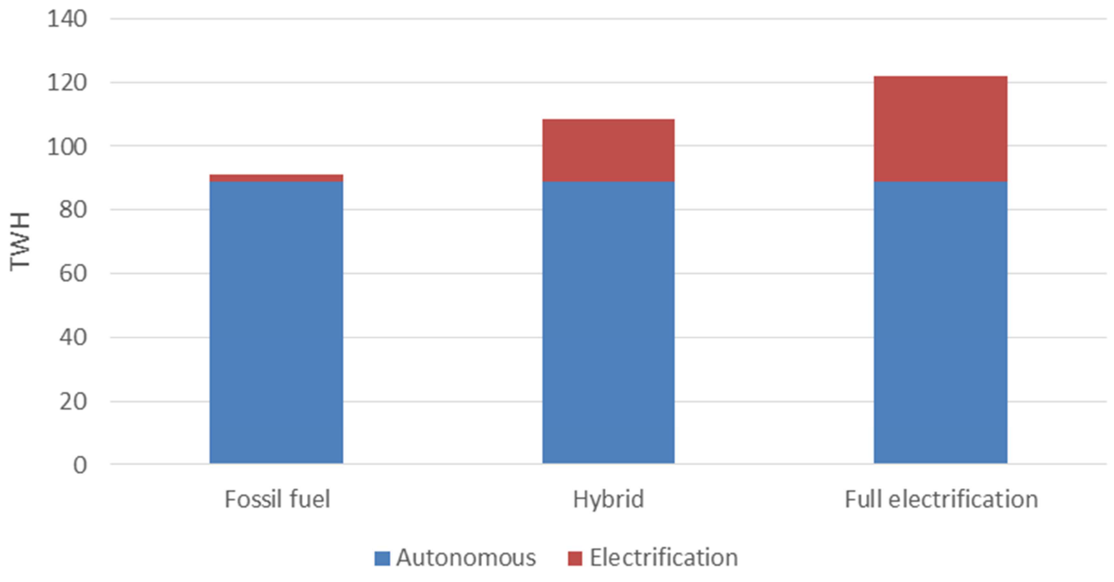


5. Total electricity consumption

Total electricity consumption not only depends on electrification, but is also altered by other factors such as GDP, general trends in energy efficiency or patterns in the amount and type of electrical appliances. The net effect of energy efficiency enhancing measures on the one side and the increase via GDP or new electrical appliances on the other is difficult to project. We assume a low growth rate in autonomous electricity usage of 0.5% each year. Therefore, the impact of electrification will only be one factor that leads to an overall rise in consumption. To shed light on the different magnitudes of autonomous demand increase and demand from electrification, Figure 6 displays the absolute demand level in 2050 broken down to autonomous growth and electrification.

First, it can be seen that even in the FOSSIL FUEL scenario, the autonomous growth leads to a significant increase in consumption as compared to the 75 TWh in Austria in 2016. However, the impact of electrification is negligible in the FF scenario. In contrast, in the full electrification scenario the absolute consumption reaches 120 TWh, of which electrification accounts for about 25%. The latter splits up into roughly 20 TWh electric demand from fully electrified passenger cars and about 8 TWh from electrified buildings, plus some additional demand from the transport sector (vans, trucks, buses).

Figure 6: Demand in 2050 broken down to autonomous demand and electrification, by scenario



6. Generation of electricity

6.1 Policy objectives

Power generation in Austria, in contrast to many other EU countries, is not the main source of CO_2 emissions. This is due to the large share of hydropower in the Austrian market. The fact that generation is already relatively low-carbon may be a reason for the fact that clear-cut policy mandates in terms of future renewable generation or installed capacity of renewable assets are less pronounced than, for instance, in Germany. Currently, the Austrian government formulated a policy goal of reaching a nearly decarbonised power market by 2030. In 2017, about 7 GW of thermal generation operated in the Austrian power market; coal, gas and oil-fired generation amounted to about 13,500 GWh (E-Control, 2017).

6.2 Data and assumptions

Our assumptions on the power market take account of this current policy discussion to phase-out this conventional generation by 2030. In detail, we enlarge the already vast majority of renewable assets so as to be able to cover full demand at an average day with average capacity factors of wind and solar – within the business as usual demand without electrification. To achieve this, we also assume that coal is being phased-out until 2030.

Table 5: Parameters for power supply

Variable	Parameter	Assumption	
Wind, increase in TWh p.a.	0.3	Target in 2030 (MW)	5000
Solar, increase in TWh p.a.	0.3	Target in 2030 (MW)	5000
Biomass	2%	Gradual increase	
Hydro	1.5%	Gradual increase	
Changes in net import	0%	No change	
Coal		Phase-out in 2030	

Table 5 gives an overview on the modelling assumptions. A phase-out of thermal gas-fired plants is not assumed, as they still may be needed on a day without significant wind and solar generation. In addition, gas-fired plants may be used as sources for power-to-gas-to-power, as discussed later. However, due to modelling supply each year within a merit order approach, the addition of renewable assets automatically crowds out thermal generation on the average day. In particular, the study assumes a further growth rate of hydropower by 1.5% (especially from smaller assets "Kleinwasserkraft"), an increase in the use of biomass of 2%, and 5 GW of wind and solar capacity each in 2030. To establish yearly projected generation mixes, these renewable expansion paths are applied to the generation mix of 2016, which is depicted Table 6.

Table 6: Generation mix in Austria in 2016

Variable	Value (TWh)
Gas-fired plants	9
Coal-fired plants	4
Other fossil fuel plants	1
Nuclear	0
Hydro	43
Wind	5
Solar	1
Biomass	6
Other	0
Net import	7
Total load	75

6.3 Results

Results for the supply mix are, of course, strongly driven by the assumptions as discussed above. In essence, the model takes as a starting point the generation, by technology, in 2016 as in Table 6. Based on the assumptions on growth rates (see Table 5), the installed capacity for each technology increases over time. Finally, the merit order also shifts accordingly, where capacity factors are constant over time (i.e. 20% for wind and 11% for solar). Also note that coal, as long as in the market, is dispatched prior to gas, i.e. the analysis assumes ETS prices that do not lead to a fuel switch.[13]

Using these simplistic assumptions, an overall picture emerges especially when comparing the usage of gas-fired plants across the scenarios. First, in the fossil fuel scenario, the 2030 policy goal is reached and renewable generation remains the single generation technology “on the average day”. Figure 7a below presents the generation mix over time in the FF scenario, which looks as anticipated by policy, with a renewable-dominated power mix.

Figure 7b depicts the resulting power generation mix for the full electrification path. As can be seen, the 2030 renewable goals will not be reached under full electrification even with our additional assumptions on wind and solar capacities. Demand cannot be covered by renewables only and gas-fired generation has to be ramped up. Thus, if electrification takes off and the 2030 power market goals ought to be fulfilled, the renewable expansion has to be further supported up to 2030, unless low-carbon imports can be used to satisfy domestic demand.

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[13] We implicitly assume an ETS price of €10. For calculating the cost of emissions, we then use social cost of carbon of €50/ton. Thus, assumed ETS prices are different to social damage done from emitting.

Figure 7a: Generation mix business-as-usual, 2016 to 2050

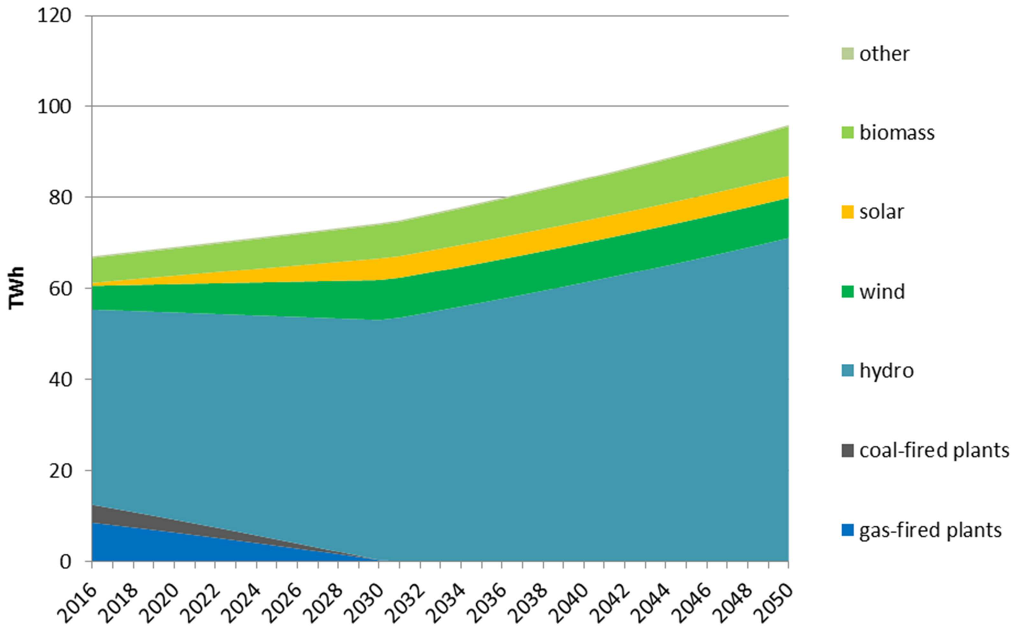
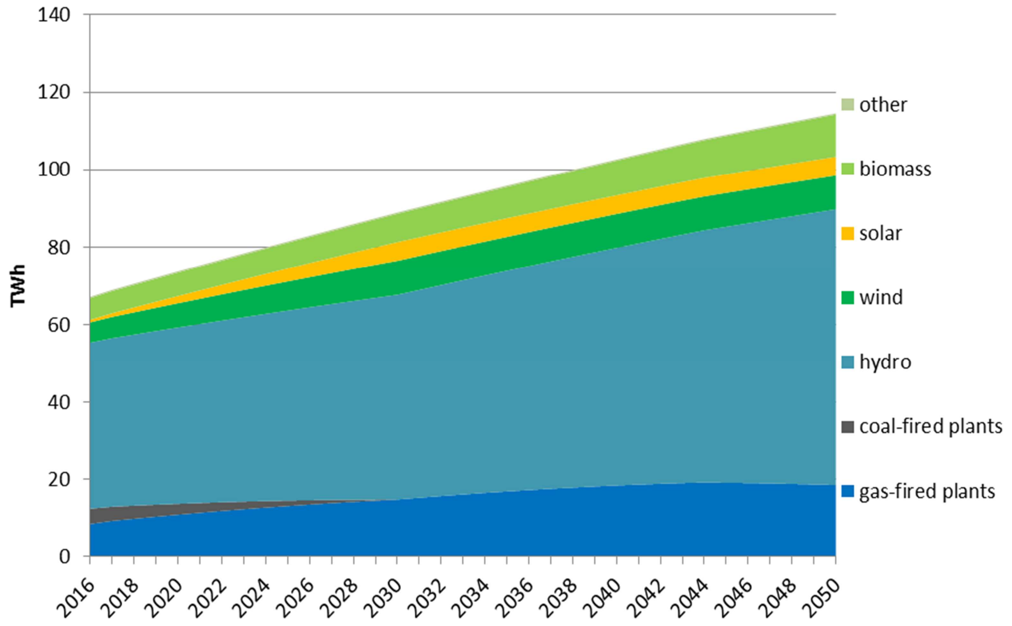


Figure 7b: Generation mix full electrification, 2016 to 2050



7. Demand and supply of flexibility

7.1 Data and assumptions

The above generation mixes illustrate supply under regular conditions, i.e. using average capacity factors for wind and solar. While for a full year this is an appropriate approach, at a more granular level, for instance within-day, the supply mix may look different. To analyse extreme conditions, the model investigates a representative “best” and “worst” day. A day among the best days may be, for instance, a summer day with low demand but high PV and wind output. In contrast, a day among the worst, may be a winter day with high demand but low renewable output. As in Moraga and Mulder (2018), the analysis below considers data on daily averages of load, temperature, wind, and solar generation and classifies days into best and worst days. Specifically, temperature, wind and solar generation are ranked from lowest (worst) to highest (best), whereas load is ranked from highest (worst) to lowest (best). Worst and best cases are then the 5th and the 95th percentiles within each distribution.

As the Austrian system is closely interlinked with the German system, this classification includes Austrian but also German load and renewable output. This approach results in a hypothetical worst day being characterised by PV output of less than 20% of what is generated on an average day, wind output of less than 36%, demand above 115% of the average day, and a low temperature, measured in heating degrees, of higher than 216% of the average day.[14] A day among the best days is characterised by PV output of more than 177% of the daily average, wind output of more than 135% of the daily average, load below 85%, and heating degree of 15% of the daily average. Note that these flexibility considerations graphed below are hypothetical and exclude a range of flexibility sources not treated in the model. Specifically, pooling effects of cross-border trade (other than with Germany) and demand response are not considered.

7.2 Results

During a best day with extreme levels of solar PV, wind, high temperatures and resulting low heating demand, as well as low load levels, demand can be fully met by renewables. The main sources of supply are hydro, wind, solar PV, and biomass, as shown in Figure 8a. Gas-fired generation is not used. The picture changes significantly when illustrating the outcome for a winter day, characterised by extremely low levels of renewable generation, low temperature, and extremely high demand. As can be seen from Figure 8b, in this case, the major back-up technology will be gas-fired. Note that generation on the y-axis is scaled as TWh by day.

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[14] The measure of heating degree days is defined as MAX(Daily Avg. Temperature – Base Temperature, 0), where 18 degrees is used as Base Temperature.

Figure 8a: Power supply on a hypothetical best day under full electrification

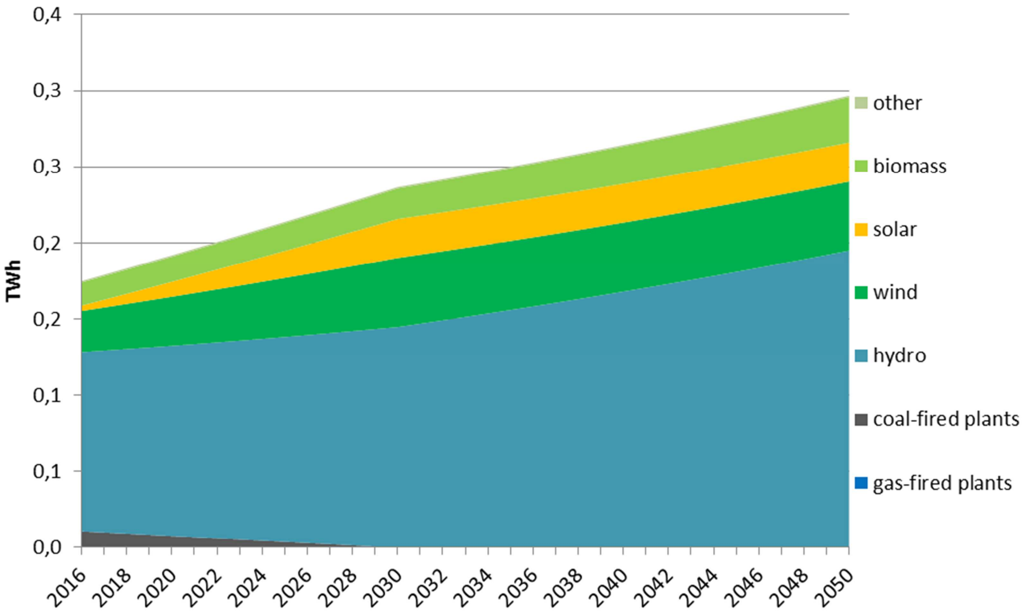
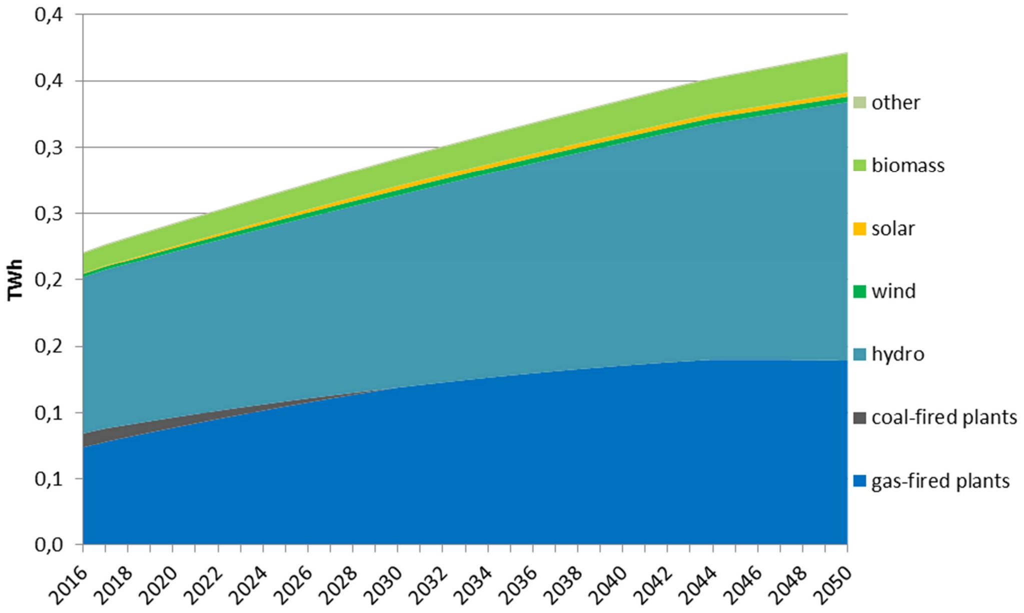


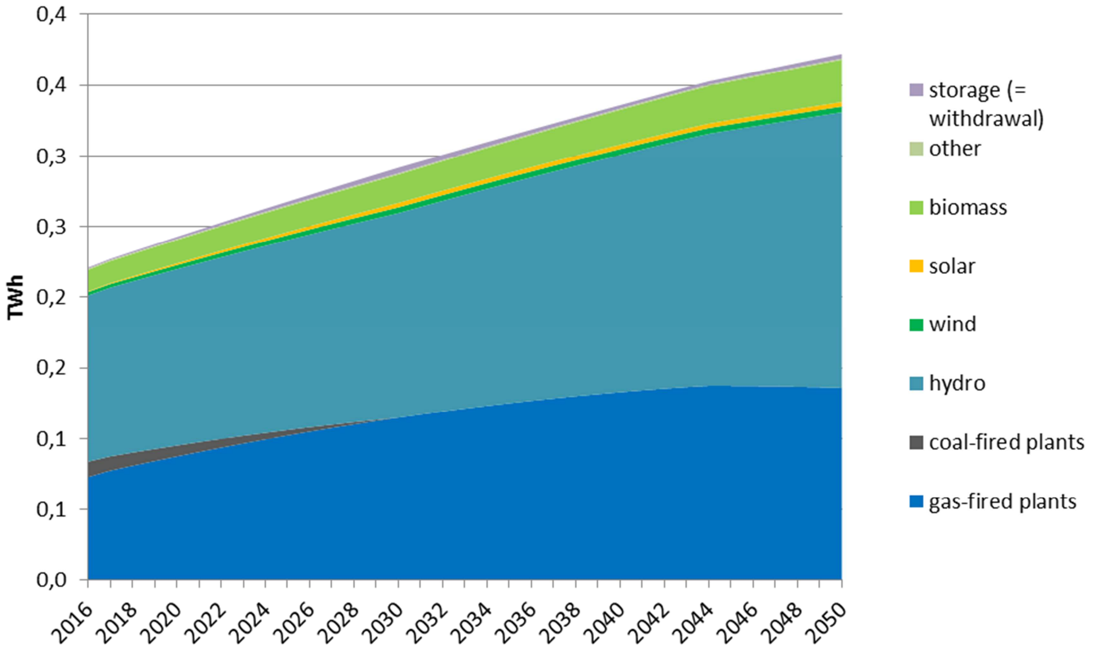
Figure 8b: Power supply on a hypothetical worst day under full electrification



Further, note that because the results above exclude flexibility sources, the shares of gas-fired generation can only be interpreted as upper bound, and will be lower if trade, storage, and demand response were included in the model.

To shed light on the role of gas (and gas storage) in the above, the model can also be used to integrate power-to-gas plants to deal with seasonal storage. Specifically, if oversupply occurs during the hypothetical best day modelled, the model considers seasonal storage provided by power-to-gas infrastructure (assuming it is installed for this purpose). Oversupply is then stored during best days by converting electricity into hydrogen. Next, the model simulates demand and supply of electricity in a worst day. If all conventional sources, excluding gas plants, are insufficient to meet demand, hydrogen from storages is used to generate electricity. If this additional supply is still insufficient to satisfy demand, gas-fired power plants are dispatched as supplier of last resort. As Figure 8c shows, oversupply indeed occurs during best days and is used to generate power (via stored hydrogen) again during worst days, even though only to a limited extent. The modelling approach specifically addresses seasonal storage. Other options that offer flexibility at a more granular time frame, e.g. hourly, are excluded as the model runs at a daily level here, and thus the more detailed breakdown of storage technologies requires additional research. Yet, allowing for seasonal storage in the model shows that the latter will play a role for the full electrification scenario. For Austria, however, storage remains hydro-dominated.

Figure 8c: Power supply on a hypothetical worst day under full electrification, with storage withdrawal



8. Consumption of natural gas

The next block of the model calculates the net impact on the consumption of natural gas in each scenario. The net impact is obtained from, on the one hand, the reduction of gas usage in residential buildings as electrification of houses increases (see Figure 5 above), and, on the other hand, the increase of gas consumption in the power sector (see Figure 7b above).

8.1 Data and assumptions

For calculating the gas consumption of gas-fired power plants we assume an efficiency of gas-fired power plants of 40%, and an annual increase in that efficiency of 1%. The assumptions made to calculate the remaining gas consumption in residential buildings have been illustrated in Tables 4 and 5 above.

8.2 Results

The net impact on gas demand changes over time. As Figure 9 shows, gas demand first decreases until 2030 in the FF and HY scenario. This decrease results from less gas usage in the power market as renewables grow, rather than from electrification of heating. In line, the decline is strongest in the FF scenario without electrification. With electrification, as the HY scenario outcome shows, gas demand declines less than in FF, as gas demand in the power market rises steadily from hybrid electrification. In the FE scenario, gas demand even increases slightly due to high additional power demand from electrification. When renewable expansion ceases in 2030, further increasing gas demand from the power market again cushions the overall decline until 2050. In all scenarios, gas consumption in 2050 is lower than today.

Figure 9: Gas demand 2016-2050 from the power and building sector, by scenario

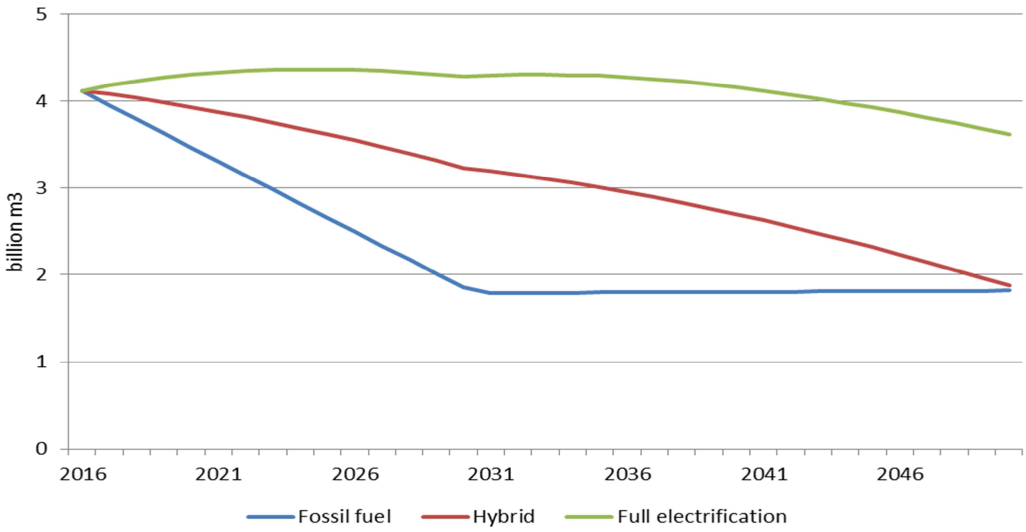
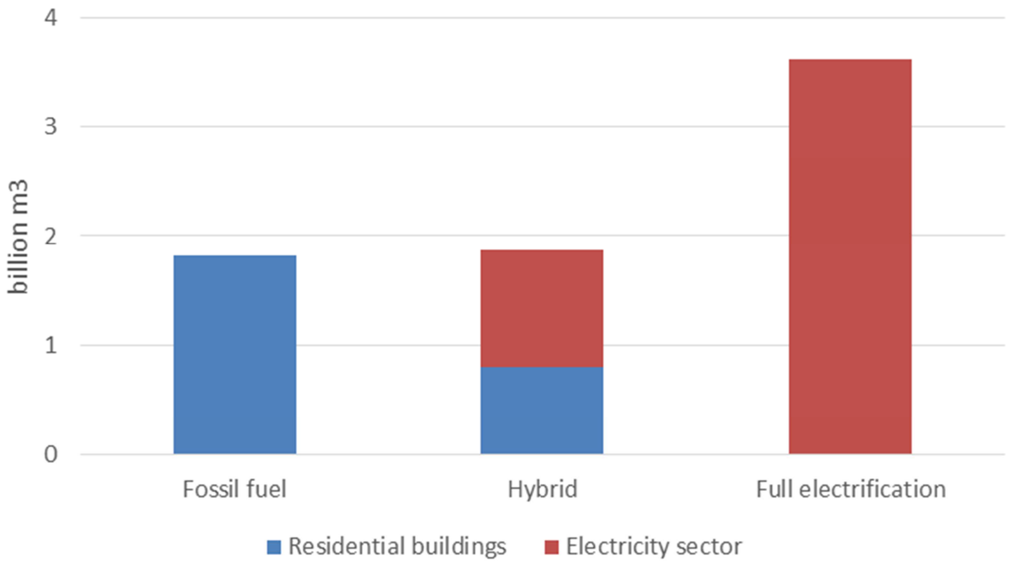


Figure 10 illustrates how gas demand is shifted from the residential sector to the power market. In particular, while in the FF scenario in 2050 almost all gas demand stems from the housing sector, in the FE scenario nearly all gas demand shifts to the power market. In addition, it becomes apparent by how much gas demand overall increases in the FE scenarios as compared to the FF scenarios.

Figure 10: Gas demand in 2050, by origin



Later in Section 10 where we calculate the emissions associated to the housing, transport and electricity sectors, we take into account that part of the gas consumed by households and gas-fired power plants is biogas. In particular, the volume of biogas in the gas system is 0.09 bcm in 2016 and we assume that this volume increases yearly by 2%.

9. Electricity and gas distribution networks

9.1 Data and assumptions

So far, the case study has derived additional power demand from electrification, how this demand will be met on the supply side, and what the net impact on gas demand will be. What remains are the effect on power and gas networks as well as on CO_2 emissions. Both electricity and gas provision rely on the use of distribution and transmission networks. Thus an increase in power generation or gas consumption has to be accompanied by sufficient network capacity. Below, we highlight the changes in load that the power grid, and the changes in gas demand that the gas network has to accommodate. Note that these demand increases represent the same 5% worst days as used above, because network capacity usually is constructed according to maximum demand instances. Thus, these conditions represent situations in which demand for electricity is above the 95th percentile and gas demand is high accordingly.[15] In what follows, we take the assumption that current distribution network capacities suffice to deal with current volumes of load and gas, respectively. In this vein, Figures 11a and 11b illustrate how the peak demands that the power and gas network have to transport change in percent as compared to today.

9.2 Results

In the FE scenario, the electricity grid has the strongest requirement to increase over the years in order to deal with the increase in peak demand, as shown in Figure 11a. In 2050, the electricity network capacity should be able to transport about a third more peak load than today. Similar results hold for the gas network. Both the HY and FE scenario also require more gas to be transported (see Figure 11b). The increase in gas grid capacity (as compared to FF) is much larger than for the power grid. One reason is that the model deploys more gas generation to cope with additional demand in the FE scenario after 2030. The assumed increase in hydro does not suffice to meet this extra demand – thus also the needs for gas and gas infrastructure increase.

Note that, where networks are not constrained today, additional needs in Figures 11a and 11b do not immediately imply that additional investments will be needed with certainty. Further note that the model does not take network topology into account. That is, as gas demand shifts to gas-fired plants and away from meshed networks in residential areas, network requirements may change locally, with more capacity needed to deliver spots of gas-fired generation, and less capacity for vast residential areas.

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[15] To the degree that other sources of flexibility reduce maximum load and gas levels, also the network needs will appear lower. As discussed for the flexibility analysis, these illustrations hence consider upper bounds.

Figure 11a: Increase in electricity network usage, as compared to FF

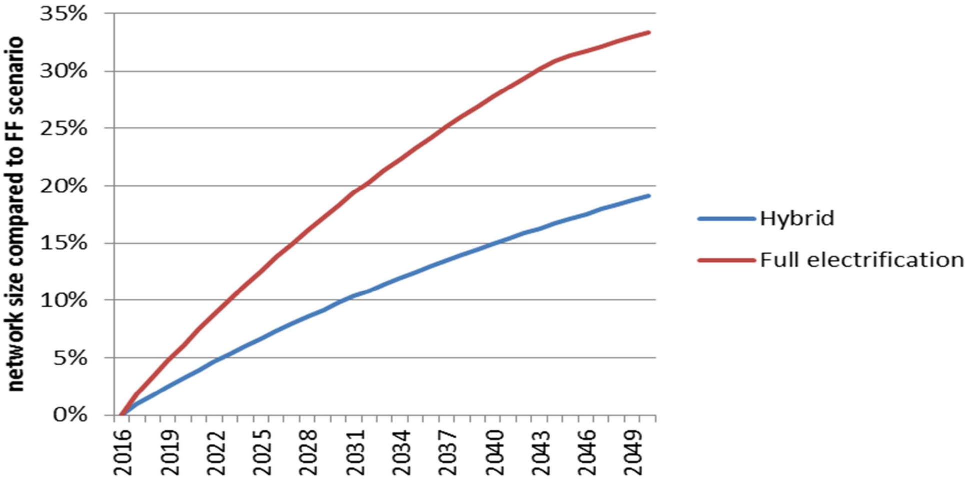
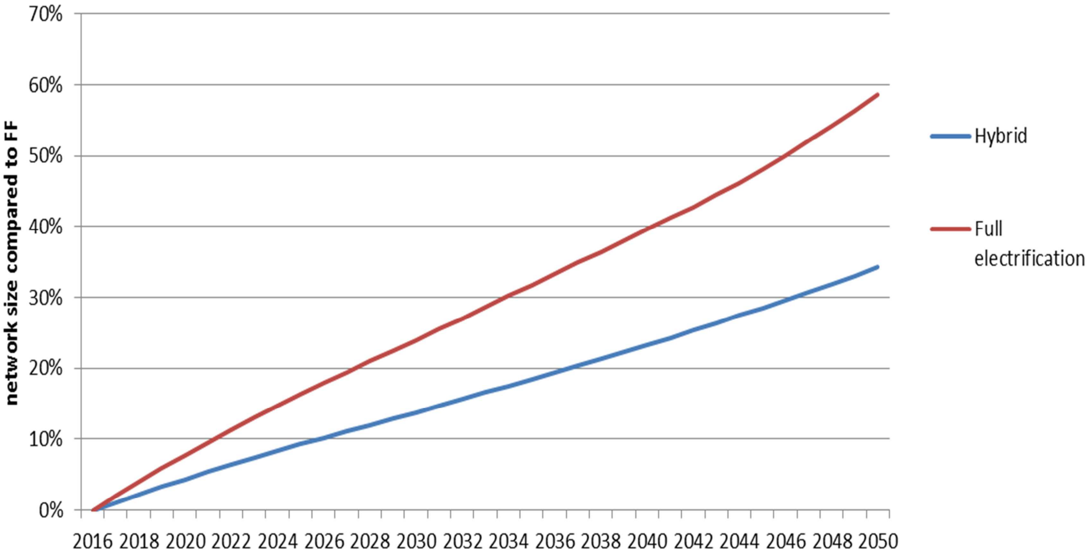


Figure 11b: Increase in gas network usage as compared to business-as-usual



10. Carbon Emissions

Policies in favour of electrification should ultimately be measured vis-à-vis the overall policy goal of reducing CO_2 emissions. The EU and Austrian objective is to reduce emissions to 80 - 95% as compared to 1990 levels. What is the effect of electrification on emissions in Austria?

First note that emissions have largely remained constant in Austria since 1990, as data from the environmental agency shows (Umweltbundesamt, 2017). Emissions remained at about 80 million tons per year, between 2000 and 2009, and even climbed to about 90 tons before falling to the 1990 level of 80 tons again in recent years. Note that, as the power market is already nearly carbon-free, the electrification strategy is a strong candidate for Austrian decarbonisation policy, because saved emissions in transport and heating are not offset by emissions from shifting energy generation to a thermal-based power market (as, potentially, in other countries).

From a gas sector perspective note that, though not modelled here, emission savings can also occur if a fraction of houses remain “un-electrified”. This happens when, e.g., heating consumption for ‘un-electrified’ houses is served with green gases produced with renewable electricity. As such, emissions savings can also occur from a *combination* of electrification and green gas consumption in the building sector. In this context, the below findings can be viewed as benchmark results for the full electrification case. Remaining gas demand in our hybrid scenario then can also be interpreted as the magnitude in the gas market left for green gases (see results in section 8 on remaining gas demand in the housing sector in the hybrid scenario).

To measure the impact on emissions as compared to 1990 levels, we, in addition to the power market emissions, need to gather data on emissions from transport and buildings in 1990. Table 9 summarises the emissions data for 1990 by sector. The transport sector emitted 13.5 million tons in 1990, with the main block stemming from passenger cars. The residential sector emitted about 13.2 million tons, while the power market emitted about 8 million tons of CO_2.

Table 9: Emissions by sector in 1990, in million tonnes of CO2 equivalent

Variable	Value
CO2 emissions in 1990 (x Mton)	
Residential buildings	13.2
Road transport	
Passenger cars	9.0
Vans	1.0
Trucks	3.5
Electricity sector	8

Table 10: Assumptions on fuel efficiency and carbon intensity of vehicles

Variable	Fuel efficiency (lt/100 km)	Carbon intensity (ton/lt fuel)
Passenger cars	6.7	0.0024
Vans	10	0.0027
Trucks	22	0.0027
Buses	29	0.0027
Motorbikes	5	0.0024

The calculation for carbon emissions for each scenario proceeds as follows. We determine the consumption of fossil energy per sector and multiply this consumption with the carbon intensity per unit of fossil energy, i.e. natural gas in electricity and heating, and oil in heating and transport. For the case of road transportation, two factors are relevant: the quantity of fuel used per unit of distance and the carbon intensity of the fuel. Table 10 above gives the assumptions made regarding these factors.[16]

To obtain emissions from gas and oil consumption by (non-electrified) residential households, the model multiplies the total gas consumption in residential buildings in m^3 by the CO_2 content per m^3. The CO_2 emissions per m^3 of natural gas are taken to be 2.2 kg. The same is done for oil-fired heating, with a factor of 2.6 tons of CO_2 per ton of oil. Last, for the electricity sector, the analysis considers the sum of CO_2 emissions stemming from fossil fuelled power plants. For coal-fired plants, CO_2 emissions per ton of coal equal to 3.66 tons are assumed. For gas-fired plants, the model applies 0.4 tons of CO_2/MWh.

10.1 Results

In the FF scenario, the overall emissions remain roughly at today’s level in 2050, as depicted in Figure 12a. Until about 2030, emissions from the power market strongly decrease (especially from coal and gas), due to the (assumed) policy of further decarbonising the power market. Thereafter, with a constant growth in road transportation, emissions increase again until they reach 2016 levels again at the end or our projection. Clearly, the true realisation of the growth in transport may deviate from our assumed growth rates. Nonetheless, the picture emerges that emission savings should hardly be expected in the business as usual scenario, and remain in line with the stagnating emission levels in the past. Note that the emissions in 2016 (covered in the graph), of about 30 million tons, lack emissions from industry and the agricultural sector, amongst others. Also note that emissions from gas and oil fired heating in the housing sector continue contributing to emissions in 2050.

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[16] Further, it is assumed that (non-electrified) cars and two-wheelers use gasoline, while vans, trucks and buses use diesel. Data stems from gemiddelden.nl.

As can be seen, in the full electrification scenario (Figure 12b), strong emissions reductions occur as compared to business as usual and to today's emissions. Reduced emission levels are foremost due to the switch from energy usage from fossil fuel intensive passenger transport to the hydro-based power market. Also, emissions from residential heating contribute to the overall reductions. Hence, the model confirms a reduction of CO_2 emissions due to the electrification of residential buildings and transport. A more detailed breakdown of emissions in road transport and residential buildings can be found in Figures A1 and A2 in the Appendix.

Figure 12a: CO2 emissions over time, fossil fuel scenario

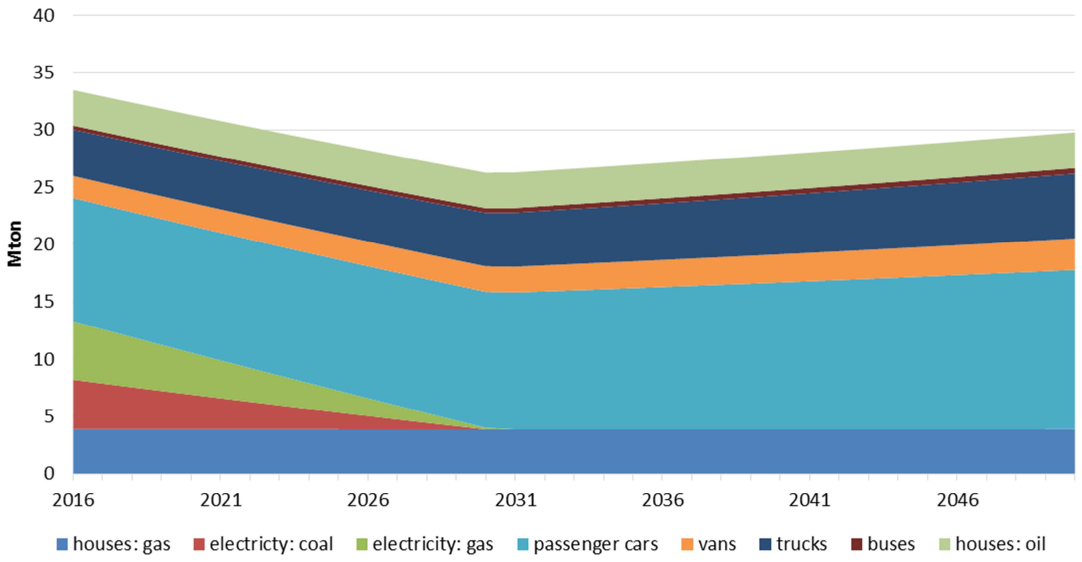
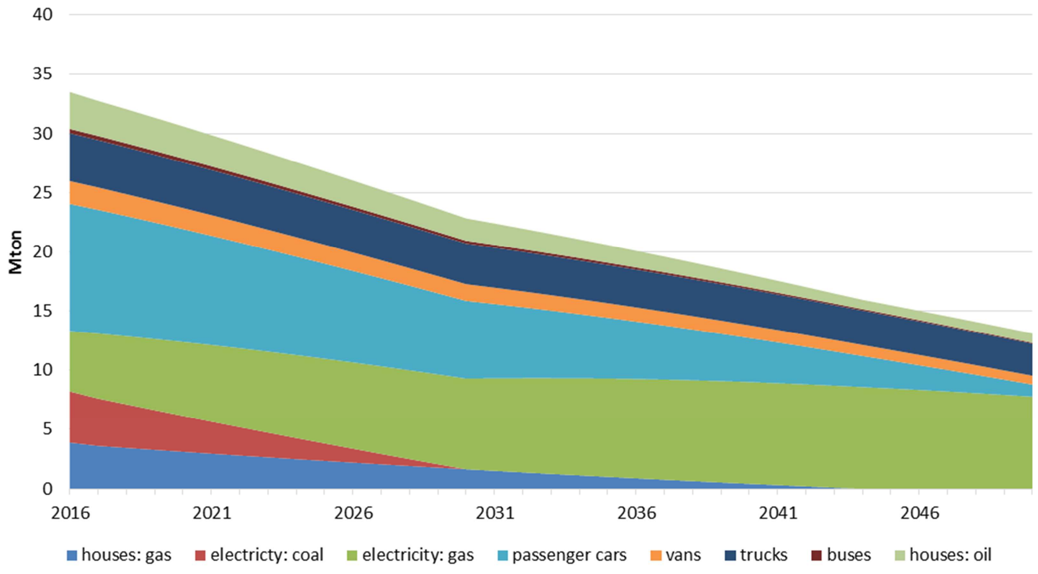


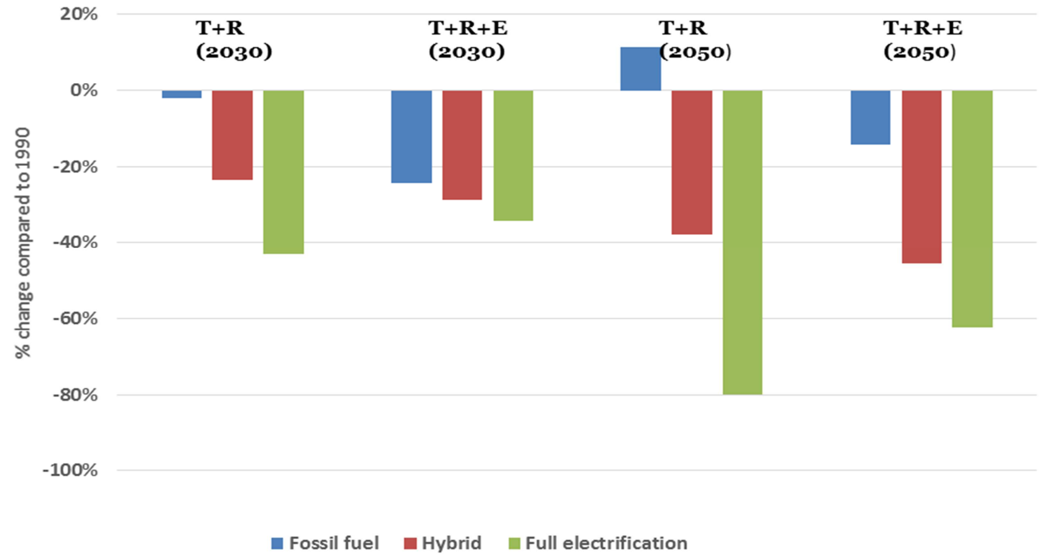
Figure 12b: CO2 emissions over time, full electrification scenario



Finally, Figure 13 illustrates the projected reductions as compared to 1990 levels by groups of sectors. When more renewables have entered the power market, emissions will reduce even in the FF scenario in 2030. In 2050, however, as houses and road transport increase without electrification, emissions increase as compared to 1990 levels. In contrast, emissions reductions in 2050 can be about 80% for the transport and housing sector in the FE scenario. Considering all three sectors combined, however, emission reductions are less than 80%, as renewable energy does not suffice to cover the additional demand from electrification.

Thus, if one remains in the business as usual case, policy goals will not be reached due to emissions from the transport and building sector. Likewise, in the FE scenario, together with the 2030 agenda for increasing renewables in the power market, envisaged emission reductions of 80% will not be reached, unless additional demand from electrification will be met with a renewable increase after 2030.

Figure 13: Projected CO2 emission reductions by sector and scenario in 2050.



Note: The first two sets of entries relate to projected reductions in 2030, first for transport and housing, and second, for all three sectors. The second set of entries relates to 2050, again first for transport and housing, and second, for all three sectors.

11. System costs

Last, the model evaluates the scenarios within a net-present value approach. In essence, this implies comparing benefits from reduced emissions against costs from switching to electrified houses and transport. As for housing, the model accounts for costs of insulating old houses, and the excess costs of installing heat pumps relative to gas boilers. As for road transport, the model accounts for the excess price of electric cars relative to conventional ones, and the costs of deploying the necessary battery charging infrastructure. The model also includes savings of conventional fuels due to electrification. Parameters for this net-present value approach are depicted in Table 11. For additional details see the Netherlands case study. The computation of the system costs below assumes a social cost of carbon of €50 per ton.

Table 11: Assumptions on cost of electrification

Variable	Value
Weighted Average Costs of Capital (WACC)	5%
Discount rate (for NPV calculations)	3%
Depreciation periods (years)	
Grid	20
Power plants	20
Houses (equipment therein, e.g. heat pumps)	40
Cars	10
Investments costs:	
Gas-fired power plants (mln euro/MW)	0.75
Electrolyser (mln euro/MW)	0.5
Storage (caverne)	30
Asset value electricity grid (billion euro)	9
Investment costs residential buildings	
Heat pump (euro / house)	7000
Renovating house (euro/m2/house)	300
Investments costs road transport	
Quick charging stations (per unit)	35000
Ratio charging stations / cars	0.08
Extra costs of electric cars (euro/car)	7500
Gas price (Euro/MWh)	20
annual change in gas price	0%
Price motor fuels (Euro/lt, excl taxes)	0.5
annual change in price motor fuels	0%
CO2 social costs (euro/ton)	50

Note that network expansion costs are not part of net present cost. Ultimately, network expansion needs depend on current utilisation rates. Thus, wherever current network capacity is not constrained, additional gas or power demand does not necessarily translate to immediate network expansion.

11.1 Results

Costs of electrification are reported by comparing total system costs in the HY and the FE scenario with the FF scenario. The degree of electrification is the only factor that is different across scenarios. Therefore, any difference in costs can be fully attributed to differences in the degree of electrification. Before we present the net-present value across each scenario, Figure 14 illustrates the main cost drivers. As can be seen, the electrification of old and new houses via heat pumps and the extra costs of electric vehicles are by far the main cost drivers. This is intuitive, as these represent the largest fixed costs. On the benefit side are, first, cost reductions due to less spending on gasoline, and second, reductions in CO_2 emissions. Figures 15a and 15b then show the overall net-present costs of electrification. While Figure 15a uses today's investment costs, Figure 15b uses 90% of today's costs for heat pumps and other electrification equipment. This latter graph represents the outcome under the assumption that learning curves apply to the respective industries and production costs may fall, as experienced, for instance, in the solar PV industry.

Figure 14: Contribution of different cost drivers (negative costs represent benefits)

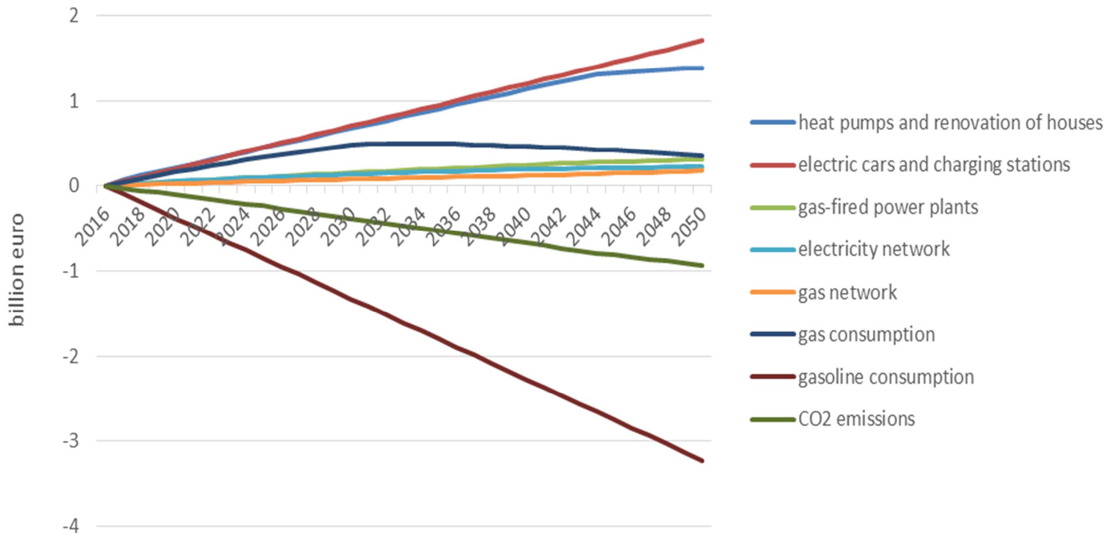


Figure 15a: Net-present system cost for Hybrid and Full Electrification scenario, today's investment cost

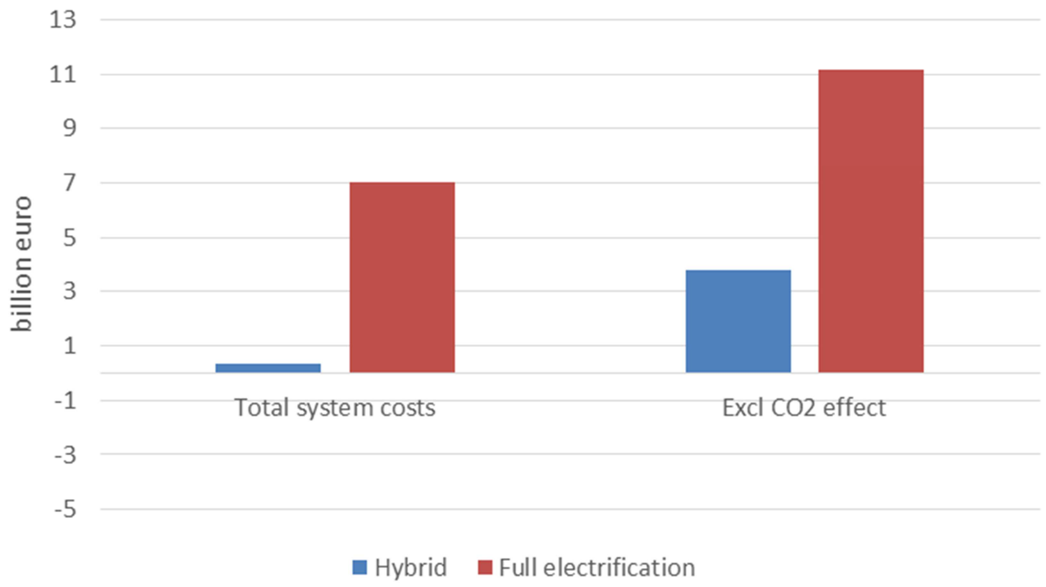
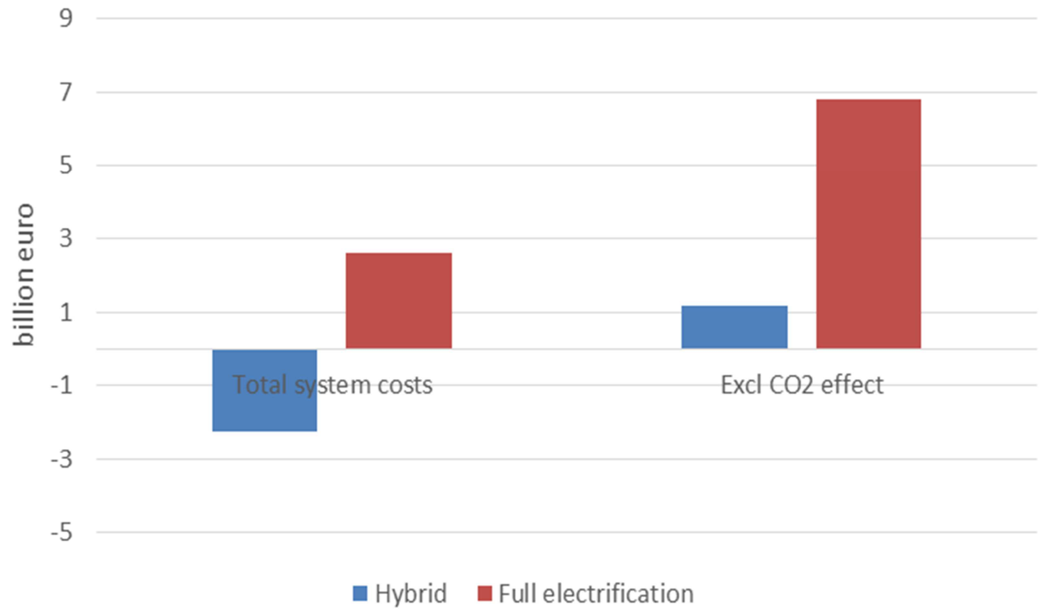


Figure 15b: Net-present cost for Hybrid and Full Electrification scenario, 90% of today's investment cost



12. Conclusion

This case study presents a scenario approach to analyse consequences of electrifying road transport and residential buildings in Austria. The analysis projects assumed electrification paths in three scenarios (business as usual, hybrid, and full electrification) towards 2050. In doing so, the analysis can be understood as a projection given chosen parameters rather than a forecast. All parameters are derived using historical data or estimates from the existing literature. The overarching motivation for this study is to investigate the benefits of electrification of transportation and housing in CO_2 emissions, taking into account costs for electrification. The study also investigates corollary findings, such as on the remaining use of fossil fuels, and in particular natural gas. That is, it analyses the net impact on gas demand of reduced gas consumption in the heating sector but increased demand for power generation.

The model shows that power market demand grows rapidly under full electrification. The net effect on gas demand (reduced gas consumption in the housing sector but increasing consumption on the power market) is positive as compared to business-as-usual. The model also sheds light on the role of gas by integrating the option for power-to-gas to deal with seasonal storage. However, in Austria's hydro dominated power market, this role is limited for power-to-gas-to-power. Yet, power-to-gas may be an option for generating green gases to couple the power and the heat sector. Combinations of electrification and greening the gas sector thus have to be further investigated. Our FE scenario can thus be viewed as the benchmark case of full electrification without green gas applications at the consumer end.

As for CO_2 emissions, the case study evaluates achieved reductions vis-à-vis the policy goal of reducing emissions in 2050. In the business as usual case, emissions increase towards 2050. This is because a major share of emissions stems from the transport sector, which experiences little electrification in the business as usual scenario, and on the contrary grows and emits further. Thus, in the business as usual case, policy goals will not be reached due to emissions from the transport and building sector. Likewise, also in the FE scenario, together with the 2030 agenda for increasing renewables in the power market, envisaged emission reductions of 80% will not be reached, unless additional demand from electrification will be met with a renewable increase after 2030. That is, the increasing demand of electrification can contradict efforts to decarbonise power generation after 2030. Still, emissions decrease in the full electrification scenario as compared to business as usual, indicating a positive net effect of electrification on emissions.

Total system costs are ambiguous. Given today' investment costs for heat pumps and market prices of electric cars, electrification has negative net-present benefit. This changes however, for cost reductions in investment costs. Another relevant cost factor is the increase in distribution grids to cover increasing peak demand. It should be noted, however, that improving distribution grids will not be required due to electrification (that is an increase in demand) only. Also, a growing decentralised power supply will likely make it mandatory to invest in distribution grids.

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Appendix 1

Figure A1: Projected CO_2 emission in road transport, by scenario

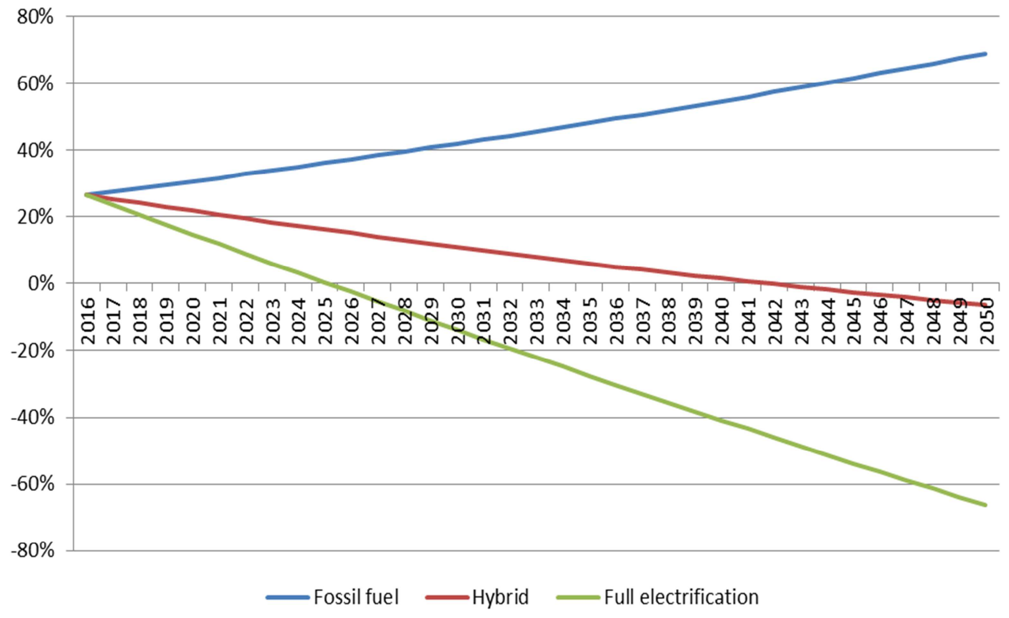

Figure A2: Projected CO_2 emission from residential buildings, by scenario