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Facilitating energy storage to allow high penetration of intermittent renewable energy

Assessment of the Future Energy Storage Needs of Austria for Integration of Variable RES-E Generation

Deliverable 5.1 – Austria

(Source: Voith)

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Acknowledgements

This report has been produced as part of the project "Facilitating energy storage to allow high penetration of intermittent renewable energy", stoRE. The logos of the partners cooperating in this project are shown below and more information about them and the project is available on www.store-project.eu

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The work for this report has been coordinated by Energy Economics Group (EEG)

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List of Abbreviations

(P)HES	…	(Pumped) Hydro Energy Storage – i.e. conventional HES as well as PHES
AGEA	…	Austrian Green Electricity Act ("Ökostromgesetz")
APG	…	Austrian Power Grid AG
BAU	…	Business-As-Usual
CHP	…	Combined Heat and Power
CO_2	…	Carbon Dioxide
CSP	…	Concentrated Solar-thermal Power
EC	…	European Commission
EEG	…	Energy Economics Group
ENTSO-E	…	European Network of Transmission System Operators for Electricity
ESS	…	Electricity Storage System
EU	…	European Union
GW	…	Giga Watt
GWh	…	Giga Watt hour
h	…	Hours
HES	…	Hydro Energy Storage (dam- or barrage-hydro power plant)
HPP	…	Hydro Power Plant
HSU	…	Helmut Schmidt University
HVDC	…	High Voltage Direct Current
kV	…	Kilo Volt
MW	…	Mega Watt
MWh	…	Mega Watt Hour
NREAP-AT	…	National Renewable Energy Action Plan for Austria
PHES	…	Pumped Hydro Energy Storage
PV	…	Photovoltaics
RES-E	…	Renewable Energy Sources for Electricity generation
TPP	…	Thermal Power Plant
TSO	…	Transmission System Operator
TWh	…	Tera Watt Hour
TYNDP	…	Ten Year Network Development Plan (ENTSO-E)

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Executive Summary

Within this Deliverable 5.1 of the stoRE project an estimation about the additional energy storage needs in electricity supply systems with high shares of variable / non-controllable electricity generation from renewable sources like wind and sun is determined. This report deals with the electricity supply system of **Austria** and aims to provide a clear overview of the energy storage infrastructure needs in order to achieve high penetration of renewable energy in the electricity system. The existing power generation mix and transmission system (including their planned development and reinforcements) are considered, along with the national plans for renewable energy development in the next decades up to 2050. The necessity of new energy storage facilities and their feasibility from an energy point of view is investigated with the aid of simulations of mainland electricity system operation characteristics using specially developed software. The produced qualitative and quantitative results highlight the need of energy storage in future electricity systems and show the benefits it can bring.

Due to the high potential of Pumped Hydro Energy Storage (PHES) in Austria a further investigation of the combined electricity system of Austria and Germany is made.

The Electricity Generation and Transmission System of Austria

The total electricity production in Austria in 2011 was about 66 TWh with a peak load of 11.3 GW. The power plant mix consisted of 8.3 GW Thermal Power Plants (TPP), including biomass and biogas, 1.3 GW variable renewable energies like wind and solar power and 13.2 GW of hydropower. Hydropower had a total share on the Austrian electricity generation of 57% in 2011. Together with other installed renewable energy sources for electricity generation (RES-E) the total share of renewable energies was already at more than 60%. Hydropower is a very important source of energy in Austria, as more than half of the electricity generation comes from hydro power plants (HPP). In the past Austria has developed a very high capacity of about 7,800 MW of (pumped) hydro energy storage systems. This, in combination with the also high amount of run-of-river (RoR) power plants, provides great flexibility to the Austrian electricity system. Fossil fired power plants can be shut down with no constrains due to system stability issues or a non-synchronous penetration limit. Already in the past years there have been periods during summer and autumn where there was no fossil-fired production unit connected to the grid and the load was fully covered by hydropower and other RES-E. The strong development of RES-E (besides hydropower) is mainly due to the political support that started in 2002 with the adoption of the Austrian Green Electricity Act ("Ökostromgesetz", AGEA). With this Act feed-in tariffs where introduced, which caused a particularly strong development of wind energy, biomass and biogas.

The Austrian transmission grid system has total length of 6,700 km and is entirely operated by the Austrian transmission system operator Austrian Power Grid (APG). The transmission system is divided into 3 voltage levels, 110 kV, 220 kV and 380 kV. The Austrian grid has high voltage grid connection points to Germany, Czech Republic, Hungary, Slovenia, Italy and Switzerland. The main characteristic of the Austrian transmission system is its ring structure, shown in Figure 1. After the so-called "Steiermarkleitung" has taken up operation in mid-2009, the gap of the Austrian 380-kV-ring in the eastern part of Austria has been closed. But still weak spots remain in the western transmission grid areas.

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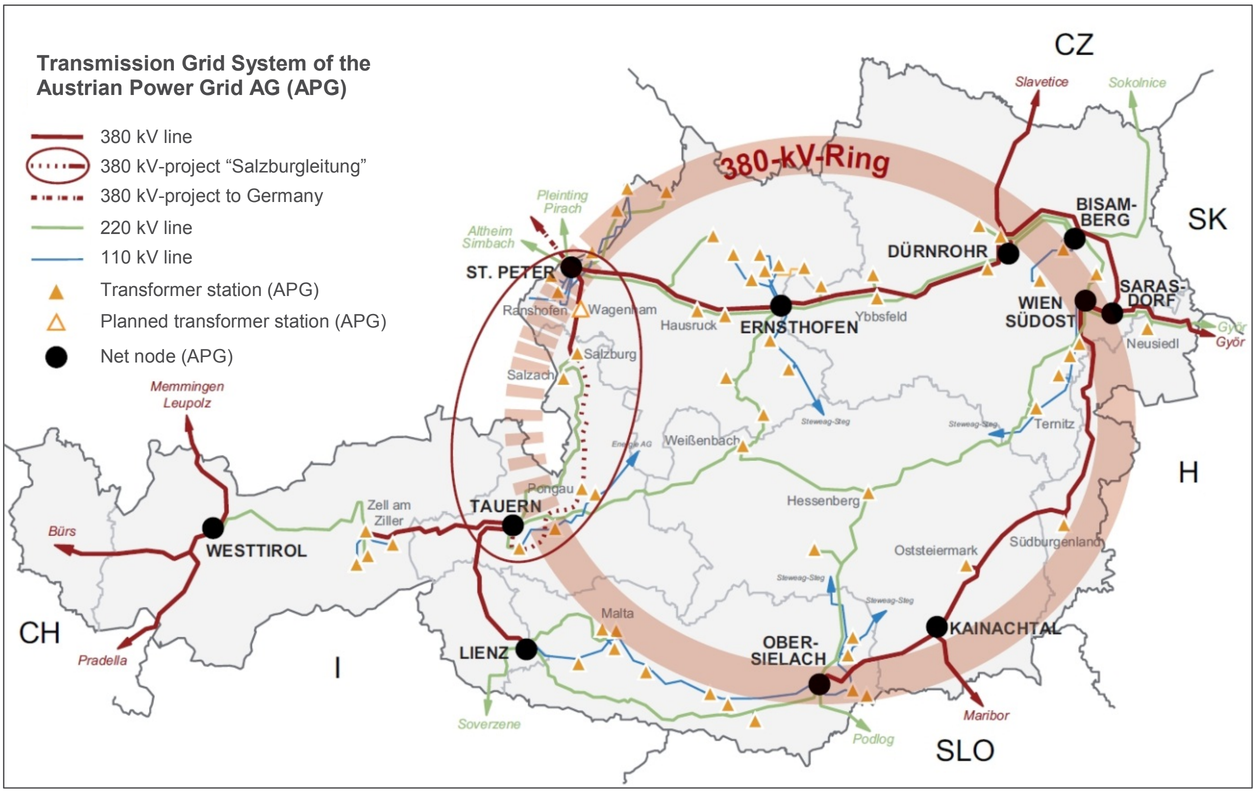

Figure 1: Status quo of the Austrian electricity transmission grid in the year 2011 (Source: APG, 2011)

Austrian System Development Plans (2020–2050)

Although Austria has already a very high share of hydropower in the electricity generation system there is still a high potential for (small-scale) hydro power plants and PHES plants - especially the revitalization / repowering of existing power plants still has an enormous potential. However, the National Renewable Energy Action Plan of Austria (NREAP-AT) does not foresee an increase of installed PHES power and neither an increased electricity generation. Energy production from hydropower should increase from 38 TWh to 42 TWh.

Although wind power is already strongly developed due to the good natural space conditions in particular in the eastern part of Austria, the NREAP plans to more than double the installed capacity, from 1 GW in 2011 to 2.5 GW in 2020. Photovoltaic (PV) will play a rather low role in the electricity mix of Austria until 2020, but the technological development in the past years and the will of the Austrian government to stronger promote PV systems could lead PV installations to a significant increase. Furthermore, the new Austrian RES legislation set the 2020 RES targets higher than in the original NREAP-AT.

For the development beyond 2020, the information about the future power plant mix is provided by the Energy Economics Group (EEG) of the Technical University of Vienna, based on modelling results of the *Green-X* RES-E deployment simulation tool. *Green-X* provides future scenarios on annual RES-E capacity installations and electricity generation per country under a variety of different possible policy settings and constraints. For this report two different future development scenarios have been defined. A business-as-usual scenario (BAU) with moderate increase of RES-E deployment and an environmental friendly scenario (GREEN) with high increase of RES-E deployment. Figure 2 and Figure 3 show the development of the power plant mix for Austria until the year 2050. In both scenarios coal and oil power plants will phase out until 2050.

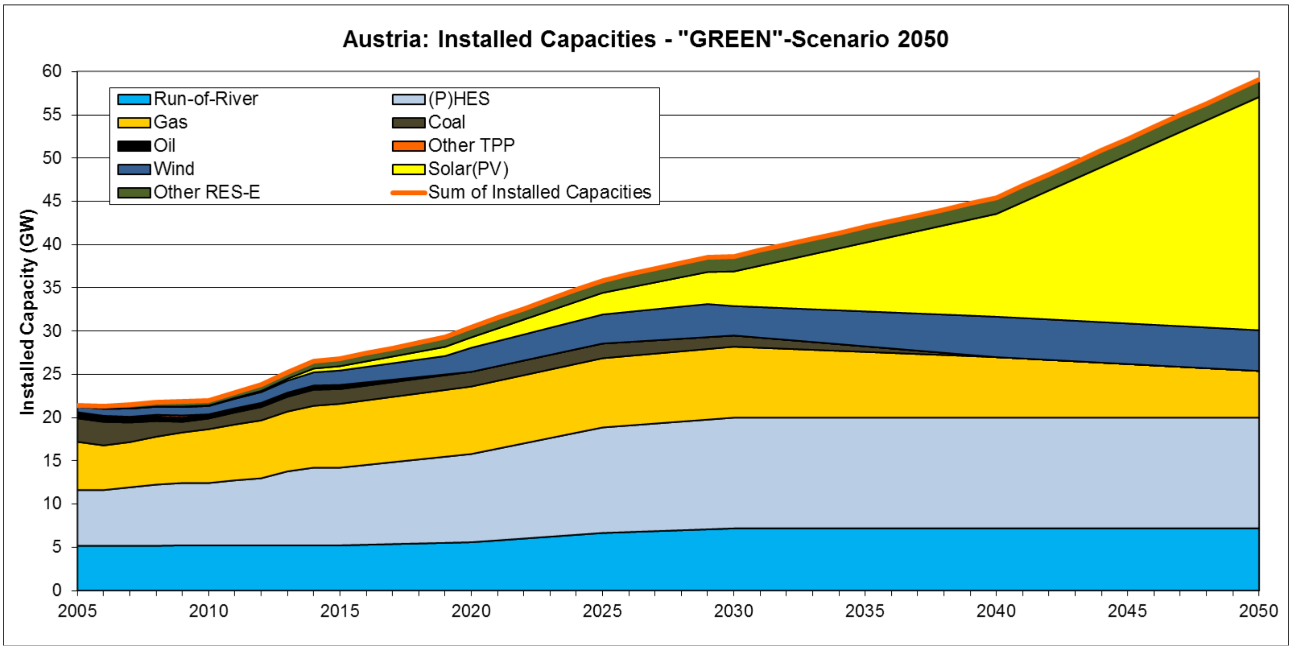

Figure 2: Development of installed capacities of the Austrian electricity generation system until 2050 in the GREEN scenario (Source: EEG)

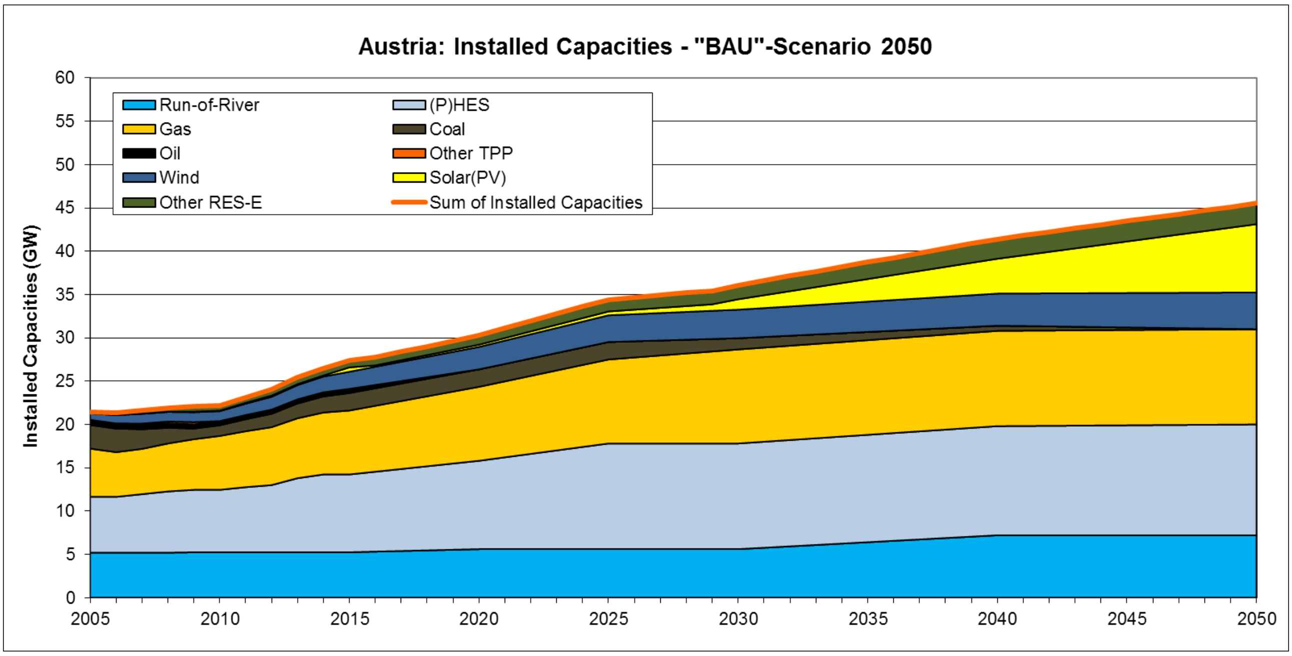

Figure 3: Development of installed capacities of the Austrian electricity generation system until 2050 in the BAU scenario (Source: EEG)

Examined Future RES-E Development Scenarios

For this study two different years have been investigated, see Table 1. The first scenario concerns the year 2020, which was chosen because the targets for RES-E development specified in the NREAP-AT end in 2020. For that reason the first scenario for 2020 (scenario A) is the scenario with the installed capacities of RES-E foreseen in the NREAP-AT. Additionally, the BAU and the GREEN scenario of EEG are investigated for 2020 (scenario B and C respectively). The 2020 scenario A to C do not differ much in their installed wind power. What can be observed is that there is a strong raise in PV installations in the GREEN scenario C. Furthermore, scenarios B and C foresee a higher installed power of PHES systems than the NREAP.

The investigations for the year 2050 are divided into two parts only, as there are no direct governmental targets for this year. For that reason only the GREEN and the BAU scenario are investigated further. Here a significant difference regarding the installed PV power can be observed in both scenarios compared to 2020. Also between the GREEN and the BAU scenario the difference in installed PV power in the year 2050 is enormous. In the GREEN scenario an installed power of 27 GW of PV is foreseen, which is twice the expected peak load of this scenario.

For 2020 as well as for 2050 the electricity consumption as well as the peak load is expected to increase. In the BAU scenario both values increase much faster than in the corresponding GREEN scenario. This is due to the expected higher efficiency in many areas of energy consumption in the GREEN scenario. Although the amount of installed RES-E is rising, the total share of RES-E on the electricity consumption is decreasing in the BAU scenario. On the other side, the expected RES-E generation in the GREEN scenario is expected to be higher than the electricity consumption by 2050, i.e. Austria is becoming a net exporter of RES-E.

Table 1: Overview of the scenario assumptions for Austria in the year 2020

[MW]	Ref. (2011)	2020 Scenarios			2050 Scenarios	
		A	B	C	B	C
Wind (onshore)	1,084	2,578	2,589	2,780	4,240	4,710
PV	187	322	264	1,200	7,880	26,960
Hydropower						
Run-of-River	5,215	5,400	5,600		7,200	
HES	3,550	3,597	3,600		3,600	
PHES	4,215	4,285	6,600		9,200	
Small Hydropower	221	221	221		250	
Other RES-E	72	1,115	1,100	1,150	2,430	2,000
Yearly Peak Load	11.3	12.8	14.9	12.4	20.7	13,6
Energy Consumption [TWh]	68.8	77.5	90.9	75.6	126	83
RES-E Generation [TWh]	39.81	52.4	54.8	56	75	94
RES-E Share[1]	60.6%	67.6%	60.3%	74.1%	~60%	~110%

The maximum excess power and the energy that would be rejected without any electricity storage system (ESS)[2] are summarized in Table 2 for all scenarios for Austria. The maximum rejected power as well as the rejected energy is always higher in the GREEN scenario C. In 2050 the rejected power is almost as high as the peak load and the rejected energy would be almost 10% of the total energy production from RES-E.

[1] On net electricity consumption, not electricity generation.
[2] I.e. negative residual load.

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Table 2: Overview of the outcomes of the residual load analysis for Austria

Scenario	Max. rejected power [MW]	Rejected Energy [GWh]
2020 A	898.73	3.56
2020 B	134.35	0.19
2020 C	1,340.90	11.91
2050 B	0	0
2050 C	12,185.30	7,694.20

Because of the high potential for PHES in the Austrian Alps, two further 2050 scenarios have been investigated. For these scenarios the two electricity systems of Austria and Germany have been combined. As Germany will have a very high need of ESS after 2020 (see D5.1 – Germany) and the Austrian PHES facilities already participate on the German market through the European Energy Exchange (EEX) this is an important investigation. In this report no bottlenecks in the transmission grid between both countries are assumed - all the energy needed for charging or discharging the reservoirs can be imported or exported respectively.

Table 3 shows the 2050 scenarios investigated for each country and the two combined scenarios. For the combined scenarios only the interaction of the GREEN scenario C of Austria with the two different German scenarios has been simulated as the high share of RES-E will be more relevant for these investigations.

Table 3: Overview of the 2050 scenario assumptions for Austria-Germany

[MW]	Germany		Austria	Total AT-DE	
	A	B	C	AC	BC
Wind (onshore)	63,000	55,000	4,710	67,710	59,710
Wind (offshore)	30,000	21,000	0	30,000	21,000
PV	45,000	100,000	26,960	71,960	126,960
Hydropower					
Run-of-River	5,700		7,200	12,900	
HES	0		3,600	3,600	
PHES	8,000		9,200	17,200	
Small Hydropower			250	250	
Other RES-E	5,000		2,000	7,000	7,000
Yearly Peak Load	79.1		13.6	92.5	92.5
Energy Consumption [TWh]	~500		83	~583	~583
RES-E Generation [TWh]	~400		94	~494	~494

The maximum excess power and the energy that would be rejected without any ESS are summarized in Table 4 for both AT-DE scenarios. It can be seen that the scenario AC, with a stronger development of wind energy (Germany A), the maximum rejected power and the overall rejected energy without energy storage is almost half of scenario BC. This is due to the lower full load hours of PV installations - to reach the same share of RES-E on the electricity consumption a higher rated power has to be installed which leads consequently to higher surpluses on e.g. sunny days.

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Table 4: Overview of the outcomes analysing the 2050 residual load of AT-DE

2050Scenario	Max. rejected power [GW]	Rejected Energy [TWh]
AC	43.07	11.34
BC	70.54	24.96

Computer Modelling

The computation methodology follows two steps. First the residual load for the scenario under investigation is calculated, for which hourly load and generation data of different years per primary energy carrier are used. The second step is the calculation of the overall storage needs. For this purpose an algorithm was developed at the Helmut-Schmidt-University (HSU) to estimate the energy storage needs just from a system point of view. The aim of the ESS in this approach is to integrate the maximum amount of RES-E possible without any focus on the electricity spot market price.

The residual load is defined as the load demand minus the non-controllable variable production of RES-E. In the case of Austria the non-controllable generation from renewable sources includes wind energy, PV and RoR HPP. As an example the residual load of Austria in 2050 scenario C is shown in Figure 4.

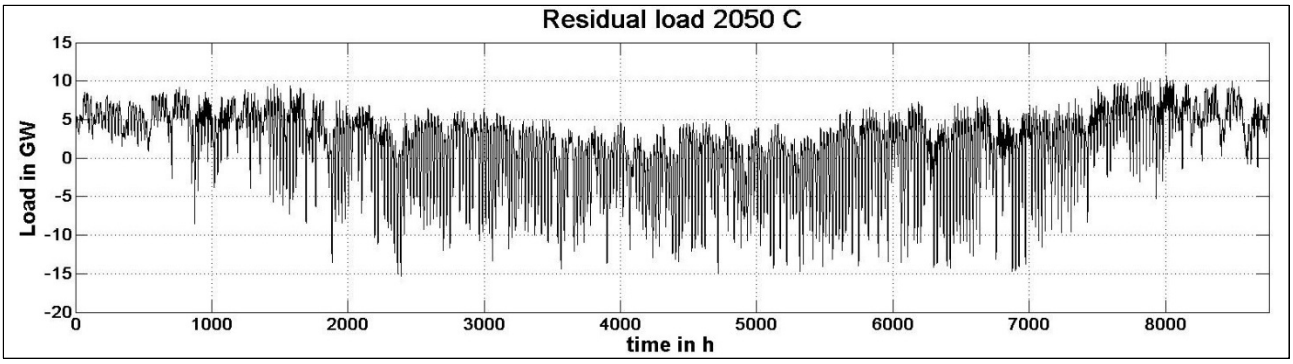

Figure 4: Residual load of Austria, 2050 scenario C (Source: HSU)

It can be seen that the residual load is negative especially during summer when there is a high feed-in from PV. A negative residual load means that there is a surplus of energy from RES-E that exceeds the electricity demand at that point in time. This surplus can either be rejected by down regulation of RES-E units, exported to neighbouring countries or stored in ESS. However, down regulation or energy export is not an option within the computation algorithm. The aim of the algorithm is to use as little power and storage capacity of the ESS to fully integrate all the surpluses due to RES-E. In principle the algorithm follows a peak-shaving and valley-filling strategy as shown in Figure 5. To minimize the energy storage needs, an intelligent operation strategy was implemented. If a high surplus of RES-E in the electricity system can be expected, the ESS plans its operation in a way to be able to fully integrate this surplus. If the surplus of RES-E is expected to exceed the capacity of the ESS, the ESS tries to plan the operation in a way to empty the reservoirs completely beforehand in order to integrate as much RES-E as possible.

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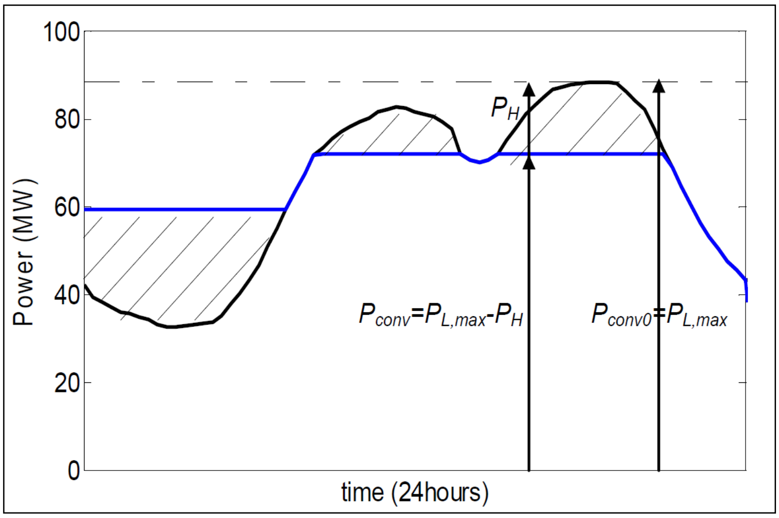

Figure 5: Indicative effects of PHES operation on the system RL curve (Source: HSU)

To estimate the additionally needed storage capacity a further technology, in addition to the already existing ESS, is introduced, which has an unlimited storage capacity and power. This technology can take the surplus of renewable energy that cannot be stored by the existing system. Due to the unlimited power and capacity this technology enables the full integration of all renewable energies. The actual used power and capacity of this second technology is an indicator of the additionally needed ESS.

Simulation Results for Austria

For all simulations the capacity of the Austrian PHES system was set to 2 TWh. The installed power varies in the different scenarios according to Table 1. The results of the simulation for the 2020 scenarios are shown in Table 5. For all scenarios the capacity of the reservoirs is just used to a very small amount - the maximum charging level in scenario A, B as well as C is just around 2% of the theoretical maximum (i.e. about 40 GWh). Also the installed power of 4.29 GW in scenario A and 6.6 GW in scenarios B and C is not fully used. The maximum used power in charging as well as in discharging mode never exceeds 4 GW. This shows that by 2020 the Austrian PHES system has enough capacity to fully integrate all RES-E in the Austrian electricity system and could also provide balancing services to neighbouring countries to increase profits.

Table 5: Overview of results in the 2020 scenarios

2020 Scenarios	Stored Energy [GWh]	Provided Energy [GWh]	Capacity Factor			Max. Used Power [GW]	
			Charge	Disch.	Total	Charge	Disch.
A	4,369.80	3,599.27	11.63%	9.58%	21.21%	3.37	3.36
B	5,205.88	4,219.82	9.00%	7.30%	16.30%	3.85	3.26
C	4,049.14	3,280.65	7.00%	5.67%	12.68%	3.31	2.77

As a rule of thumb it can be assumed that a PHES plant is economically feasible when its capacity factor is 25% or higher. Yet, in all three scenarios the capacity factor is below 25% using the PHES system just for the Austrian system alone. It could be increased by storing also surpluses of neighbouring countries, higher residual load smoothing (see 2050 scenario B) or participating in

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other markets. However, as previously mentioned, the simulation does not take into account market framework conditions and the future electricity price development.

For the 2050 scenario B the full storage capacity as well as the full power of the Austrian PHES system was not used at all during the year. To utilise more storage capacity, three different operational strategies have been used to determine how much influence this could have on the PHES system, see Table 6. The first strategy is to balance the residual within a one-day rhythm, which means that the ESS tries to fill and empty the reservoir within 24 hours. This, however, leads to a maximum used storage capacity of only 1.5% of the available 2 TWh. The installed charging and discharging power of 9.2 GW is never used during the year and there is still a lot of unused potential. When looking at the next strategy, where the balancing time is raised to 48 hours, the used power in charging as well as discharging mode is getting to about 2/3 of the installed power. The charging level of the reservoirs is rising as well but still stays on a very low level (3%). As a final operational strategy the charging / discharging cycle was set to 200 hours. Although enabling the balancing of the residual load over a period of almost 8 days, the maximum available power is still not fully used. The capacity used reaches it maximum at around 200 GWh, which is just 10% of the potential. However, even with increased residual load smoothing the capacity factor of the PHES system is lower than 20% in all scenarios – the PHES system

In the 2050 scenario C the Austrian PHES system reaches its limits for the first time, which is due to the very high amount of installed PV power. As Figure 6 shows, the residual load after use of the PHES system still has negative peaks which indicate a surplus of RES-E. This surplus appears only in the time span between spring and autumn and is due to the strong feed-in from photovoltaic. The maximum power of the ESS is just reached in charging mode and thus it cannot store further production from RES-E. The charging level of the system now reaches 80% and has a clear seasonal character – the ESS is charged during summer (high feed-in from RES-E) and is discharged again during winter. The capacity factor of the Austrian PHES system in the 2050 scenario C reaches about 23% – since only 6 GW out of 9.2 GW of turbine power are needed for the integration of RES-E, there is still potential for participating in other markets.

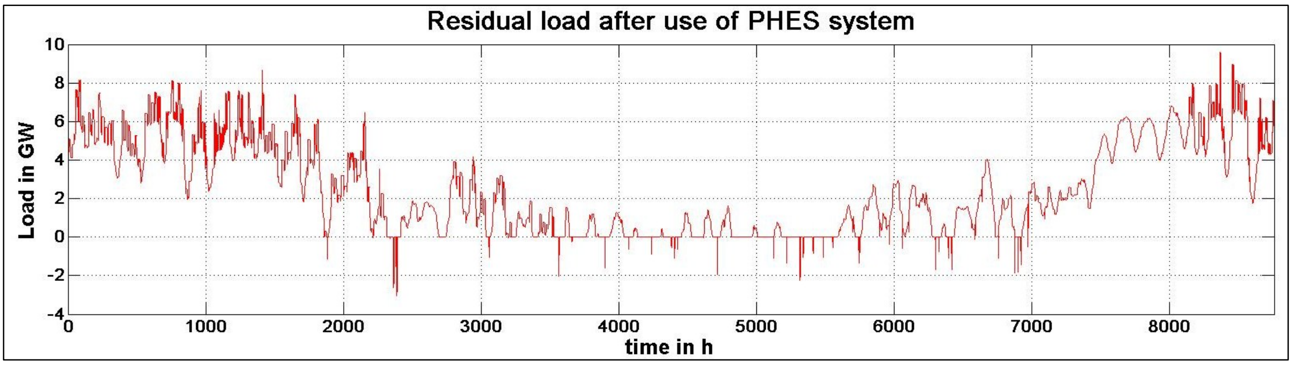

Figure 6 Residual load after the use of the Austrian PHES system in the 2050 scenario C (Source: HSU)

In a next step, to fully integrate all energy from RES-E, the charging power of the PHES system was set to unlimited. As can be observed in Figure 7, there are no more surpluses and the residual load never turns negative. The used power and the charging level of the ESS are shown in Figure 8. The maximum used power in charging mode is 12.18 GW and the maximum charging level is again at almost 80%. Once more the charging level shows a clear seasonal characteristic and the high capacity is only used to store the surplus of PV production during summer and to provide it again during autumn and beginning of winter. The rest of the year the reservoirs are just filled to a small amount and the PHES system is only used to smooth the residual load. However, due to the extension of the pump power by 3 GW to 12.2 GW in total, the capacity factor is decreased to about 20%.

All outcomes of the 2050 scenarios for Austria are summarized in Table 6.

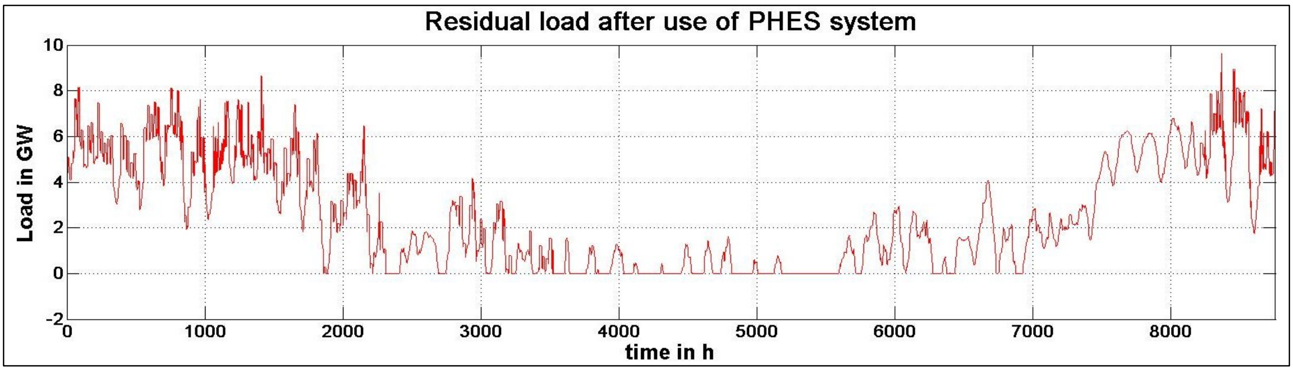

Figure 7: Residual load after the use of the Austrian PHES system in the 2050 scenario C (PHES expansion, source: HSU)

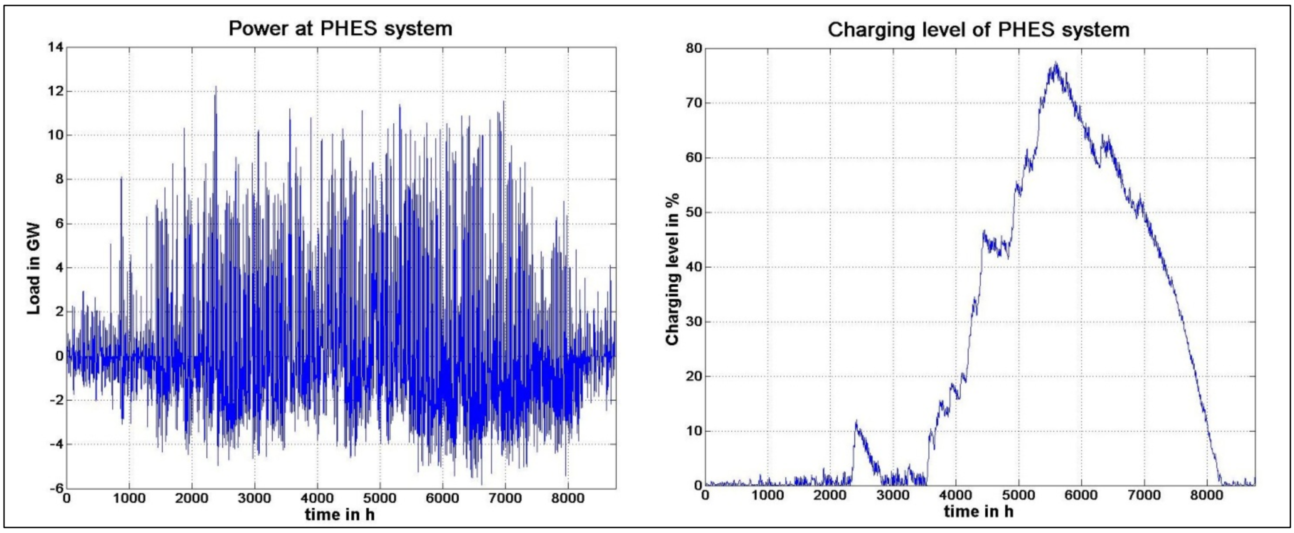

Figure 8: Power (left) and charging level (right) of the Austrian PHES system, 2050 scenario C (PHES expansion, source: HSU)

Table 6: Overview of results in the 2050 scenarios for Austria

2050 Scenarios		Stored Energy [GWh]	Provided Energy [GWh]	Capacity Factor			Max. Used Power [GW]	
				Charge	Disch.	Total	Charge	Disch.
B	24 h	5,539.32	4,499.02	6.87%	5.58%	12.46%	4.96	3.14
	48 h	6,088.11	5,135.19	7.55%	6.37%	13.93%	5.15	4.52
	200 h	8,364.93	6,720.35	10.38%	8.34%	18.72%	6.67	5.49
C	Existing PHES	10,204.47	8,281.92	12.66%	10.28%	22.94%	9.20	6.00
	Power Expansion	10,300.68	8,359.85	9.65%	10.37%	20.03%	12.18	6.00

Simulation Results for the Combined Electricity System of Austria and Germany

As it was highlighted within the analysis of the Austrian electricity system, there is still a high unused PHES potential in Austria. Therefore, in next step it has been investigated how much the Austrian PHES potential could help the German electricity system to handle its surpluses produced by a high feed-in from variable RES-E.

In all the investigated scenarios the capacity of the already existing Austrian reservoirs is high enough to take all the surpluses produced by German RES-E units, mainly wind and PV. However the installed amount of turbines and pumps is not enough to integrate all energy. For that reason an unlimited power extension (charging as well as discharging) has been simulated to show the maximum additional power that would be needed to fully integrate all RES-E in both countries. These scenarios are called AC_{full} and BC_{full} in the following.

Figure 9 shows the residual load after the use of the Austrian and German PHES systems in scenario BC_{full}. As can be seen the residual load never turns negative and surpluses from renewable energies can be fully utilised.

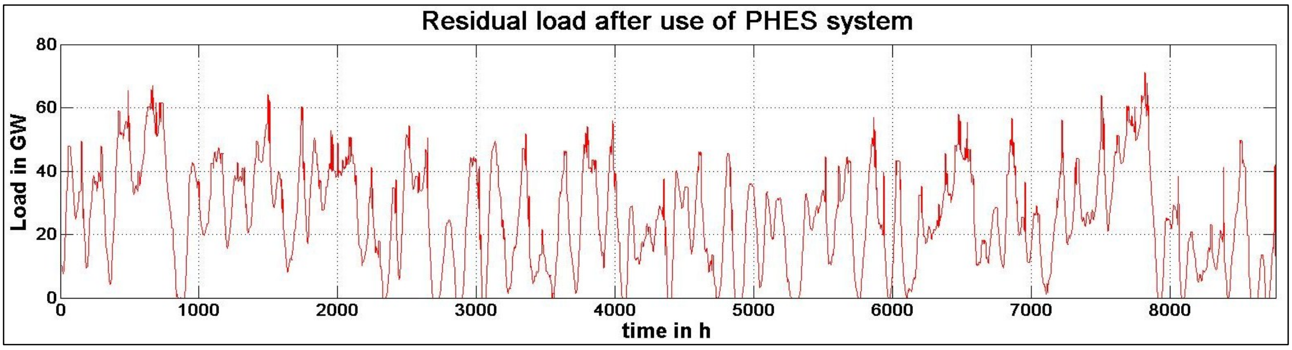

Figure 9: Residual load after the use of the Austrian and German PHES system, 2050 scenario BC_{full} (Source: HSU)

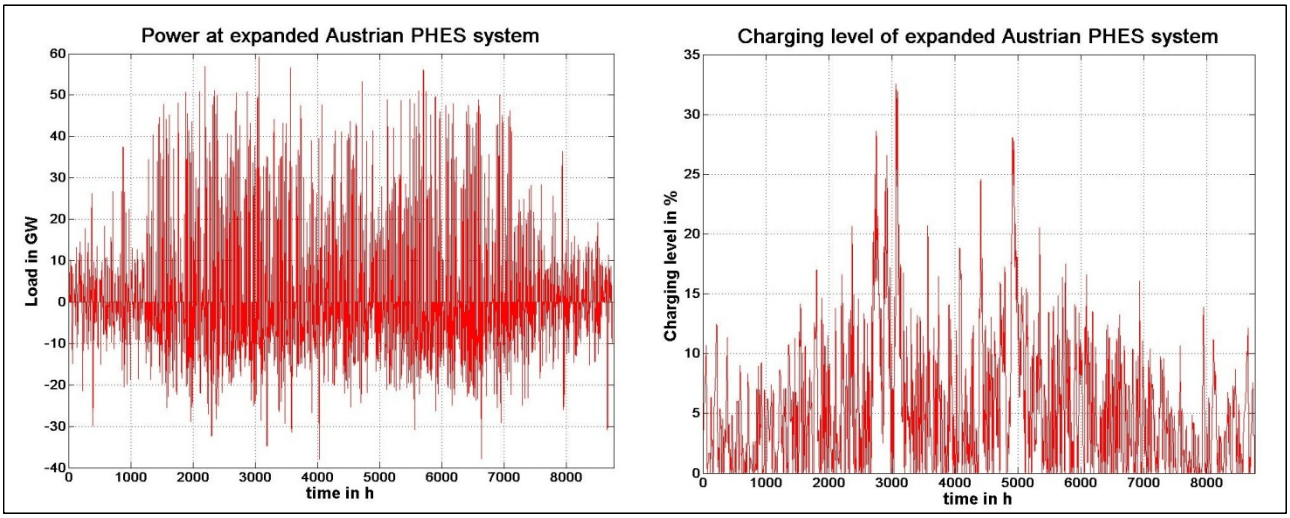

Figure 10 Power and charging level of expanded Austrian (below) PHES system, 2050 scenario BC_{full} (Source: HSU)

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The used power in charging (positive values) and discharging (negative values) mode as well as the needed capacity are shown in Figure 10. It can be stated that the installed power of the actual Austrian PHES system is exceeded by 42 GW in charging mode and 20 GW in discharging mode. Nevertheless, the capacity of the reservoirs is again just filled to maximum of less than 35%. Due to the combination of the German and the Austrian system the storage capacity needed in Austria is decreasing whereas the additionally needed power would increase strongly.

The outcomes of the simulation of AT-DE are summarized in Table 7. Without any power expansion the capacity factor of the Austrian as well as the German system is very high due to strong fluctuations also during times of positive residual load. Especially the German system is charged and discharged completely very often, which is leading to a capacity factor of 44% in scenario AC and 52% in scenario BC. The increased capacity factor in the second scenario is caused by the higher installed PV power and the resulting higher fluctuations of the residual load.

When looking at the scenarios with full exploitation of the Austrian PHES system, it can be observed the capacity factor is falling due to highly increased installed power. The capacity factor reaches 15% in scenario AC_{full} and 19% in scenario BC_{full}. As the capacity of the PHES system is not used to a high extend, the capacity factor could still be increased by participating in other (balancing) markets or by higher residual load smoothing.

As a final finding the difference in the used However, the capacity factor of the expanded Austrian PHES system is higher than the one of the additionally needed PHES system in Germany to cover the surpluses just in the islanded German system. Furthermore the additionally needed power in the islanded German system is much higher than the needed expansion of turbine and pump power in the PHES facilities in Austria in the combined system.

capacity of the Austrian PHES system in the single Austrian system and in the combined system with Germany has to be highlighted. Although also covering the high surpluses of renewable energies in the German system, the storage capacity used in the Austrian reservoirs is less than half. This indicates that the Austrian PHES system operates more economical when connected to the German system.

Table 7: Overview of simulation results for the 2050 scenarios AT-DE

2050 Scenario	Additionally needed power and capacity in combined system AT-DE			Additionally needed power and capacity in single German system		
	P_{charge}	$P_{discharge}$	E_{max}	P_{charge}	$P_{discharge}$	E_{max}
AC	19.17 GW	19.98 GW	0	38.79 GW	25.17 GW	1,534 GWh
BC	42.00 GW	20.51 GW	0	55.16 GW	29.04 GW	950 GWh
	Capacity factor					
	German PHES			**Austrian PHES**		
	Charge	Disch.	Total	Charge	Disch.	Total
AC	24.49%	19.80%	44.29%	25.22%	19.88%	45.10%
AC_{full}	24.42%	19.75%	44.17%	8.47%	6.57%	15.04%
BC	28.87%	23.35%	52.22%	25.88%	20.80%	46.68%
BC_{full}	28.79%	23.29%	52.08%	8.50%	10.80%	19.30%

Conclusions

Already in 2011 Austria had a high share of RES-E on the net electricity consumptions. This is mainly due to the great deployment of HPP (RoR and (P)HES in the Alps). As hydropower is a synchronous generation there are no grid stability problems when fossil-fired power plants are shut down and the whole electricity consumption is provided by hydropower and other variable RES-E.

Although the share of RES-E on the net electricity consumption was already at more than 60% in 2011, the Austrian government has ambitious targets for the further development of especially wind and solar power. In the GREEN scenario for 2050 the production of renewable energies exceeds the total load demand so that Austria is going to be net exporter of renewable energy.

To facilitate this RES-E expansion target Austria has already a high amount of PHES systems in place that is planned to be expanded continuously until the year 2050. However, to be able to integrate all projected RES-E in the GREEN scenario of 2050, our analyses showed that the installed power has to be developed even stronger. Large amounts of surplus electricity generation from variable RES-E (especially PV) lead to an increased need in charging / pumping power of PHES systems. Therefore, as the scenario outcomes show, pumping power will be needed more than turbine power. Especially when looking at a combined system of Austria and Germany is seems reasonable for developers to further extend and upgrade the existing Austrian (P)HES facilities.

However, in all cases investigated, the storage capacity of the Austrian reservoirs was high enough to fully integrate all RES-E. When upgrading the installed power accordingly, there is still a high storage potential left for Austrian PHES systems to participate in other (balancing) markets in different countries.

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1 Introduction

The information and discussions presented in this report are part of the European project stoRE (www.store-project.eu). stoRE aims to facilitate the realization of the ambitious objectives for high penetration of variable renewable energies in the European grid by 2020 and beyond, by unblocking the potential for energy storage technology implementation. In the stoRE project the focus of analysis and discussions is set predominantly on bulk energy storage technologies (EST), namely pumped hydro energy storage (PHES) and compressed air energy storage (CAES)[3].

Bulk EST are expected to be one of the key enabling technologies for the integration of large amounts of variable electricity generation from renewable energy sources (RES-E). In particular, the ability to quickly discharge large amounts of stored electricity or to reduce loads during certain points in time throughout a day (i.e. output smoothing)[4] can mitigate many challenges that arise from high shares of variable RES-E generation in the electricity system. Furthermore, bulk EST could also play an important role in optimising the physical and financial functioning of electricity markets and the corresponding commercial energy trading activities[5].

Work-package 5 (WP5) of the stoRE project aims to identify regulatory and market barriers to the development and operation of electricity storage systems (ESS) in the six target countries (Austria, Denmark, Germany, Greece, Ireland and Spain). For achieving that, this document, Deliverable 5.1 (D5.1), provides information about the electricity storage needs in each of the target countries necessary for integrating future RES-E generation in the incumbent electricity system.

This report is dealing with **Austria** (D5.1 – Austria) and is structured into three main parts.

Section 2 gives an overview of the Austrian electricity system – the status-quo in the year 2011 as well as future prospects until 2020 / 2050 of the Austrian electricity generation portfolio and the transmission grid system.

Section 3 of this report provides the development of the Austrian (hourly) residual load until the years 2020 and 2050 – a precondition for the following modelling exercise of the electricity storage needs.

In section 4, the analysis of the future electricity storage needs in Austria[6] is conducted, considering the existing electricity generation mix and transmission grid system (incl. planned development and reinforcements) along with the national plans for renewable energy development up to 2050. The necessity of new ESS and their feasibility from an energy point of view is investigated with the aid of simulations of mainland electricity system operation characteristics, using specially developed software. The produced qualitative and quantitative results highlight the need of energy storage in the future Austrian electricity system and show the benefits it can bring.

Overall conclusions from the analysis carried out in this report are drawn in section 5.

[3] For a complete picture of energy storage options see Deliverable 2.1 (Zach et al., 2012b) of the stoRE project, which also provides a brief overview of other (non-bulk) EST being outside the scope of stoRE.

[4] Other benefits of bulk EST, i.e. black start capability, area control, frequency response (secondary and tertiary control) etc., are described in Deliverable 2.1 in detail.

[5] See Deliverable 2.2 (Zach et al., 2012c) of the stoRE project for more details about the role of bulk EST in future electricity systems with high shares of RES-E generation.

[6] Due to the high potential of PHES in Austria also a further investigation of the combined electricity system of Austria and Germany is made.

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2 Overview of the Austrian Electricity System

2.1 Electricity Generation in Austria

2.1.1 Status Quo of the Electricity Generation System

Hydropower generation covered approximately 57% of Austrian electricity generation in the year 2011. It is the main electricity generation technology in Austria with an installed capacity of about 13,200 MW (see Table 8). In the past, Austria has developed a capacity of about 7,800 MW on (P)HES due to its geographical characteristics in the Alpine region. The key policy instrument at the national level to support RES-E technologies is the Austrian Green Electricity Act ("Ökostromgesetz", AGEA). After its adoption in 2002 and several following amendments, feed-in tariffs caused a particularly strong deployment of wind energy, biomass and biogas. However, with an actual installed wind capacity of around 1,100 MW, wind energy only accounts for about 3% of the total Austrian electricity generation in the year 2011. In total, RES-E had a share of about 65% on total electricity generation in Austria in the year 2011.

Table 8: Electricity generation system in Austria in the year 2011 (Source: E-Control, 2012)

Electricity Generation System in Austria 2011						
Power Plant Technologies			Count	Power Capacity [MW]	Electricity Generation [GWh]	Share on Total Electricity Generation
Hydro Power Plants (HPP)	Run-of-River	> 10 MW	90	4,433	21,024	31.95%
		< 10 MW	601	782	4,252	6.46%
	(P)HES	> 10 MW	67	7,615	11,996	18.23%
		< 10 MW	44	150	429	0.65%
	Other Small-scale HPP		1,869	221		
	Sum HPP		**2,671**	**13,200**	**37,701**	**57.29%**
Thermal Power Plants (TPP)	Fossil Fuels and Derivatives	Coal	4	1,171	5,315	8.08%
		Derivatives	7	444	1,931	2.93%
		Oil-Derivatives	11	362	1,179	1.79%
		Natural Gas	64	5,102	11,556	17.56%
		Sum	86	7,079	19,982	30.36%
	Biomass and Biogas		107	508	2,694	4.09%
	Co-Firing		10	497	2,086	3.17%
	Other TPP		380	166	1,071	1.63%
	Sum TPP		**583**	**8,249**	**25,832**	**39.25%**
	(of which CHP-units)		(185)	(6,599)	(21,063)	(32.00%)
RES-E	Wind[7]		656	1,084	1,934	2.94%
	Photovoltaics[8]		n.a.	187	174	0.26%
	Other RES-E		10,375	72		
	Sum RES-E		**11,031**	**1,343**	**2,108**	**3.20%**
Other Electricity Generation			n.a.	n.a.	170	0.26%
TOTAL			**14,285**	**22,793**	**65,812**	**100.00%**

[7] Data source for wind energy: IG Windkraft, 2012.

[8] Data source for PV: Biermayr et al., 2012.

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Table 9 gives an overview of the domestic electricity consumption in Austria in the year 2011. In total, about 74 TWh of electricity were consumed, including 5 TWh for pumping purposes in Austrian PHES systems. In general, Austria is a net importer of electricity. In the year 2011 the net import/export balance was about 8 TWh (imports).

Table 9: Domestic electricity consumption in Austria in the year 2011 (Source: E-Control, 2012)

Domestic Electricity Consumption in Austria 2011		
Category	Consumption [GWh]	Share on Total Consumption
Final Electricity Consumption	63,296	85,67%
Transmission Losses	3,472	4,70%
Station Supply	2,055	2,78%
PHES Consumption (Pumping)	5,060	6,85%
TOTAL	**73,883**	**100%**

2.1.2 Operation of (Pumped) Hydro Energy Storage Systems in Austria

The operational capability of Austrian (P)HES systems is strongly dependent on the available water resources, e.g. from natural inflow and snow water, in the reservoirs. When looking at the monthly storage capacities[9] for Austrian (P)HES systems in Figure 11, a typical sinusoidal-like development can be seen over a year, with the lowest available storage capacities around March / April and the highest available storage capacities in August / September.

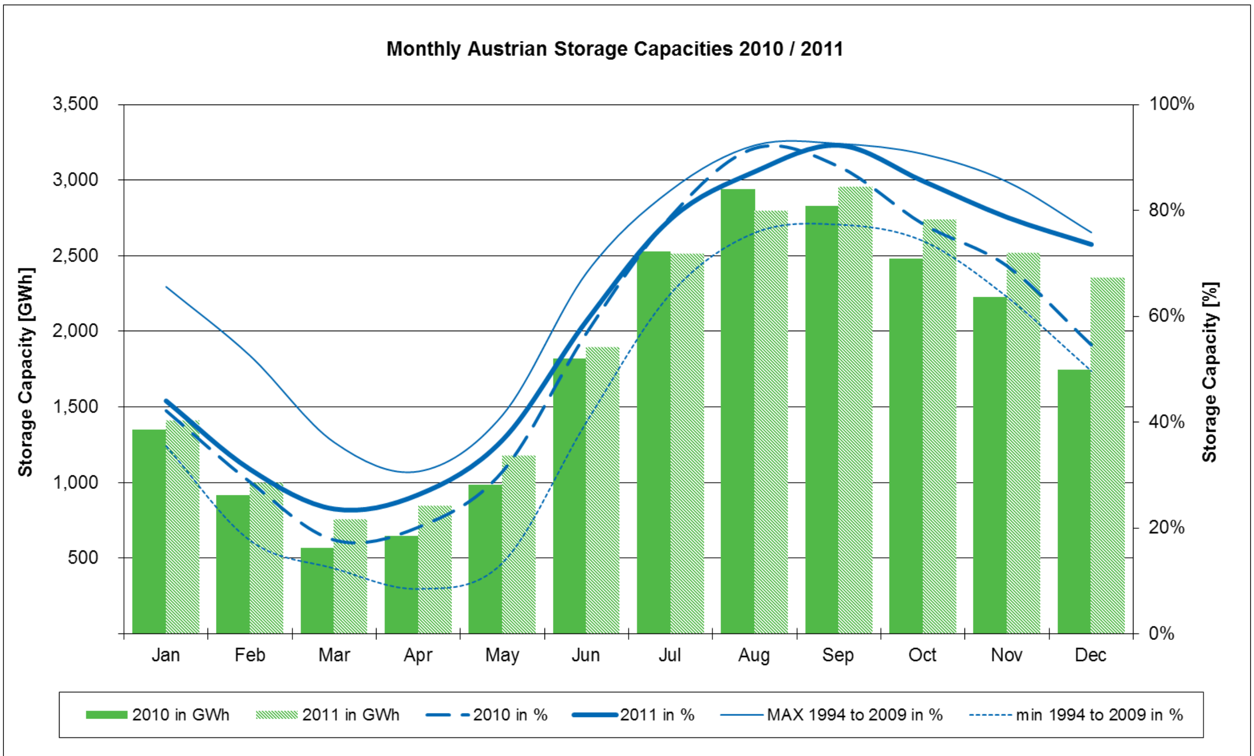

Figure 11: Comparison of the monthly Austrian storage capacities in 2009 and 2010 (Source: E-Control, 2012)

[9] These storage capacities include all (P)HES systems connected to the transmission grid system or with a power capacity of ≥25 MW. The values represent data from the last day of the respective month.

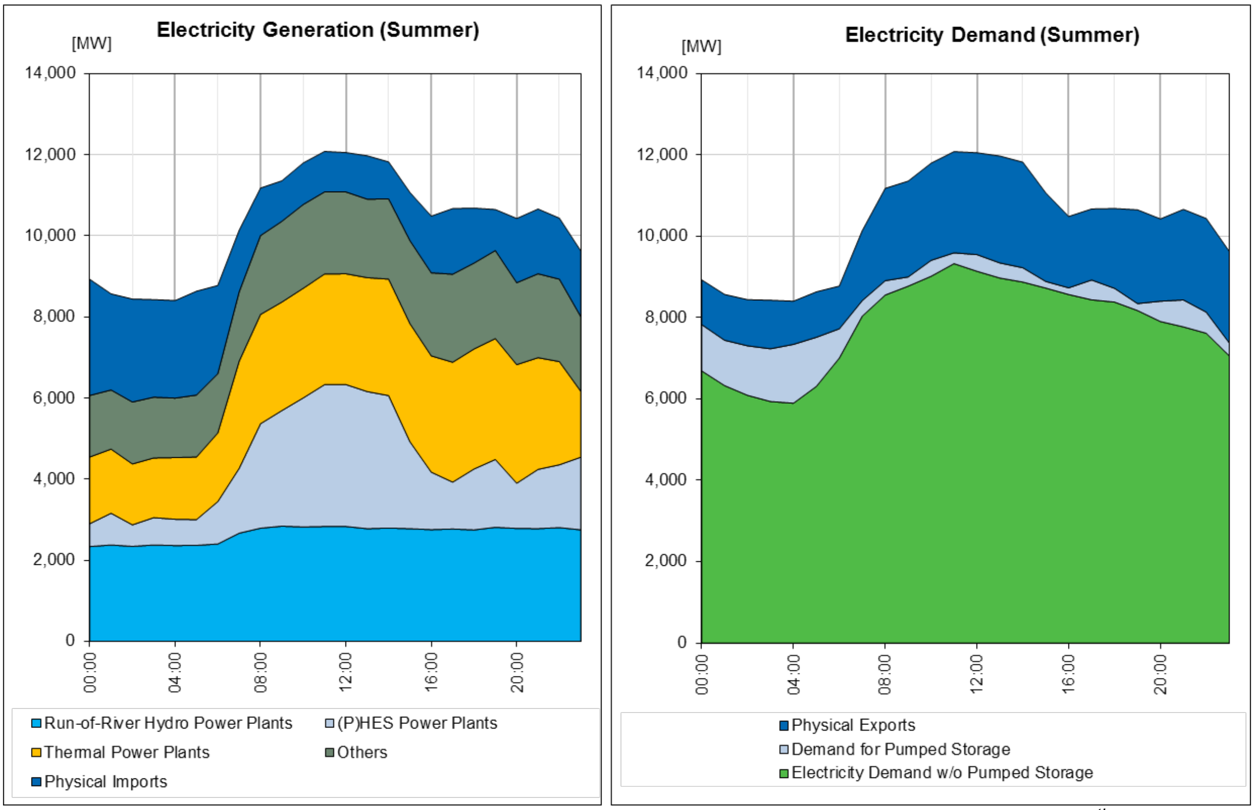

Figure 12: Austrian electricity generation (left) and demand (right) on typical summer day (20th July 2011), (Source: E-Control, 2012)

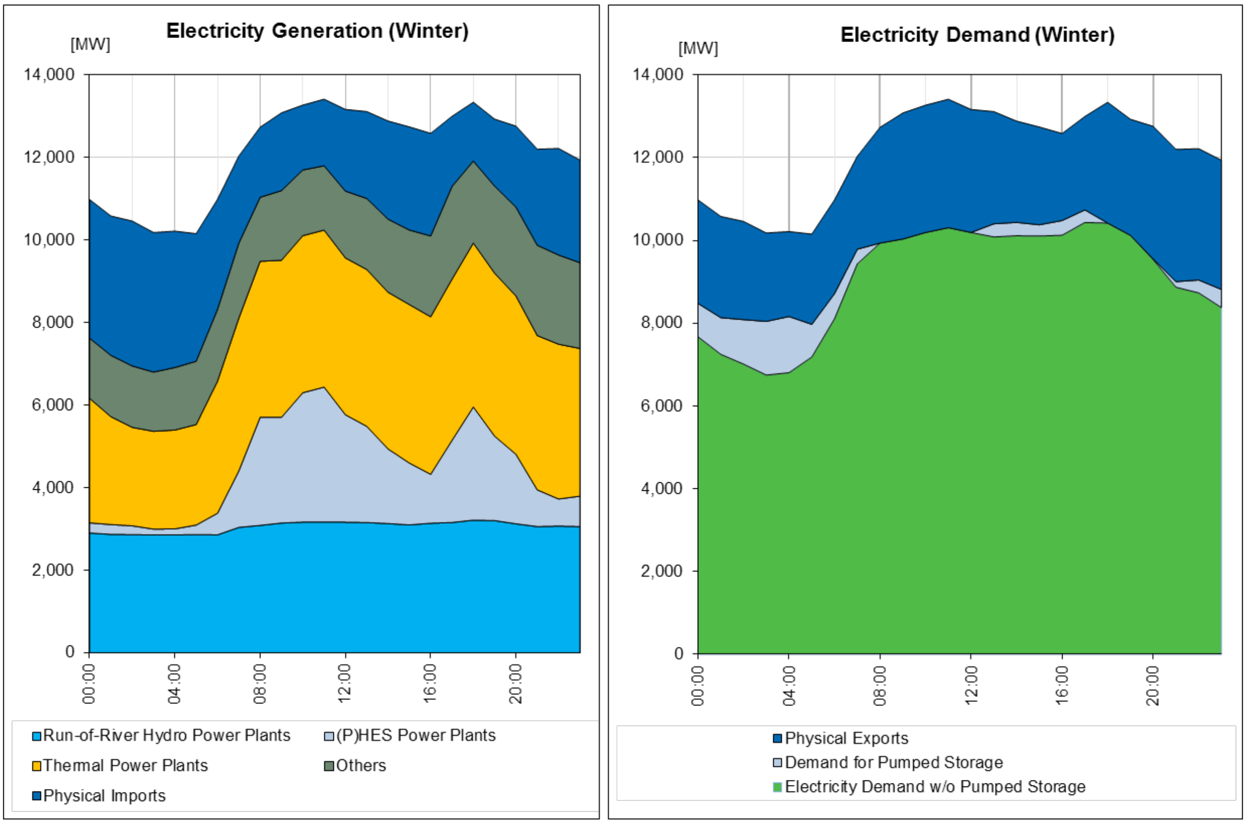

Figure 13: Austrian electricity generation (left) and demand (right) on typical winter day (19th January 2011), (Source: E-Control, 2012)

The Figure 12 and Figure 13 show the Austrian electricity generation and demand on a typical summer / winter day in the year 2011. It can be seen that in the Austrian electricity system the (P)HES power plants are operated to follow the electricity demand, while the other generation technologies form more or less stable generation-bands. Generally, large amounts of (P)HES power plants are operated in generating mode during peak-times while off-peak times, especially in the night, are used for “storing” electricity (pumping mode). Both days show a similar development of the generation with slightly shifted peaks towards later hours on the summer day. The summer day also sees a higher overall generation level of storage generation plants.

In 2011 Austria had an installed (P)HES capacity of about 7.7 GW in total (cf. Table 8). About half of this installed capacity for electricity generation (i.e. about 3.9 GW) is allocated to PHES systems. The pumping capacity of the Austrian PHES systems was about 2.9 GW in the year 2011.

2.1.3 Future Development of the Electricity Generation System

Austria still has a development potential for (small-scale) HPP and PHES - in combination with revitalization/repowering measures at existing power plants. Actually wind power is already strongly developed due to the good natural-space conditions in particular in the eastern part of Austria (Lower Austria, Vienna and Burgenland). Under consideration of the future transmission grid situation (see next section) further development potential also exists. PV and geothermal energy are currently of minor importance in Austria. However, with the further development of building-integrated PV systems, PV could also play a significant role in the future.

Table 10: Development of RES-E technologies according to the NREAP-AT (Source: Karner et al., 2010)

Development of RES-E Technologies in Austria (NREAP)					
RES-E Technology		**2005**	**2010**	**2015**	**2020**
HPP	[MW]	7,907	8,235	8,423	8,997
	[GWh]	37,125	38,542	39,423	42,112
Pumping (PHES)	[MW]	3,929	4,285	4,285	4,285
	[GWh]	2,738	2,732	2,732	2,732
Geothermal	[MW]	1	1	1	1
	[GWh]	2	2	2	2
PV	[MW]	22	90	179	322
	[GWh]	21	85	170	306
Wind	[MW]	694	1,011	1,951	2,578
	[GWh]	1,343	2,034	3,780	4,811
Biomass	[MW]	976	1,211	1,228	1,281
	[GWh]	2,823	4,720	4,826	5,147
Renewables in Electricity	**[MW]**	**9,600**	**10,547**	**11,781**	**13,179**
	[GWh]	**41,314**	**45,383**	**48,200**	**52,377**
Gross Final Electricity Consumption	**Reference**	**66,581**	**65,523**	**70,838**	**77,525**
	Efficiency	**66,581**	**65,523**	**67,651**	**74,164**

Table 10 presents the estimation of total contribution (installed capacity, gross electricity generation) expected from each RES-E technology in Austria to meet the binding EU-2020 targets (EU Directive 2009/28/EC) according to the National Renewable Energy Action Plan of Austria

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(NREAP-AT, Karner et al., 2010). Further on, also the gross final electricity demand is given in Table 10 for the two different scenarios defined in NREAP-AT: a reference and an efficiency scenario. The resulting share of RES-E generation on final consumption in the year 2020 is about 67.6% for the reference scenario and 70.6% for the efficiency scenario respectively.

However, the new Austrian RES legislation changes some of the RES deployment ambitions up to 2015 and 2020 for some of the RES technologies, notably PV generation. A main difference in the amendment of the AGEA 2012 (Ökostromgesetz - Novelle 2012, BGBl I Nr. 75/2011) is that the PV deployment target is significantly increased to an additional 500 MW on PV capacity from 2010 until 2015 (compared to 17 MW previously) and 2 GW until 2020 respectively. Table 11 summarizes the targets of additional RES-E deployment until 2015/2020 according to the AGEA 2012.

Table 11: Targets of additional RES-E deployment according to the Austrian Green Electricity Act 2012 (Source: OESG, 2011)

RES-E Technology		2015	2020
HPP	[MW]	700	1,000
	[GWh]	3,500	4,000
PV	[MW]	500	1,200
	[GWh]	500	1,200
Wind	[MW]	700	2,000
	[GWh]	1,500	4,000
Biomass & Biogas	[MW]	100	200
	[GWh]	600	1,300
Additional RES-E	**[MW]**	**2,000**	**4,400**
	[GWh]	**6,100**	**10,500**

For the long-term development of the electricity generation system, the Energy Economics Group (EEG) generated future RES-E deployment scenarios until the year 2050 based on modelling results derived from the Green-X RES-E deployment simulation tool[10]. Green-X provides future scenarios on annual RES-E capacity installations and electricity generation per country under a variety of different possible policy settings and constraints. Two different future deployment scenarios of the (European) electricity generation system[11] were generated and further enhanced by incorporating several results of studies on national and European level[12]: A business-as-usual scenario (BAU) with moderate increase of RES-E deployment and an environmental friendly scenario (GREEN) with high increase of RES-E deployment. In the BAU scenario the national EU-2020 are reached late somewhere around the year 2030, whilst the GREEN scenario foresees a similar RES-E expansion as in the NREAPs.

[10] Used and updated within many European projects within the last 10 years (e.g. recently: RE-Shaping www.reshaping-res-policy.eu/). See www.green-x.at and Huber et al. (2004) for more details.

[11] These scenarios were also used / derived for the analysis in work-package 2 of the stoRE project which focused on the contribution of ESS in nine different European electricity regions; see Zach et al. (2012a) for more details.

[12] E.g. PLATTS database (PLATTS, 2010), NREAPs (Beurskens et al., 2011), ENTSO-E's system adequacy forecast (ENTSO-E, 2010), FP7 project "SUSPLAN" (www.susplan.eu), etc.

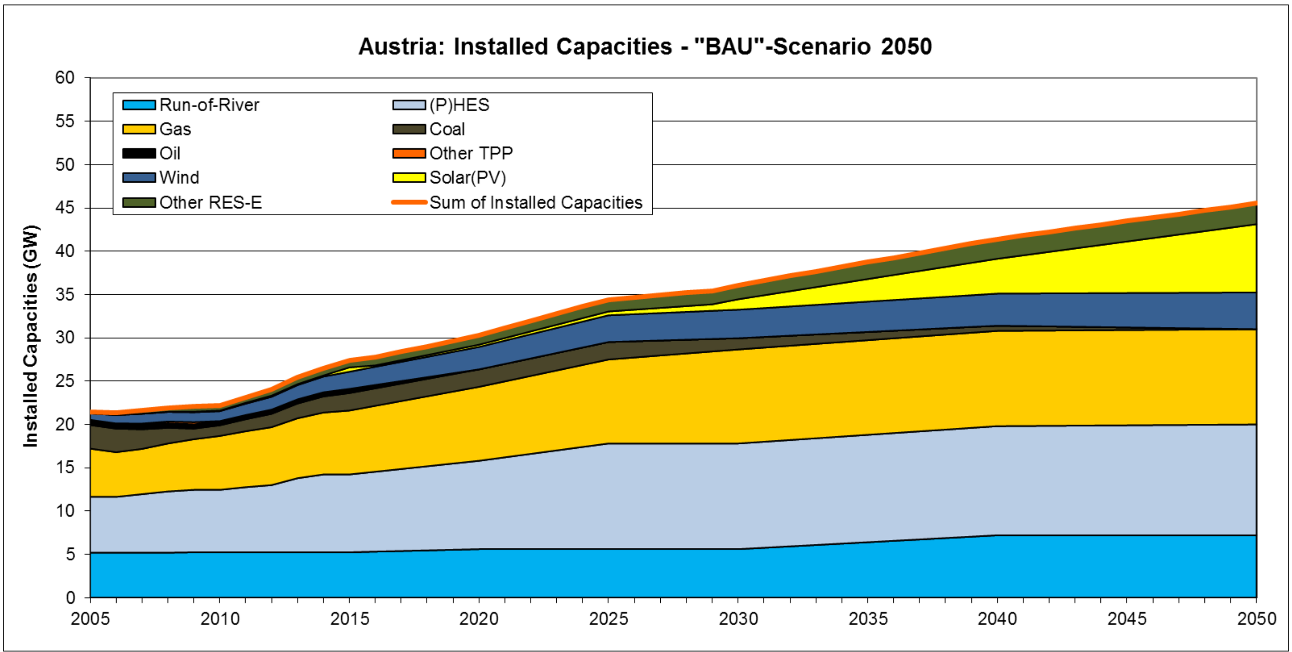

Figure 14: Development of the installed capacities of the Austrian electricity generation system until 2050 in the BAU scenario (Source: EEG)

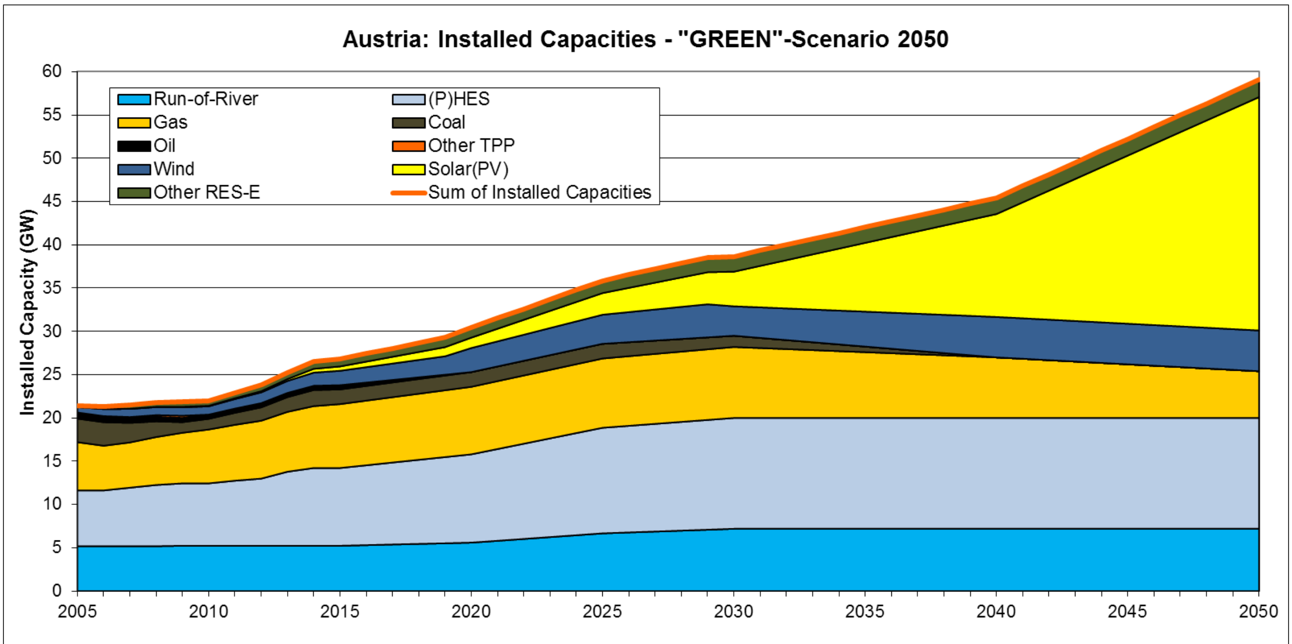

Figure 15: Development of the installed capacities of the Austrian electricity generation system until 2050 in the GREEN scenario (Source: EEG)

The generated (long-term) development of the installed capacities in the Austrian electricity generation system is given in Figure 14 and Figure 15 for the BAU and GREEN scenario respectively. Beginning with the year 2030, both scenarios show a rapidly increasing deployment of PV installations in Austria, whilst other RES-E technologies (wind and biomass) cannot increase their capacities significantly. In the GREEN scenario the installed PV capacities reach about 27 GW in the year 2050. Both scenarios see a face-out of coal and also oil-fired TPP until 2040 in the GREEN and 2040 in the BAU scenario respectively. Gas-fired TPP will continue to be a main part

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of the Austrian electricity generation system in the BAU scenario, whereas in the GREEN scenario their share is decreasing until 2050. Installed HPP capacities are equally expanded in both scenarios and reach about 20 GW in the year 2050.

2.2 Transmission Grid System of Austria

2.2.1 Status Quo of the Transmission Grid System

Since 2012 the whole Austrian transmission grid system is operated by the Austrian Power Grid AG (APG). It has an overall system length of over 6,700 km and is divided into three voltage levels: 380 kV, 220 kV and 110 kV.

The Austrian transmission grid system is characterised by its ring structure (see Figure 16). After the so-called “Steiermarkleitung” has taken up operation in mid-2009, the gap of the Austrian 380-kV-ring in the eastern part of Austria has been closed. But still weak spots remain in the western transmission grid areas; particularly the north-south connection St. Peter-Salzach-Tauern (“Salzburgleitung”), the lines to Germany and the Zell / Ziller transformer. Furthermore, the Lienz-Soverzene line represents a structural congestion in the southern part of Austria, which at present can only be managed by different congestion management measures like the implementation of phase-shifting transformers (cf. Figure 17).

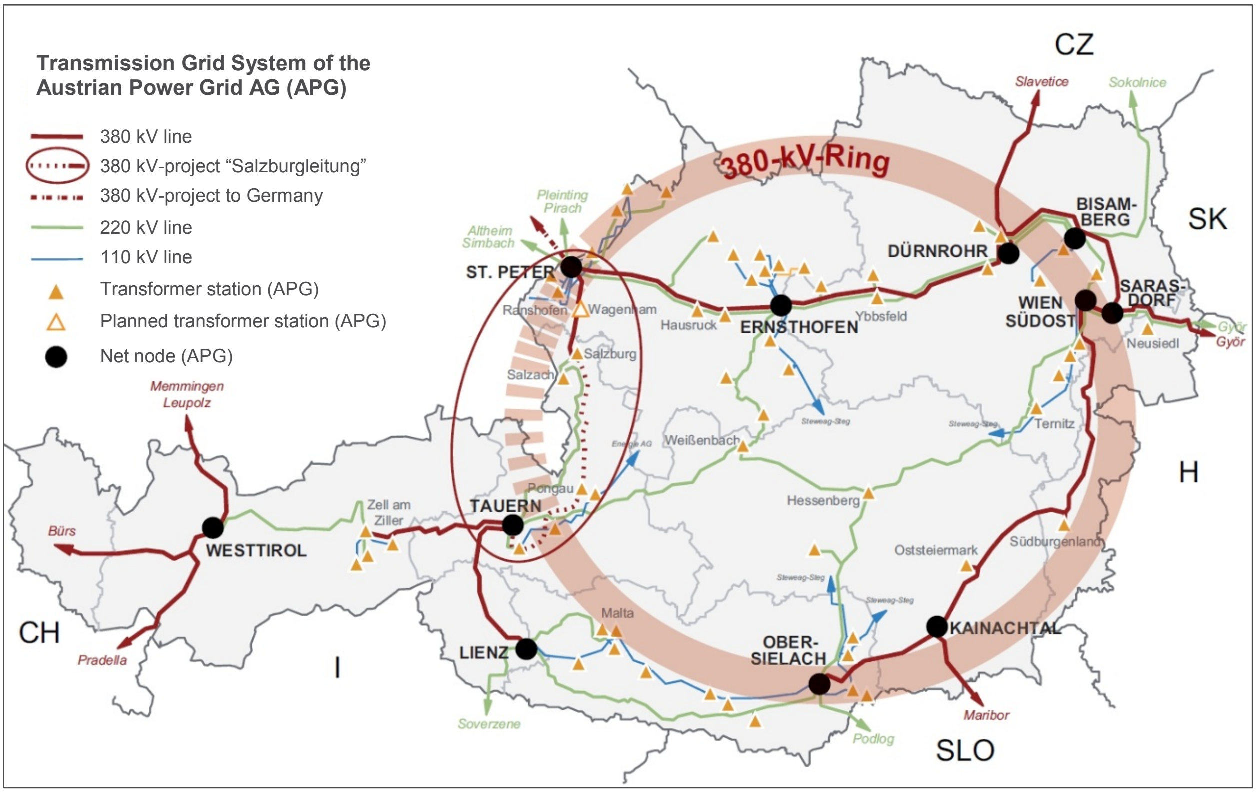

Figure 16: Status quo of the Austrian electricity transmission grid in the year 2011 (Source: APG, 2011)

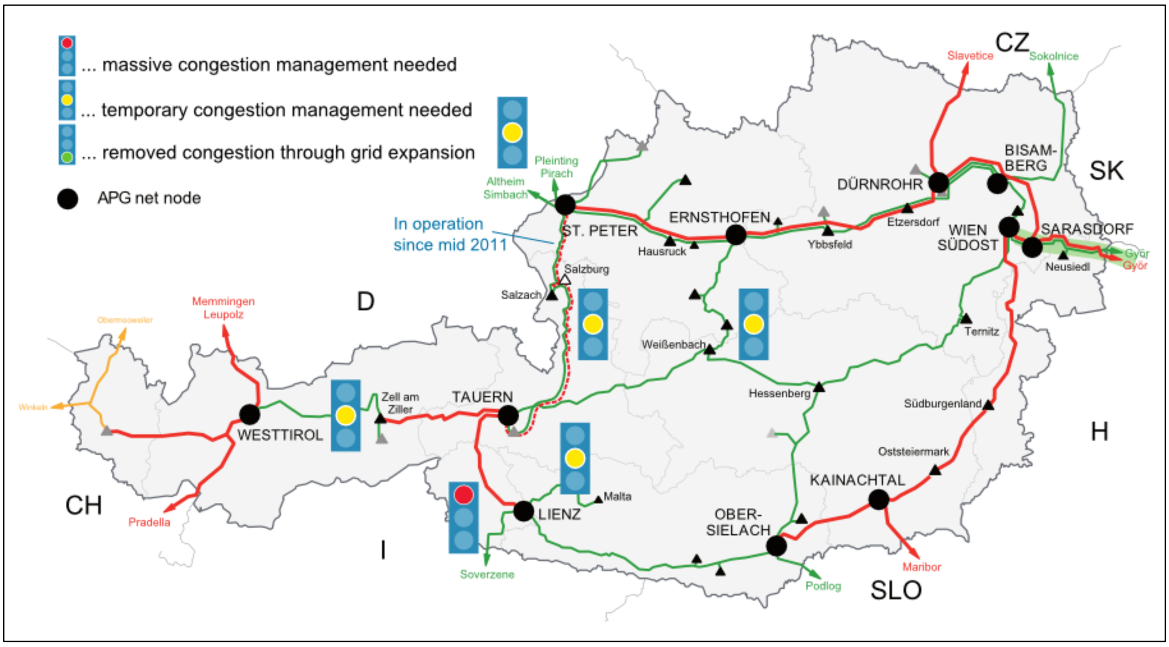

Figure 17: Status quo of the Austrian transmission grid in year 2011; still open "380-kV-ring" and congestions. (Source: APG, 2011)

2.2.2 Future Transmission Grid Expansion

An important driver for further transmission investments is the implementation of the still unexploited RES-E generation potential in Austria. The two major candidates of RES-E generation technologies expecting significant investments into transmission capacities are (pumped) hydro power plants, on the one hand, and wind power plants, on the other hand (cf. Figure 18):

- PHES systems have been playing an important role already in the last decades due to the fact that they guarantee a high degree of flexibility of the electricity systems not only in Austria but also in the neighbouring countries (e.g. economically attractive "peak-base" exchange contracts with Germany). In the future, the provision of flexible reserve capacities and balancing power demanded by large-scale onshore and offshore wind integration into the Central European electricity systems is expected to enable further attractive business opportunities for additional PHES capacities (e.g. Kaprun-Limberg II & III etc.).
- The most attractive Austrian wind power plants already in operation (and also still not exploited wind potentials) are largely located in the eastern part of the country ("Parndorfer Platte"), flexible PHES potentials in the western part ("Alps") and, last but not least, there is a lack of sufficient transmission capacities between these two areas. Therefore, incentives to further increase "east-west" transmission capacities in Austria are supposed to be evident.

In the near future, according to "APG Masterplan 2020" (APG, 2011), the latest version of the official 10 years generation and transmission adequacy forecast of the Austrian TSO APG[13], up to 5,000 MW of new PHES installations are envisaged up to 2020. Moreover, according to "APG Masterplan 2020" also significant investments into the Austrian transmission grid are planned within the footprint of APG in the upcoming years (closure of the so-called "Austrian-Ring" up to year 2020 as well as on the different interconnectors to the neighbouring countries). This is also

[13] An updated version of the "APG Masterplan" is due beginning of 2013.

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based on the expectation that Austria's high shares and still unexploited future potentials on PHES can be better connected with the high wind potentials in Northern Europe and the high solar-CSP potentials in Southern Europe. The strategic development of the Austrian transmission grid, therefore, is a precondition to enable this.

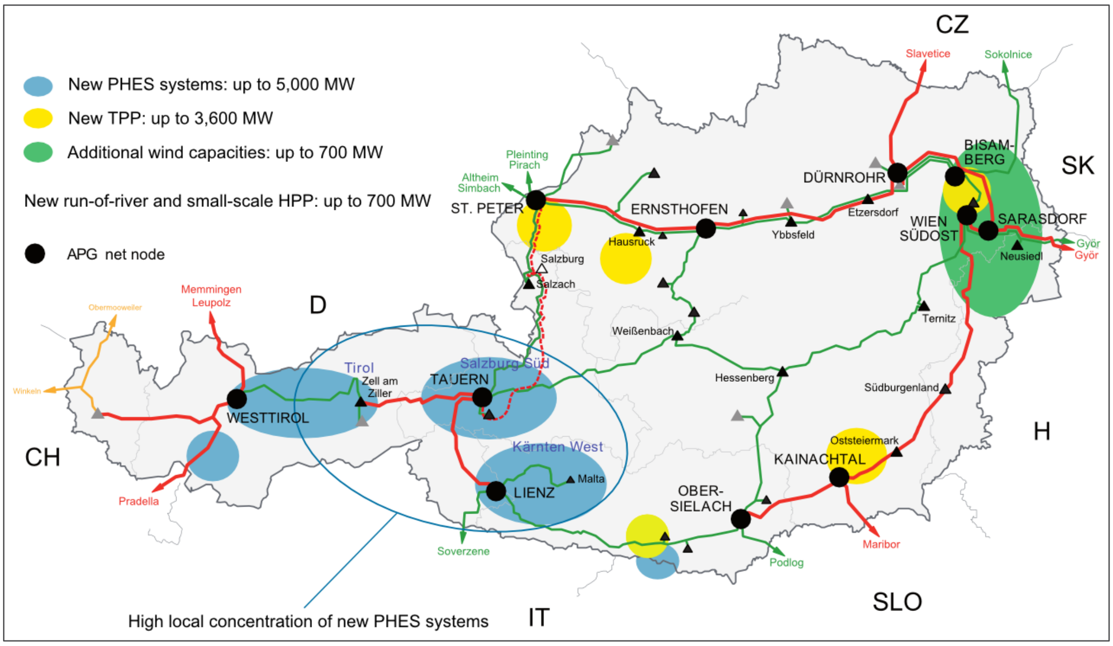

Figure 18: Expansion plans of the major RES-E and TPP capacities in Austria up to 2020 (Source: APG, 2011)

In terms of the topography of the Austrian transmission grid this means that – compared to the status quo in 2011 (see Figure 17) – the missing transmission links "north-south / south-east" and "east-west" need to be closed. Moreover, this means that up to 2020 the so-called "Austrian Ring" shall be finally implemented (see Figure 19).

Grounded on the expected finalisation of the "Austrian Ring" inside the country towards 2020/2025, the following cross-border transmission capacity developments are most probable on the Austrian borders in the next 1-2 decades (see Figure 20 below):

- On the one hand, increased cross-border transmission capacities are supposed to be necessary in several of the 4-5 Austrian borders in order to be able to handle future Central European power trades in both directions "north-south" and "east-west". Developments like these, however, have to be analysed in a wider context, i.e. ENTSO-E's overall strategies to further develop the transmission grid in Central Europe.
- On the other hand, the so-called "Brenner-Basis-Tunnel" project (railway project with two tunnels) is supposed to be a perfect occasion to implement a HVDC line in the pilot/ancillary tunnel being necessary for the purpose of soil and rock analysis in the construction phase of the project. A HVDC link crossing the Alps finally would be the ultimate solution to solve the lacking connection of Italy towards the northern countries Austria and Germany.

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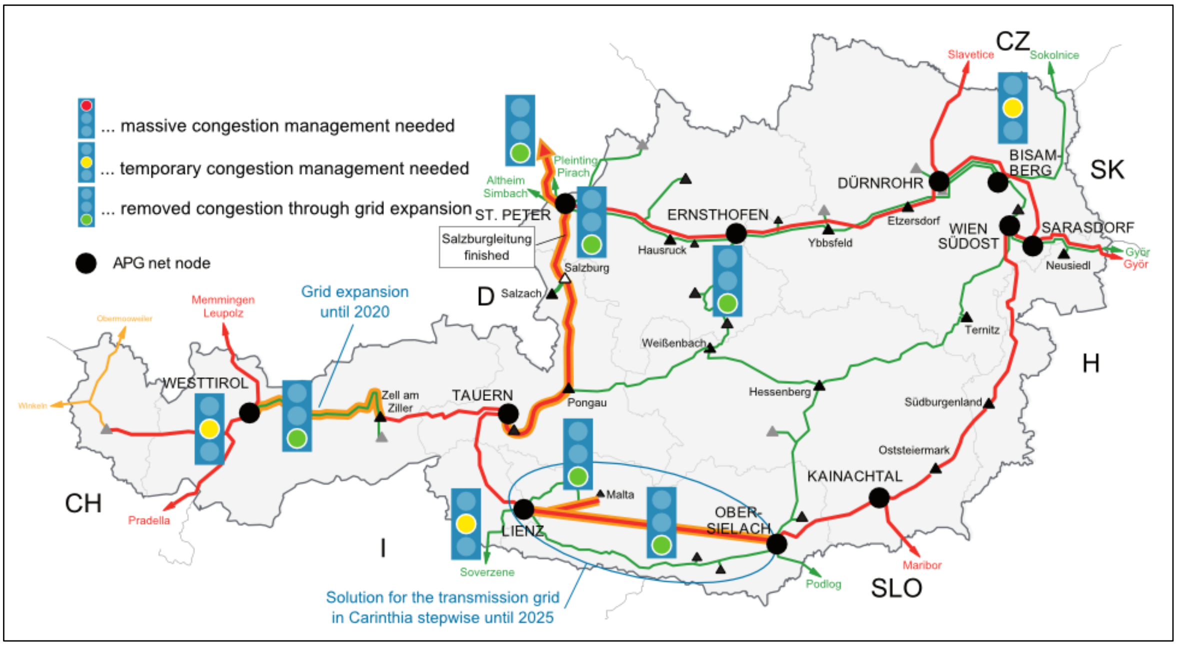

Figure 19: Planning Austrian transmission grid in year 2020/2025; fully closed "380-kV-ring" (Source: APG, 2011)

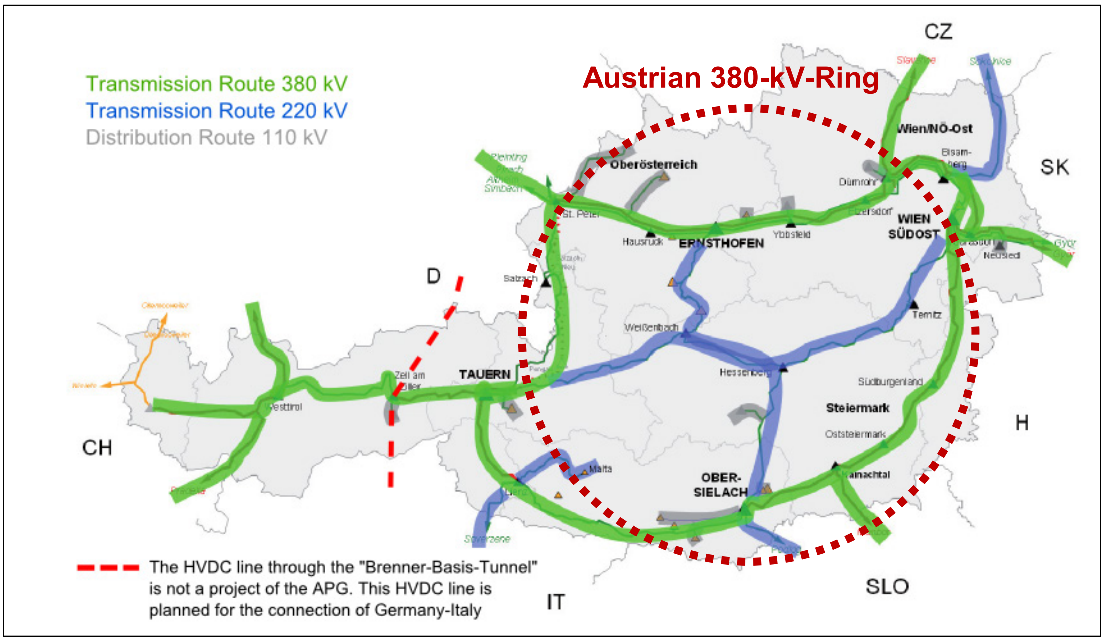

Figure 20: Expected transmission routes (incl. indication of possible HVDC line of "Brenner-Basis-Tunnel") in Austria in year 2020 and beyond (Source: VERBUND-APG, 2009)

3 Development of the Residual Load

3.1 Input Data and Scenario Assumptions for the Analysis

Before analysing the future electricity storage needs in Austria, the development of the (hourly) residual load until 2020 and 2050 has to be studied as a precondition. For this, hourly data sets for the different RES-E technologies and the electricity load of the year 2011 were taken as input and linearly scaled up to 2020 and 2050 respectively.

The data used for the hourly HPP generation and the electricity load were provided by *E-Control*, the regulatory authority of Austria. The data include only electricity generation units with an installed capacity of more than 25 MW (cf. Figure 21). However, this is enough to get the generation curves of the different hydropower production units, namely Run-of-River (RoR), Hydro Energy Storage (HES) and Pumped Hydro Energy Storage (PHES). Concerning hydropower, these units covered by the *E-Control*-data generated about 19 TWh in 2011 - yet, all hydropower plants in Austria produced a total of 25.28 TWh in the year 2011. Therefore, for the following investigations the measured generation curves have been scaled up to reach the total hydropower production, namely with a factor k_{RoR}=1.33.

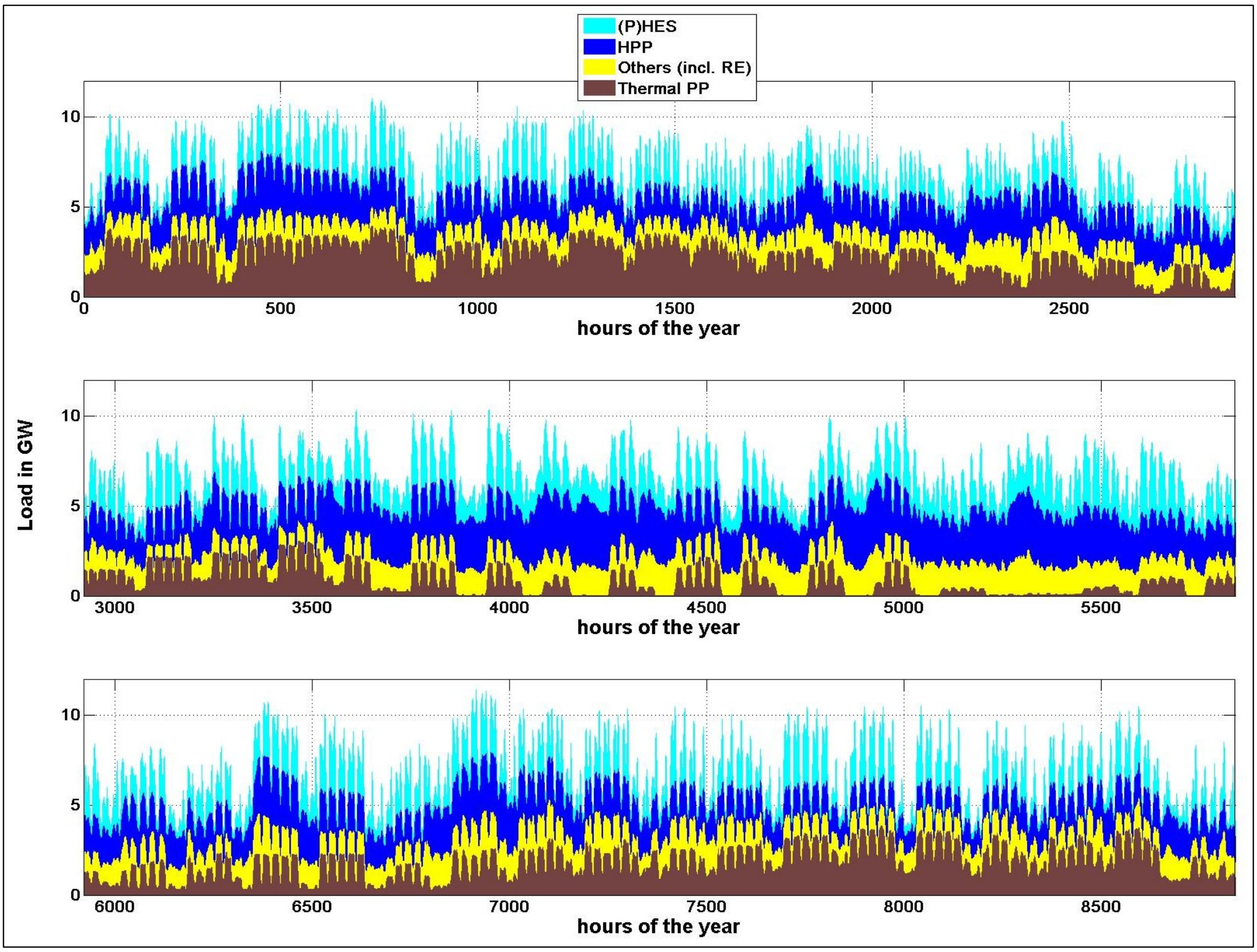

Figure 21: Hourly electricity generation profile in Austria in the year 2011 (Source: E-Control, HSU)

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Since Austrian wind and solar electricity generation are not covered by the used data of *E-Control*, real wind feed-in data was used from the Austrian TSO APG from the year 2011. For hourly photovoltaic generation, the global radiation density, provided by the German and Austrian weather service, was used to calculate the actual feed-in curves of the different scenarios.

As can be seen in Figure 21, which shows the hourly electricity generation profile of Austria in the year 2011, even in 2011 Austria's electricity supply system was able to handle a complete absence of thermal production units for some times. Therefore, it is assumed that for all scenarios the Austrian electricity supply system will be flexible enough to handle 100% load coverage by renewable sources.

Table 12 provides an overview about the RES-E deployment and electricity load development in the different scenarios investigated. In total six different cases are analysed in detail. For the year 2020, three different scenarios are analysed: scenario A, which complies with the NREAP-AT (cf. Table 10), scenario B, corresponding to the BAU Scenario of EEG (cf. Figure 14), and scenario C, corresponding to the GREEN scenario of EEG (cf. Figure 15). Also for the year 2050 three different scenarios are investigated. Besides scenarios B and C (i.e. BAU and GREEN scenario of EEG), scenario A investigates the possible contribution of the Austrian (P)HES plants to the combined / coupled Austrian-German electricity system in the year 2050 (see section 4.3). It can be seen, that in scenarios A and B the same deployment of HPP capacities is assumed (e.g. 6.6 GW of PHES in 2020 and 9.2 GW of PHES in 2050), while the deployment of other RES-E technologies (especially of PV) and also the electricity demand differ. While in scenario B a RES-E share of only about 60% is reached in the year 2050, in scenario C Austria gets a net exporter of RES-E with a RES-E share of over 110%.

Table 12: Overview of the scenario assumptions

<table>
<tr><th rowspan="2">[MW]</th><th rowspan="2">Ref. (2011)</th><th colspan="3">2020 Scenarios</th><th colspan="3">2050 Scenarios</th></tr>
<tr><th>A</th><th>B</th><th>C</th><th>A</th><th>B</th><th>C</th></tr>
<tr><td>Wind (onshore)</td><td>1,084</td><td>2,578</td><td>2,589</td><td>2,780</td><td rowspan="13">AT + DE</td><td>4,240</td><td>4,710</td></tr>
<tr><td>PV</td><td>187</td><td>322</td><td>264</td><td>1,200</td><td>7,880</td><td>26,960</td></tr>
<tr><td>Hydropower</td><td></td><td></td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td>Run-of-River</td><td>5,215</td><td>5,400</td><td colspan="2">5,600</td><td colspan="2">7,200</td></tr>
<tr><td>HES</td><td>3,550</td><td>3,597</td><td colspan="2">3,600</td><td colspan="2">3,600</td></tr>
<tr><td>PHES</td><td>4,215</td><td>4,285</td><td colspan="2">6,600</td><td colspan="2">9,200</td></tr>
<tr><td>Small Hydropower</td><td>221</td><td>221</td><td colspan="2">221</td><td colspan="2">250</td></tr>
<tr><td>Other RES-E</td><td>72</td><td>1,115</td><td>1,100</td><td>1,150</td><td>2,430</td><td>2,000</td></tr>
<tr><td>Yearly Peak Load</td><td>11.3</td><td>12.8</td><td>14.9</td><td>12.4</td><td>20.7</td><td>13,6</td></tr>
<tr><td colspan="5"></td><td colspan="2"></td></tr>
<tr><td>Energy Consumption [TWh]</td><td>68.8</td><td>77.5</td><td>90.9</td><td>75.6</td><td>126</td><td>83</td></tr>
<tr><td>RES-E Generation [TWh]</td><td>39.81</td><td>52.4</td><td>54.8</td><td>56</td><td>75</td><td>94</td></tr>
<tr><td>RES-E Share[14]</td><td>60.6%</td><td>67.6%</td><td>60.3%</td><td>74.1%</td><td>59.3%</td><td>113.3%</td></tr>
</table>

[14] On net electricity consumption, not production

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3.2 Results for the Residual Load Development

The residual load for the different years and scenarios is obtained by subtracting the hourly wind, PV, other RES-E and hydro-RoR electricity generation from the corresponding electricity load. The results of this calculation are depicted in Figure 22 for different scenarios and years. It can be seen that due to low RES-E deployment and high demand increase in scenario B (i.e. BAU scenario, top two graphs in Figure 22) the residual load hardly reaches zero or negative values in the years 2020 or 2050. On the contrary, the residual load in scenario C (i.e. GREEN scenario, bottom graph in Figure 22) shows very high amplitude fluctuations and many negative values. This can be explained by the very high installed PV capacities (nearly 27 GW) and the low peak loads (annual maximum of 13.6 GW - about half of the installed PV capacity) in this scenario.

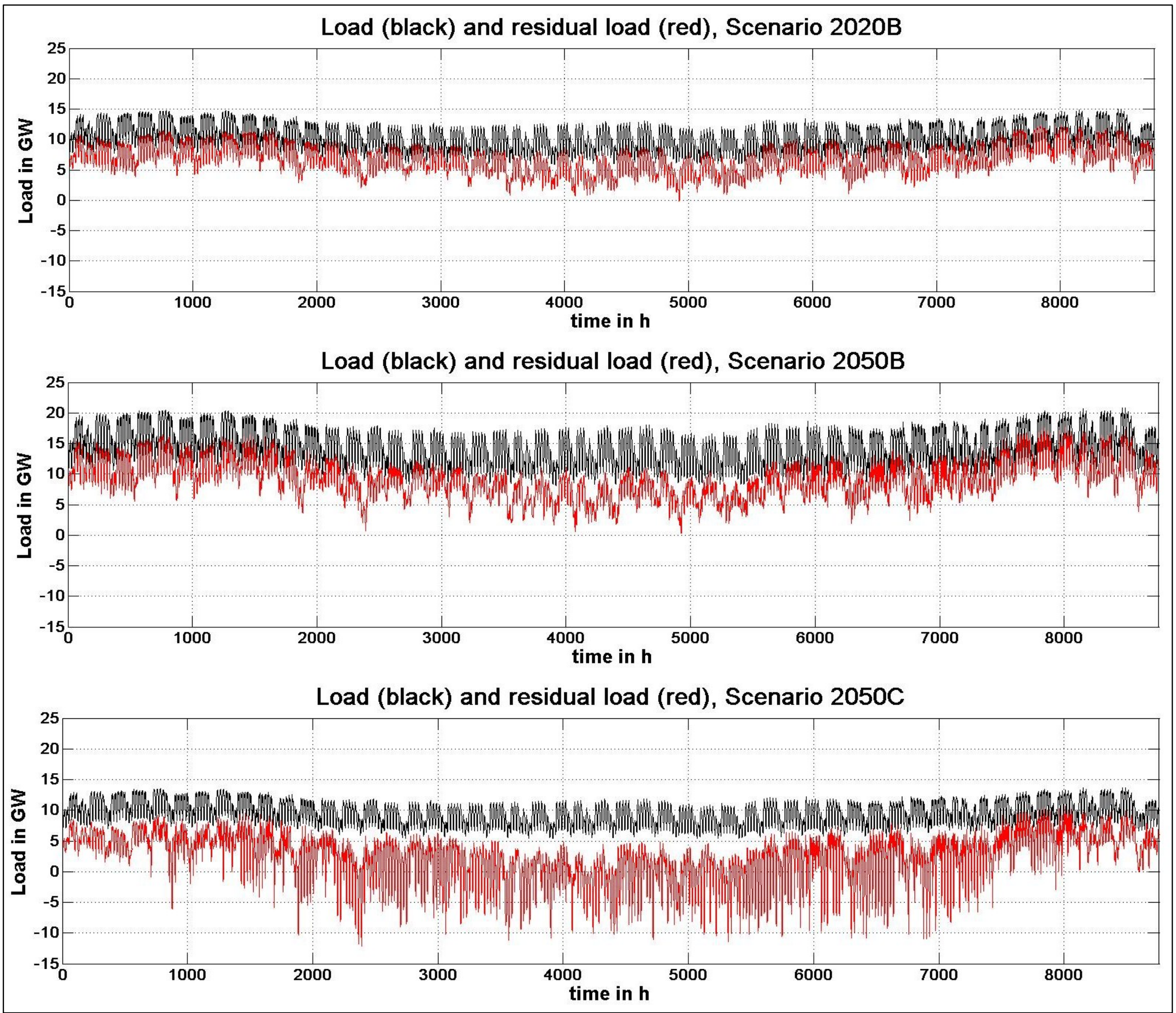

Figure 22: Load (black) and residual load (red) curves for different scenarios in Austria (Source: HSU)

Due to the higher share of variable RES-E (especially PV) the system load variations increase strongly in all scenarios. As an example, Figure 23 shows load variations of scenario C in the year 2020 and 2050. The 2020 residual load variations during 1 hour are about 5 GW; due to the

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influence of variable RES-E this limit increases to about 15-20 GW in the year 2050 (cf. Figure 23). Whereas the fluctuations of load demand and residual load reach a maximum of about 20 GW / 8h in 2020, the fluctuations of the residual load become more than 50 GW / 8h in the year 2050 (cf. Figure 23). A similar behaviour can be found in scenarios A and B, but due to lower RES-E deployment in these scenarios the increase of load fluctuation is smaller than in scenario C.

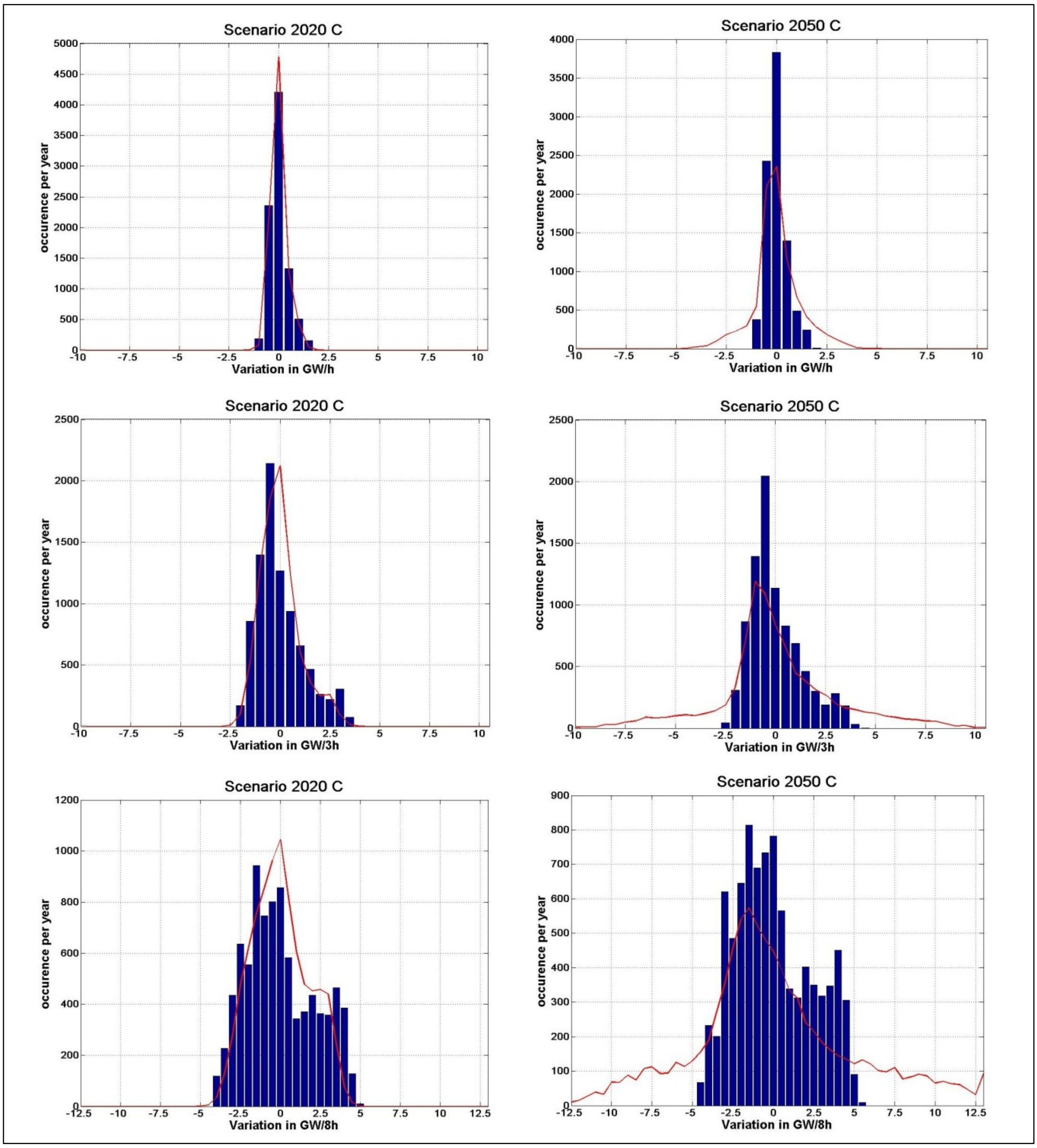

Figure 23: Variations of load demand (blue bars) and residual load (red line) for scenario C in the year 2020 (left) and 2050 (right) (Source: HSU)

Table 13 summarizes the results of the residual load analysis and shows the maximum rejected power and energy in the different scenarios. While rejections increase considerably (by a factor 10) in scenario C between 2020 and 2050, rejections in scenario B reach zero in 2050. This again can be explained by the high demand increase and low RES-E deployment in comparison to the other scenarios. However, the maximum rejected power as well as the rejected energy is always higher in the GREEN scenario C. In 2050 the rejected power is almost as high as the peak load and the rejected energy would be almost 10% of the total energy production from renewable sources.

Table 13: Overview of the outcomes of the residual load analysis

Scenario	Max. rejected power [MW]	Rejected Energy [GWh]
2020 A	898.73	3.56
2020 B	134.35	0.19
2020 C	1,340.90	11.91
2050 B	0	0
2050 C	12,185.30	7,694.20

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4 Storage Needs

In the following the 2020 and 2050 scenarios for Austria (and two 2050 scenarios for Austria-Germany) described beforehand are investigated in respect to their electricity storage needs for the complete integration of all energy from (variable) RES-E generation. For that purpose an algorithm was developed by the Helmut-Schmidt-University (HSU) to calculate the electricity storage needs from an electricity system point of view - this implies that there are no market models or economic considerations made within the algorithm. The main aim of the operation of the electricity storage system (ESS) in the analysis therefore is, on the one hand, the smoothing of the residual load as far as possible to allow an easier and safer planning of the operation of the remaining power plants and to integrate the rejected (surplus) RES-E on the other hand. A brief explanation about the implemented optimization algorithm can be found in the following section – for a more detailed description it is referred to “Deliverable 5.1 – Germany” (Weiß, 2013) of the stoRE project.

4.1 Computer Modelling

The computation methodology follows two steps. First, the residual load for the scenario under investigation is calculated (see previous chapter). The second step is the calculation of the overall storage needs. For this purpose an algorithm was developed at the HSU to estimate the electricity storage needs just from a system point of view. The aim of the energy storage facilities in this approach is to integrate the maximum amount of RES-E possible without any focus on the electricity spot market price.

The residual load is defined as the load demand minus the non-controllable RES-E generation. In the case of Austria the non-controllable generation from RES-E includes wind energy, photovoltaic and RoR HPP. As an example the residual load curve of Austria in the 2050 scenario C is shown in Figure 24.

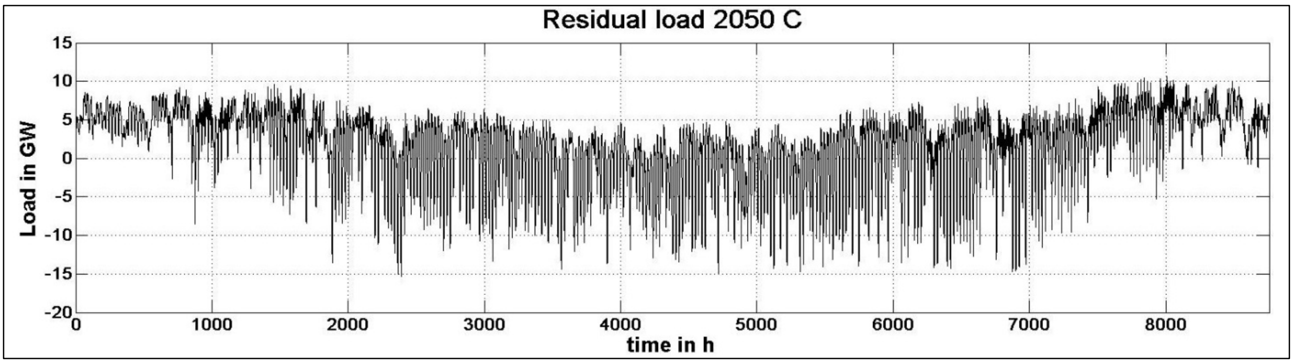

Figure 24: Residual load in Austria, 2050 scenario C (Source: HSU)

As can be seen in Figure 24, the residual load is negative especially during summer when there is a high feed in from PV. A negative residual load means that there is a surplus of electricity from RES-E that exceeds the electricity demand. This surplus can either be rejected by down regulation of RES-E generation units, exported to neighbouring countries or stored in ESS. However, down regulation or energy export is not an option within the computation algorithm. The aim is to use as

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little power and capacity of the ESS to fully integrate all the surplus RES-E generation. In principle the algorithm follows a peak-shaving and valley-filling strategy as shown in Figure 25. To minimize the energy storage needs, an intelligent operation strategy was implemented. If a high surplus of RES-E in the electricity system can be expected, the ESS plans its operation in a way to be able to fully integrate this surplus. If the surplus of renewable energy is expected to exceed the storage capacity of the ESS, it tries to plan the operation in a way to empty the reservoirs completely beforehand in order to integrate as much RES-E as possible.

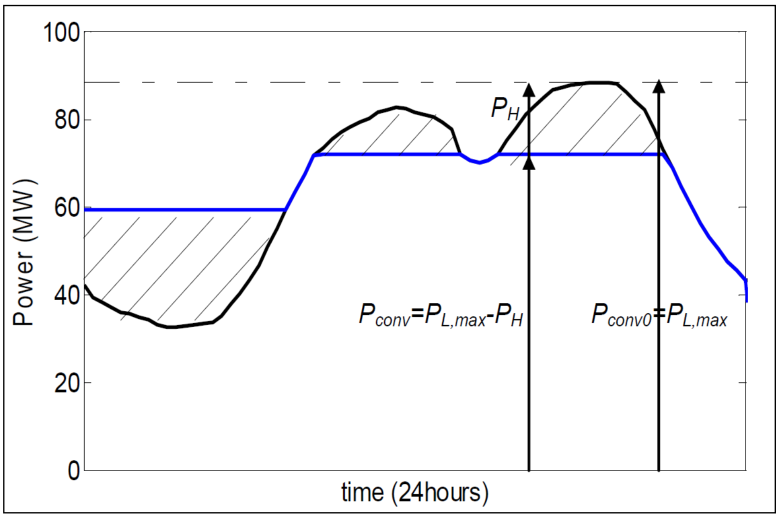

Figure 25: Indicative effects of PHES operation on the residual load curve (Source: HSU)

To estimate the additionally needed storage capacity a further technology, in addition to the already existing ESS, is introduced which has an unlimited storage capacity and power. This technology can take the surplus RES-E that cannot be stored by the existing system. Due to the unlimited power and capacity this technology enables the full integration of all RES-E. The actual used power and capacity of this second technology is an indicator of the additionally needed ESS.

4.2 Austria

For the analysis of the electricity storage needs in Austria, the PHES turbine and pumping power are both set equal to the installed PHES capacity in the respective scenarios (cf. Table 12), while the storage capacity of Austrian PHES is set to **2 TWh** in all scenarios 2020 and 2050[15]. This assumption implies, that the majority of new PHES installations are only extensions / upgrades of existing (P)HES systems with no or negligible changes in the storage capacity of the existing dams / reservoirs. Other new PHES systems (i.e. “on the green field”) are said to be mainly configured as (intra-)day-storage systems with storage capacities of around 10 GW, and, therefore, also lead only to a small increase of the already existing storage capacity. Further on, the seasonal fluctuations of the Austrian storage capacity (cf. Figure 11) due to natural inflow are not considered in the analysis, i.e. the storage capacity stays constant the whole year.

[15] Cf. Figure 11, the maximum storage capacity of (P)HES systems currently is about 3 TWh in Austria.

4.2.1 2020 Scenarios for Austria

In the 2020 scenarios, a PHES operation strategy of daily balancing, which means a strategy to charge and discharge the facility within 24 hours, has been applied. Figure 26 to Figure 28 show the result of the output smoothing of the Austrian residual load by PHES systems in the year 2020 for the three different scenarios. In comparison to the 2020 residual load curve in Figure 22, the residual load curves after use of PHES system clearly show a variation decrease in amplitude as well as in frequency.

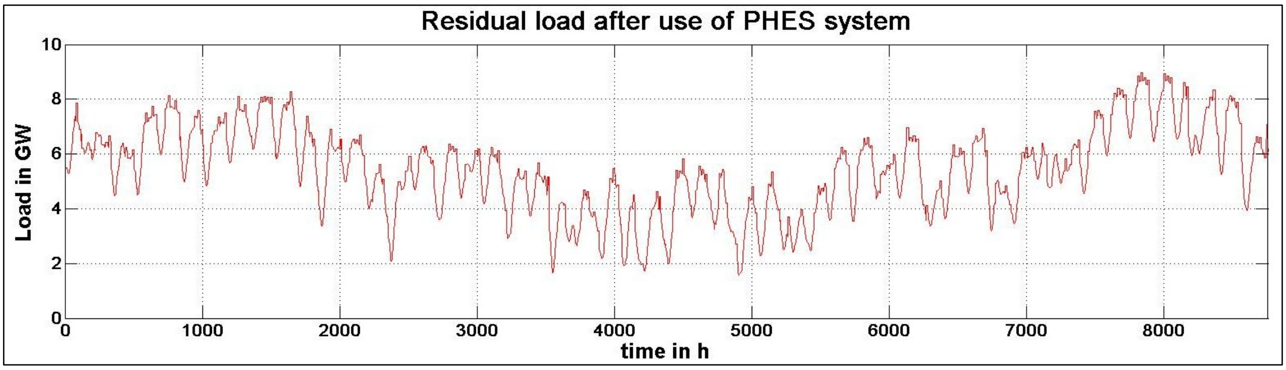

Figure 26: Residual load after the use of the Austrian PHES system in the scenario 2020 A (NREAP-AT, source: HSU)

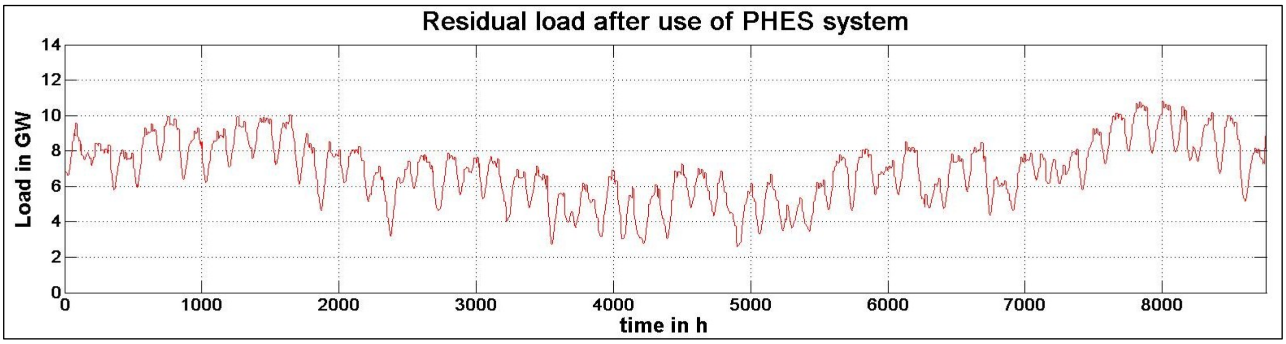

Figure 27: Residual load after the use of the Austrian PHES system in the scenario 2020 B (BAU, source: HSU)

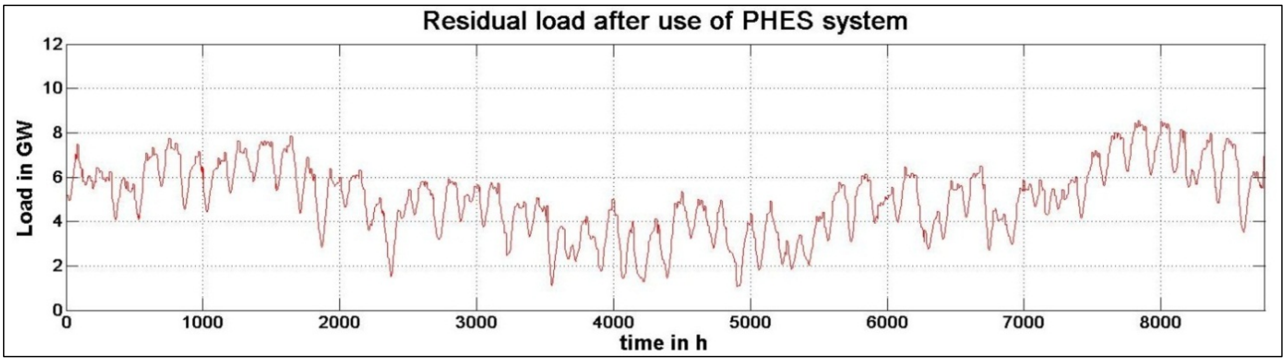

Figure 28: Residual load after the use of the Austrian PHES system in the scenario 2020 C (GREEN, source: HSU)

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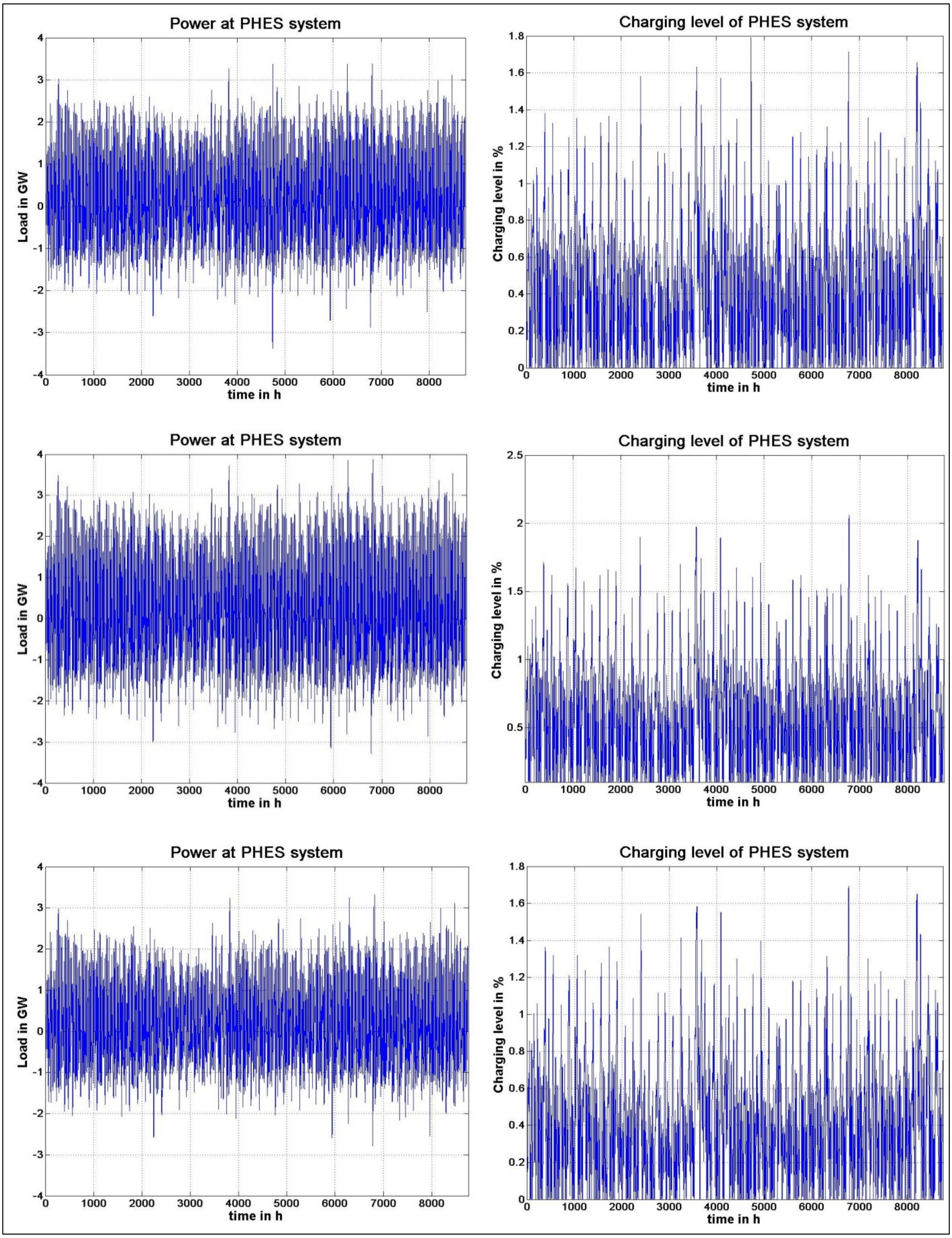

Figure 29: Power (left) and charging level (right) of PHES system for the 2020 scenarios A to C (from top to bottom, source: HSU)

Figure 29 presents the operation of the Austrian PHES system in the three different 2020 scenarios. The graphs on the left side of Figure 29 show the power at the PHES systems, positive load is according to pumping and negative load to turbining operation respectively. It can be seen that in all three 2020 scenarios the pump and turbine capacity of Austrian PHES systems is not used to its full extend – only 3–4 GW out of 6.6 GW are needed to smoothen the residual load. Also the right side of Figure 29, the charging level of PHES systems, leads to a similar conclusion, namely that the storage capacity of PHES systems is not used to its full extend. Only around 2% of the total storage capacity is needed for the smoothing operation in all three scenarios. Concluding, it can be said that there is no need to expand the PHES systems beyond the envisaged 6.6 GW in 2020 to safely operate the Austrian electricity system and to integrate RES-E technologies.

An overview of the results of the residual load smoothing analysis in the three different 2020 scenarios is also shown in Table 14. It shows that by 2020 the Austrian PHES system has enough capacity to fully integrate all RES-E in the Austrian electricity system and could also provide balancing services to neighbouring countries to increase profits. As a rule of thumb it can be assumed that a PHES plant is economically feasible when its capacity factor[16] is 25% or higher. Yet, in all three scenarios the capacity factor is below 25% using the PHES system just for the Austrian system alone. It could be increased by storing also surpluses of neighbouring countries, higher residual load smoothing (see 2050 scenario B) or participating in other markets. However, as previously mentioned, the simulation does not take into account market framework conditions and the future electricity price development.

Table 14: Overview of results in the 2020 scenarios

2020 Scenarios	Stored Energy [GWh]	Provided Energy [GWh]	Capacity Factor			Max. Used Power [GW]	
			Charge	Disch.	Total	Charge	Disch.
A	4,369.80	3,599.27	11.63%	9.58%	21.21%	3.37	3.36
B	5,205.88	4,219.82	9.00%	7.30%	16.30%	3.85	3.26
C	4,049.14	3,280.65	7.00%	5.67%	12.68%	3.31	2.77

4.2.2 2050 Scenario B for Austria

In contrary to the 2020 scenarios, for the 2050 scenario B three different PHES operation strategies have been investigated to analyse an increasing utilisation of the Austrian PHES storage capacity and to reach higher capacity factors:

- An operation strategy of daily balancing, which means a strategy to charge and discharge the facility within 24 hours (same as in the 2020 scenarios)
- An operation strategy for 2-day balancing
- An operation strategy with 200 hours balancing[17]

[16] The capacity factor for charging (for instance) is calculated as follows: stored energy divided by pumping power and by 8,760 hours.

[17] 200 h have been used because the Austrian PHES system with 9.2 GW installed power and 2 TWh storage capacity could discharge approximately 200 h with its rated power.

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The operational strategies were implemented as follows:

- A floating arithmetic average from the residual load was calculated (24 h average, 48 h average and 200 h average respectively)
- This arithmetic mean was then set as the target value for the ESS operation. This means that the aim of the storage facility was to balance out the residual load to reach these target values.

A) Scenario B with daily peak smoothing strategy (24 hours)

Figure 30 shows the result of the 2050 scenario B with PHES systems operating in daily peak load smoothing operation. It can be seen, that variation in the residual load is again reduced and - when looking at Figure 31 (i.e. power and charging level of PHES systems) – the capacity as well as the maximum power of the PHES systems is not fully used. Especially the storage capacity shows a very low use with charging levels always below 1.5%.

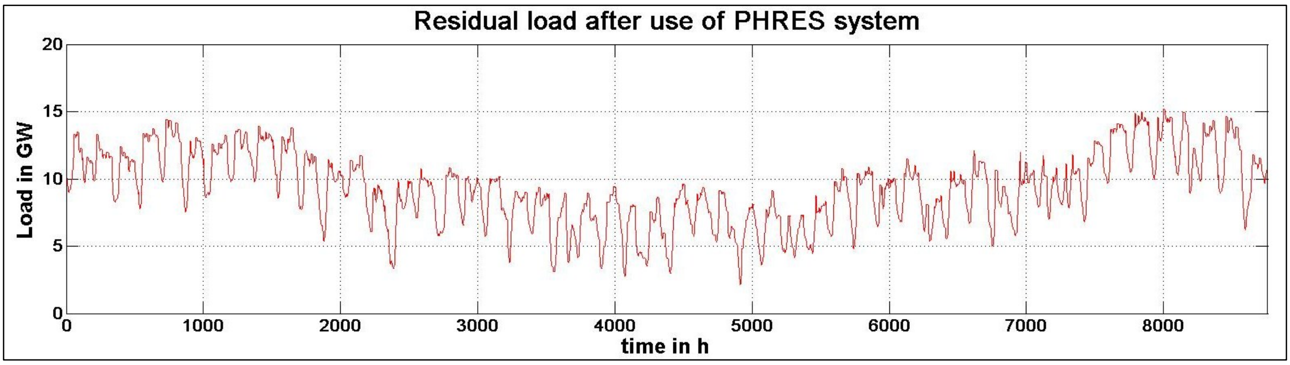

Figure 30: Residual load after the use of the Austrian PHES system in the 2050 scenario B (24 h balancing, source: HSU)

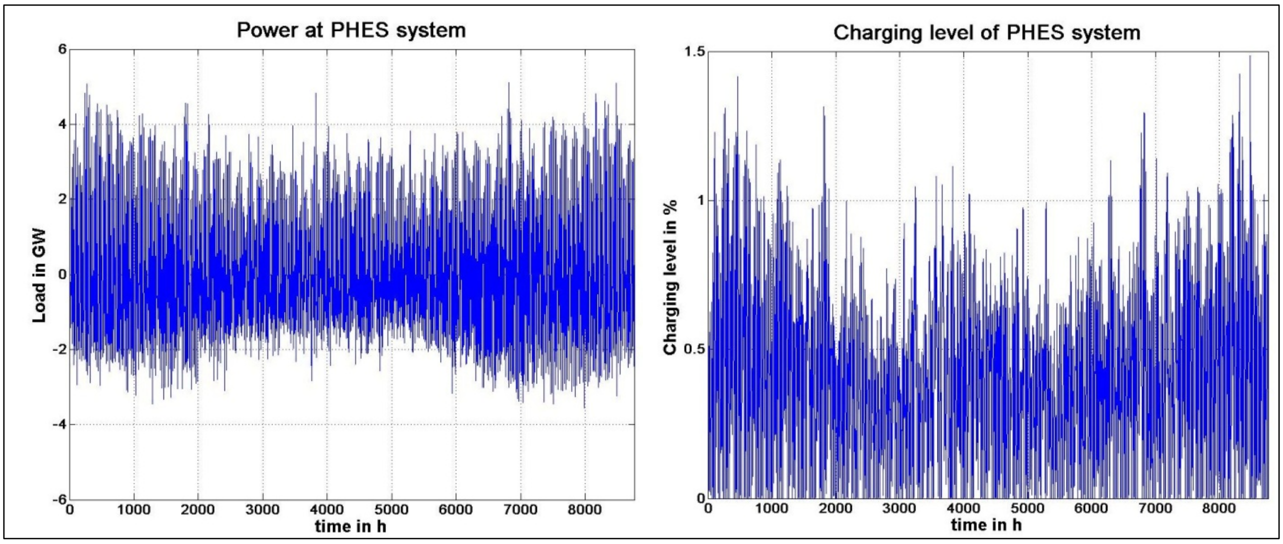

Figure 31: Power (left) and charging level (right) of the Austrian PHES system, 2050 scenario B (24 h balancing, source: HSU)

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B) Scenario B with 2-days peak smoothing strategy(48 hours)

In 2-day peak smoothing operation, PHES systems in Austria are able to reduce the variation in the 2050 residual load even further (cf. Figure 32) – again without being utilised to their full potential (charging level max. 2–3%, max. charging power around 5 GW, cf. Figure 33).

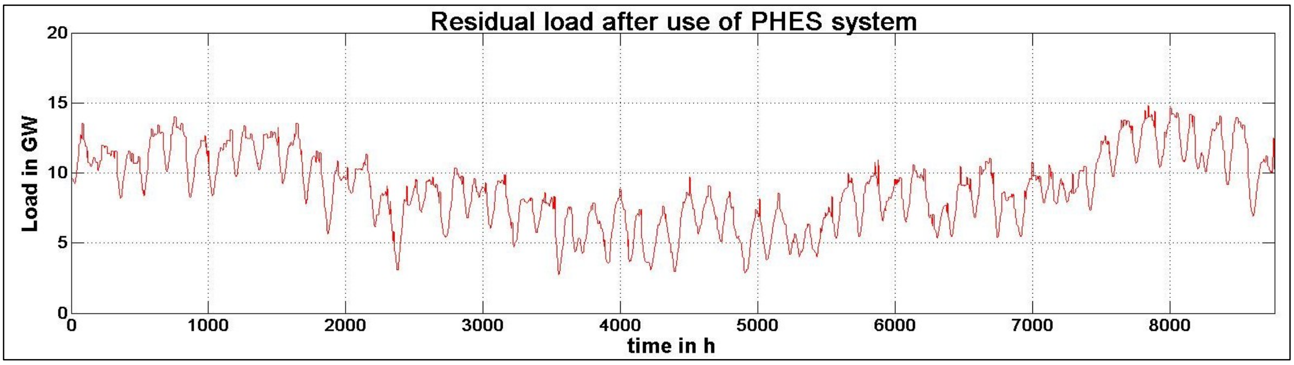

Figure 32: Residual load after the use of the Austrian PHES system in the 2050 scenario B (48 h balancing, source: HSU)

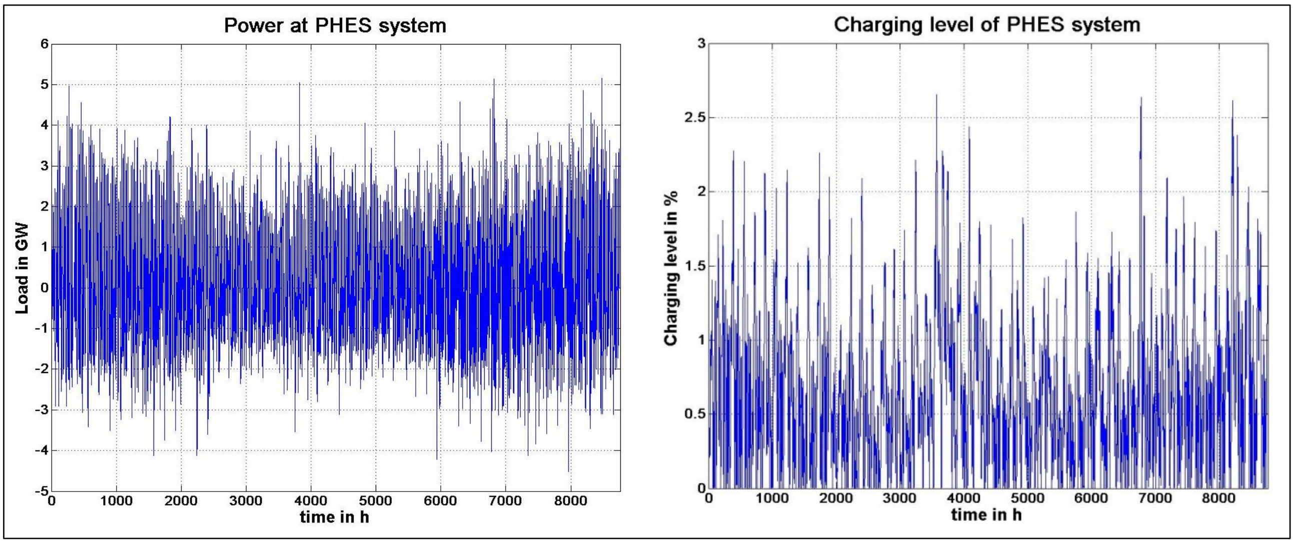

Figure 33: Power (left) and charging level (right) of the Austrian PHES system, 2050 scenario B (48 h balancing, source: HSU)

C) Scenario B with max. peak-shaving strategy (200 hours)

As a final operational strategy the charging / discharging cycle was set to 200 hours. Although enabling the balancing of the residual load over a period of almost eight days, the maximum available power is still not fully used[18]. The results of the optimization can be seen in Figure 34 and Figure 35. The storage capacity used reaches it maximum at around 200 GWh, which is just 10% of the total storage potential.

[18] The "spikes" in the residual load (Figure 34) are due to empty reservoirs, i.e. no more power can be provided by the PHES system. They can be removed by setting the initial charging level >0 GWh.

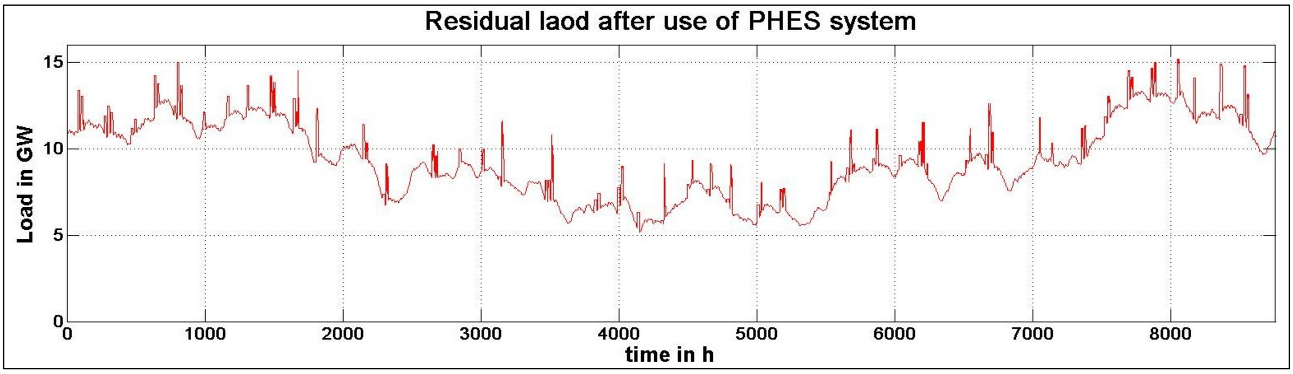

Figure 34: Residual load after the use of the Austrian PHES system in the 2050 scenario B (200 h balancing, source: HSU)

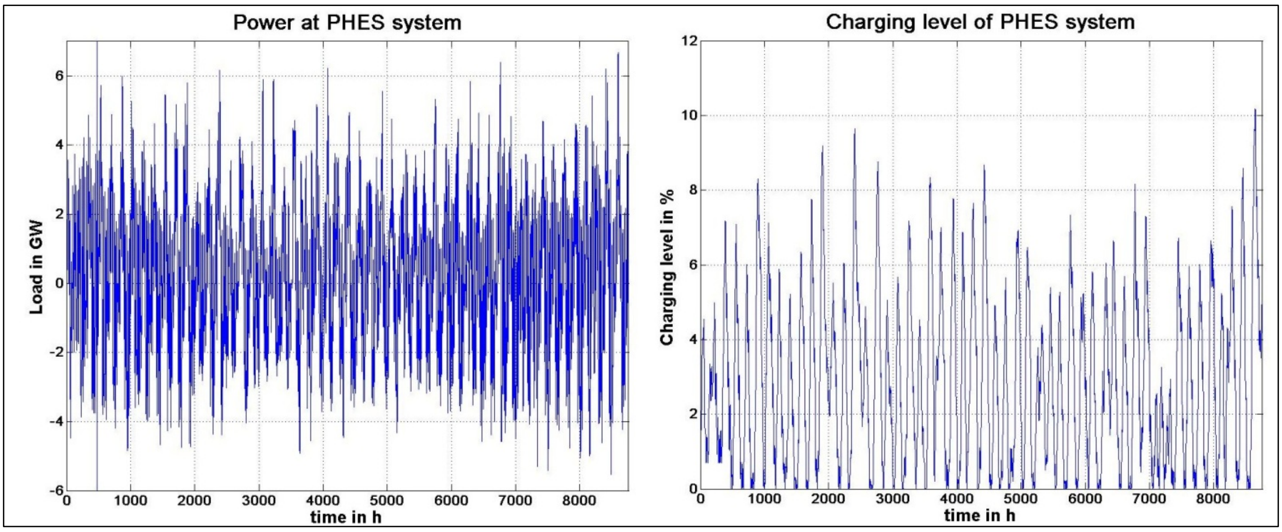

Figure 35: Power (left) and charging level (right) of the Austrian PHES system, 2050 scenario B (200 h balancing, source: HSU)

4.2.3 2050 Scenario C for Austria

A) Scenario C with only existing and planned PHES plants

As can be seen in Figure 36, the expected Austrian PHES system according to the scenario assumptions will not be able to fully integrate all energy from RES-E in the year 2050.

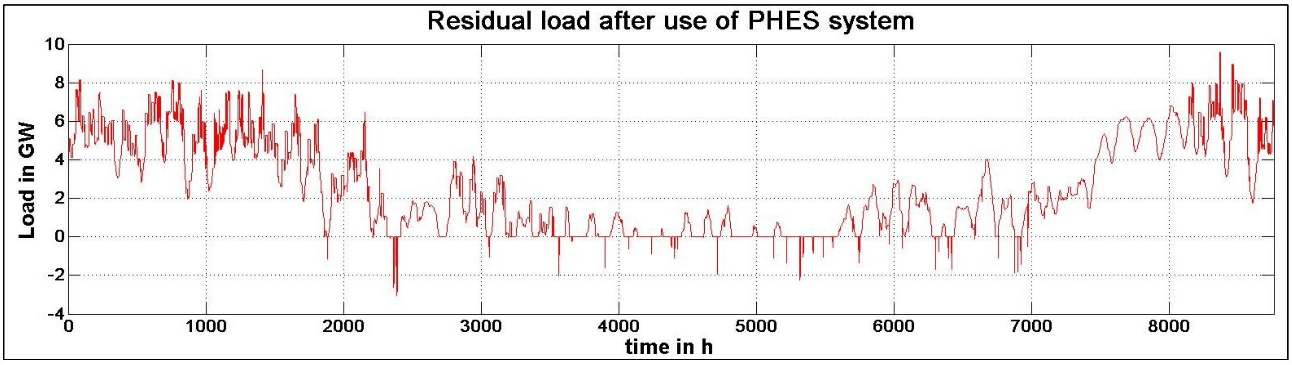

Figure 36: Residual load after the use of the Austrian PHES system in the 2050 scenario C (9.2 GW PHES installed, source: HSU)

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The maximum charging power of 9.2 GW is reached often during summer where there is a high feed-in from PV power plants. Also the charging level of the Austrian PHES system in Figure 37 shows that the storage capacity is only used to a small account before summer. In the summer period the high PV feed-in leads to a steady increase of the charging level until about 75%. Then, in autumn and winter the PHES systems are fully discharging again. The capacity factor of the Austrian PHES system in the 2050 scenario C reaches about 23% – since only 6 GW out of 9.2 GW of turbine power are needed for the integration of RES-E and residual load smoothing, there is still potential for participating in other markets.

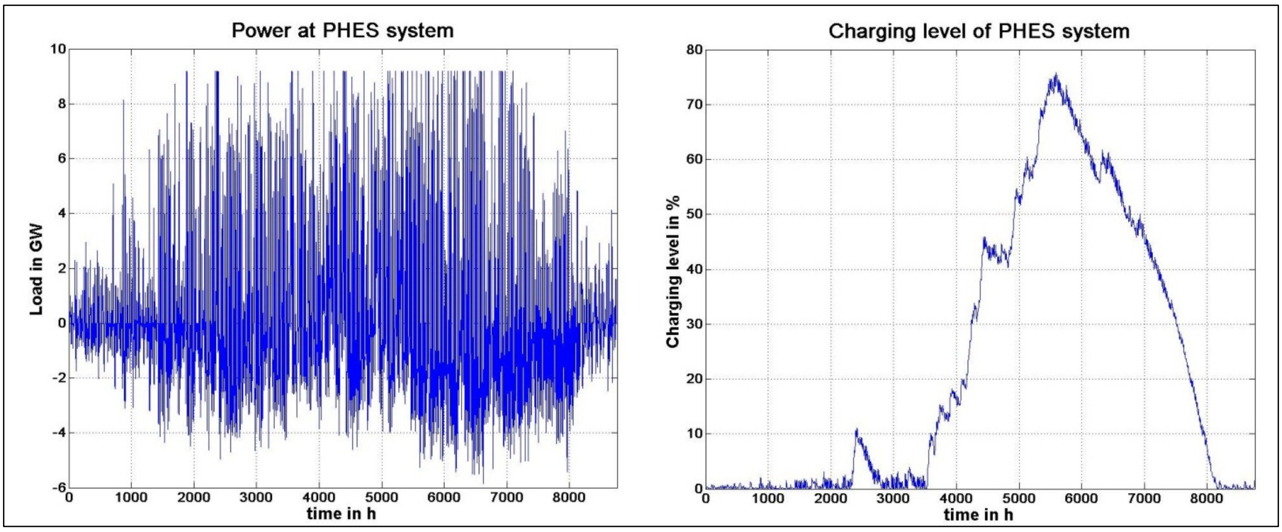

Figure 37: Power (left) and charging level (right) of the Austrian PHES system, 2050 scenario C (9.2 GW PHES installed, source: HSU)

B) Scenario C with a power extension of PHES systems

For an additional analysis of the 2050 scenario C utilising the full RES-E feed-in, the charging power of the Austrian PHES system was set to unlimited. As can be observed in Figure 38, there is no more surplus RES-E generation and the residual load never turns negative.

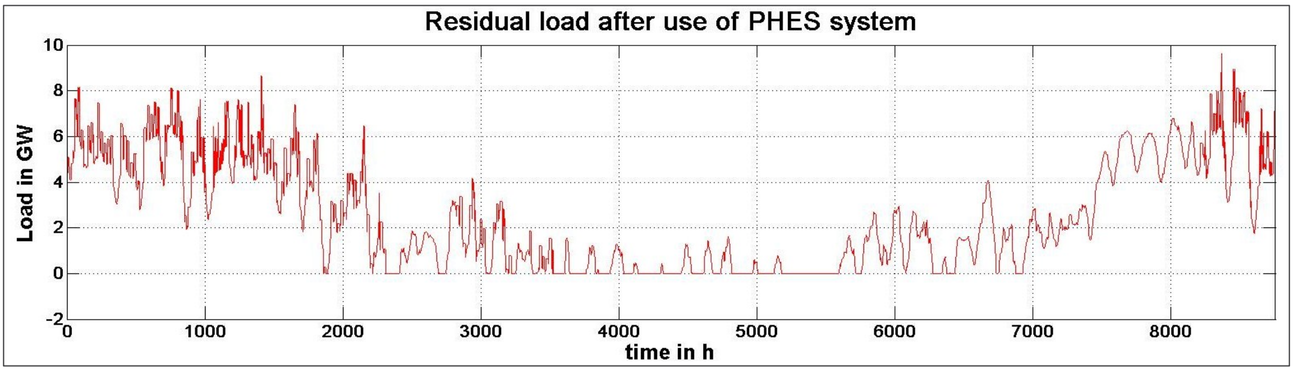

Figure 38: Residual load after the use of the Austrian PHES system in the 2050 scenario C (unlimited PHES, source: HSU)

The used power and the charging level of the Austrian ESS are shown in Figure 39. The maximum used power in charging mode is 12.18 GW and the maximum charging level is at almost 80%.

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Again the charging level shows a clear seasonal characteristic - the high capacity is only used to store the surplus of PV generation during the summer and to provide it again during autumn and beginning of winter. The rest of the year the reservoirs are just filled to a small amount and the PHES system is only used to smooth the residual load. However, due to the extension of the pump power by 3 GW to 12.2 GW in total, the capacity factor is decreased to about 20% (cf. Table 15).

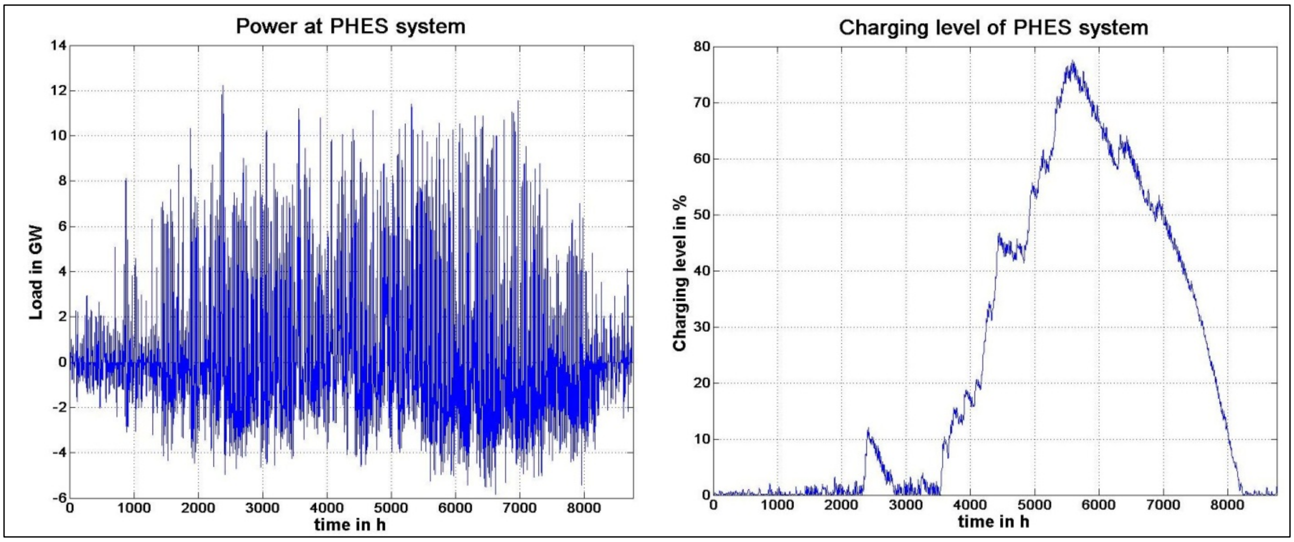

Figure 39: Power (left) and charging level (right) of the Austrian PHES system, 2050 scenario C (unlimited PHES, source: HSU)

4.2.4 Conclusions for Austrian Storage Needs

As seen in the analyses for the 2020 scenarios, the Austrian PHES system is capable of fully utilising the RES-E generation. The installed power as well as the storage capacity is not fully used – the PHES charging level reaches a maximum of just more than 2% in the 2020 scenario B. Similar results occur in the 2050 scenario B, even with a balancing strategy of more than eight days, the capacity as well as the maximum power of the PHES system is not fully used. The charging power reaches a maximum of about 6.7 GW in the 200 hours optimization (cf. Table 15).

Table 15: Overview of results in the 2050 scenarios

2050 Scenarios		Stored Energy [GWh]	Provided Energy [GWh]	Capacity Factor			Max. Used Power [GW]	
				Charge	Disch.	Total	Charge	Disch.
B	24 h	5,539.32	4,499.02	6.87%	5.58%	12.46%	4.96	3.14
	48 h	6,088.11	5,135.19	7.55%	6.37%	13.93%	5.15	4.52
	200 h	8,364.93	6,720.35	10.38%	8.34%	18.72%	6.67	5.49
C	Existing PHES	10,204.47	8,281.92	12.66%	10.28%	22.94%	9.20	6.00
	Power Expansion	10,300.68	8,359.85	9.65%	10.37%	20.03%	12.18	6.00

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Due to the high amounts of installed PV power, the charging power of the Austrian PHES system is not enough to integrate all the surplus PV generation in the 2050 scenario C. The turbine power on the other side is never fully used, only 6 GW are used maximally (cf. Table 15). When expanding the pumping power, all initially rejected RES-E generation can be integrated and the storage reservoirs are filled almost up to 80% during summer due to PV feed-in. The charging curve of the PHES system in the 2050 scenario C shows a clear seasonal storage characteristic. It is charged during summer time due to high feed-in from PV and is discharged during autumn and winter.

4.3 Austria and Germany

Because of the high unused PHES potential in Austria (e.g. storage capacity and also turbine power were not used to its full extend in the Austrian scenario analysis), two further 2050 scenarios with the two electricity systems of Austria and Germany combined have been analysed. In detail, the German scenarios A, a favoured development of wind energy, and B, a favoured development of photovoltaic, are considered (see D5.1 – Germany[19] for more details). In order to limit the number of scenarios, for Austria only the 2050 scenario C, GREEN, is investigated. For the combined electricity system of Austria and Germany therefore the following two scenarios are defined:

- Scenario AC: German scenario A, favoured development of wind, with the GREEN scenario of Austria
- Scenario BC: German Scenario B, favoured development of PV, with GREEN scenario of Austria

For the two scenarios it is assumed that the transmission capacity between Austria and Germany is unlimited, i.e. there are no bottlenecks in the transmission grid.

Table 16 shows the scenarios investigated for each country and the two combined scenarios.

Table 16: Overview of the 2050 scenario assumptions for Austria-Germany

[MW]	Germany		Austria	Total AT-DE	
	A	B	C	AC	BC
Wind (onshore)	63,000	55,000	4,710	67,710	59,710
Wind (offshore)	30,000	21,000	0	30,000	21,000
PV	45,000	100,000	26,960	71,960	126,960
Hydropower					
Run-of-River	5,700		7,200	12,900	
HES	0		3,600	3,600	
PHES	8,000		9,200	17,200	
Small Hydropower			250	250	
Other RES-E	5,000		2,000	7,000	7,000
Yearly Peak Load	79.1		13.6	92.5	92.5
Energy Consumption [TWh]	~500		83	~583	~583
RES-E Generation [TWh]	~400		94	~494	~494

19 See Weiß (2013).

The maximum excess power and the energy that would be rejected without any ESS are summarized in Table 17 for both 2050 scenarios AT-DE. It can be seen that the scenario AC, with a stronger development of wind energy (Germany A), the maximum rejected power and the overall rejected energy without ESS is almost half of scenario BC. This is due to the lower full load hours and high simultaneity of PV installations. To reach the same share of RES-E on electricity consumption a higher rated power has to be installed which leads consequently to higher surpluses on e.g. sunny days.

Table 17 Overview of the outcomes analysing the 2050 residual load of AT-DE

2050Scenario	Max. rejected power [GW]	Rejected Energy [TWh]
AC	43.07	11.34
BC	70.54	24.96

4.3.1 2050 Scenario AC for AT-DE

A) Scenario AC: Only existing and planned PHES units

The expected PHES systems in Austria and Germany will not be able to fully integrate all energy from RES-E of the combined electricity systems. The maximum charging power of 9.2 GW (Austria) and 8 GW (Germany) is fully used very often during a year, but there are still surpluses of RES-E of more than 20 GW occasionally (cf. Figure 40).

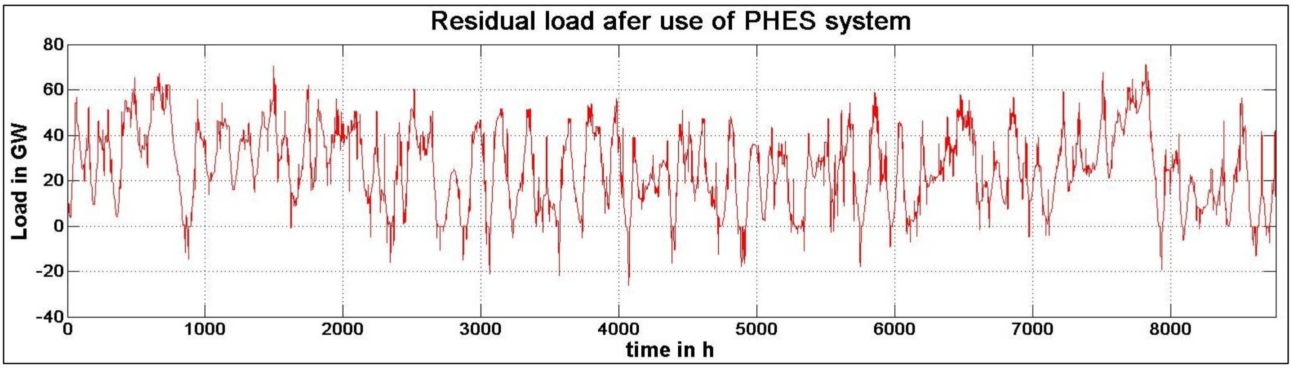

Figure 40: Residual load after the use of the Austrian and German PHES system, 2050 scenario AC (Source: HSU)

The German PHES system reaches its limits regarding the storage capacity regularly whereas the storage capacity of the Austrian PHES system has still a lot of unused potential (cf. Figure 41). This results also in very high capacity factors for the Austrian as well as for the German PHES facilities (cf. Table 18). However, the rejected energy from variable RES-E reaches 2,299 GWh.

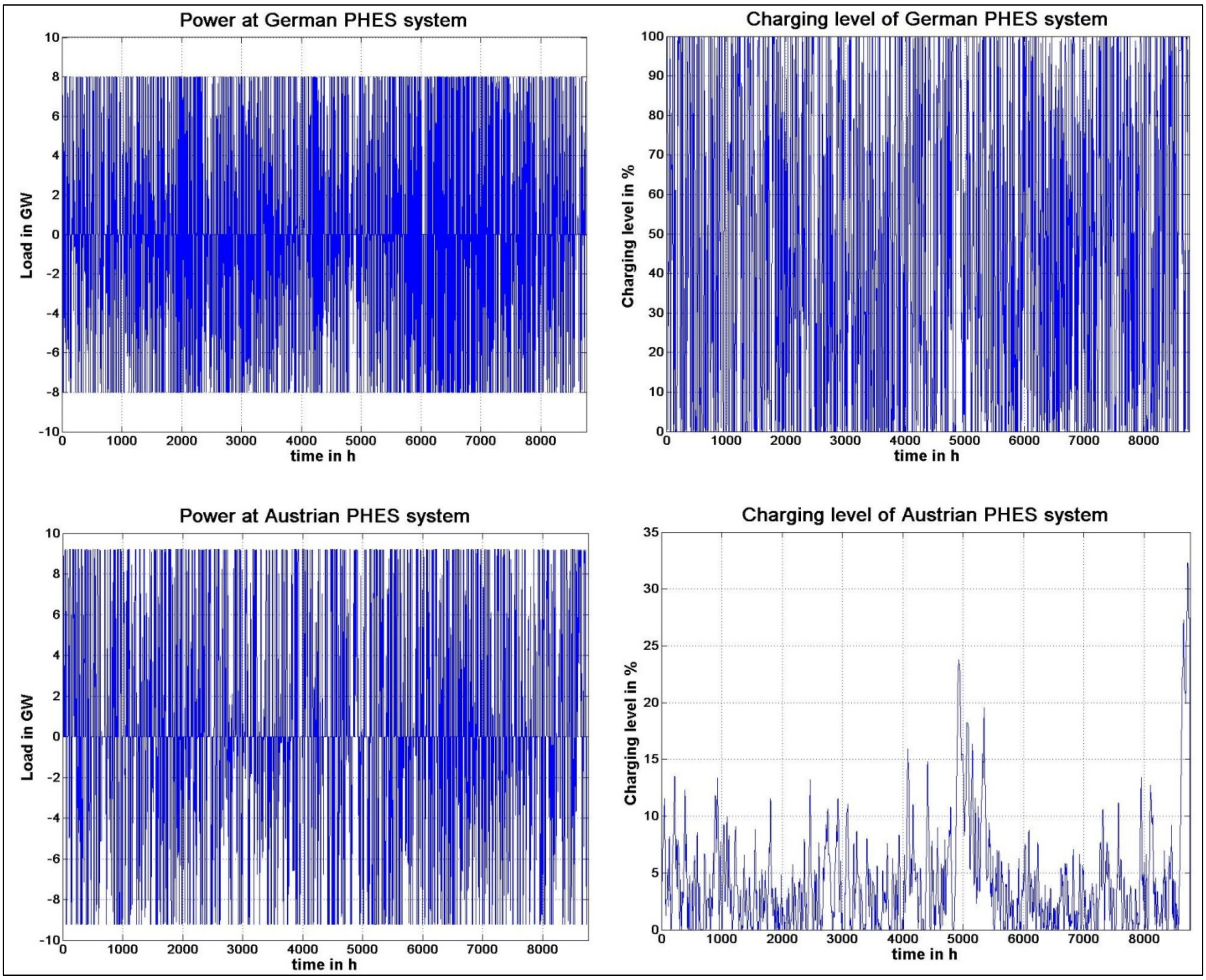

Figure 41: Power (left) and level (right) of the German (above) and the Austrian (below) PHES system, 2050 scenario AC (Source: HSU)

B) Scenario AC_{full}: Full exploitation of Austrian PHES system

In all the investigated scenarios the storage capacity of the already existing Austrian reservoirs is high enough to take all the surpluses produced by German RES-E units, mainly wind and PV. However the installed amount of turbines and pumps is not enough to integrate all energy. For that reason an unlimited power extension (charging as well as discharging) has been simulated to show the maximum additional power that would be needed to fully integrate all RES-E in both countries. These scenarios are called AC_{full} and BC_{full} respectively.

Figure 42 shows the residual load after the use of the German and Austrian PHES system in the 2050 scenario AC_{full}. As can be seen the residual load never turns negative and all surpluses from renewable energies can be stored. The used power in charging (positive values) and discharging (negative values) mode as well as the needed capacity are shown in Figure 43.

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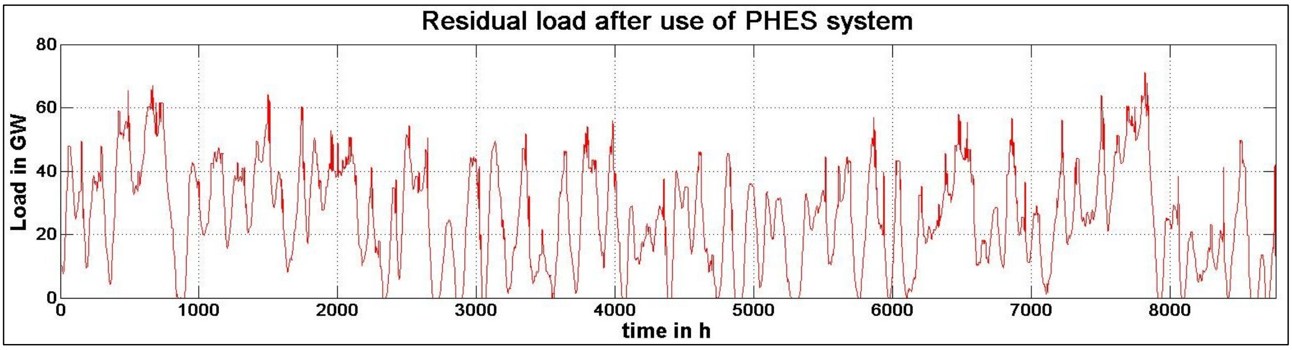

Figure 42: Residual load after the use of the Austrian and German PHES system, 2050 scenario AC_{full} (Source: HSU)

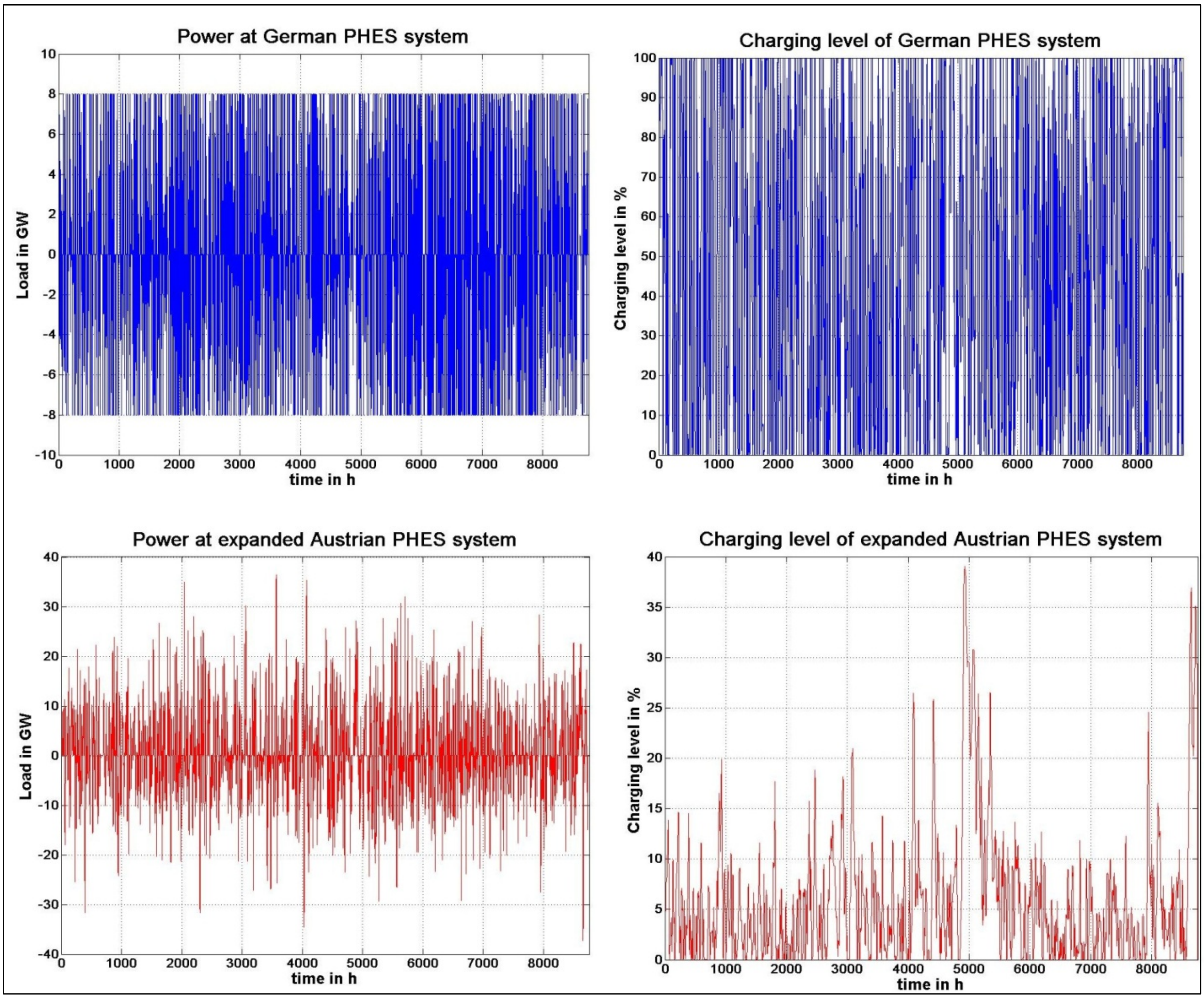

Figure 43: Power (left) and charging level (right) of German (above) and expanded Austrian (below) PHES system, 2050 scenario AC_{full} (Source: HSU)

It can be stated that the installed power of the actual Austrian PHES system is exceeded by about 30 GW in charging as well as discharging mode. Nevertheless the capacity of the reservoirs is again just filled to maximum of less than 40%. Due to the combination of the German and the

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Austrian electricity systems the needed storage capacity in Austria is decreasing whereas the additionally needed installed power would increase strongly.

4.3.2 2050 Scenario BC for AT-DE

A) Scenario BC: Only existing and planned PHES units

Like in scenario AC, the expected PHES system in Austria and Germany will not be able to fully integrate all energy from RES-E. The surplus RES-E feed-in reaches up to 50 GW – especially during summer high negative residual load values are obtained due to high PV generation (cf. Figure 44). Again, the maximum charging power of both PHES systems is fully used very often (cf. Figure 45 and Figure 46). While the storage capacity of the German PHES system is again fully utilised, the Austrian PHES system shows even lower usage levels as in scenario AC. In the 2050 scenario BC the rejected energy from variable RES-E is rising in comparison to scenario AC and reaches 9,027 GWh in total.

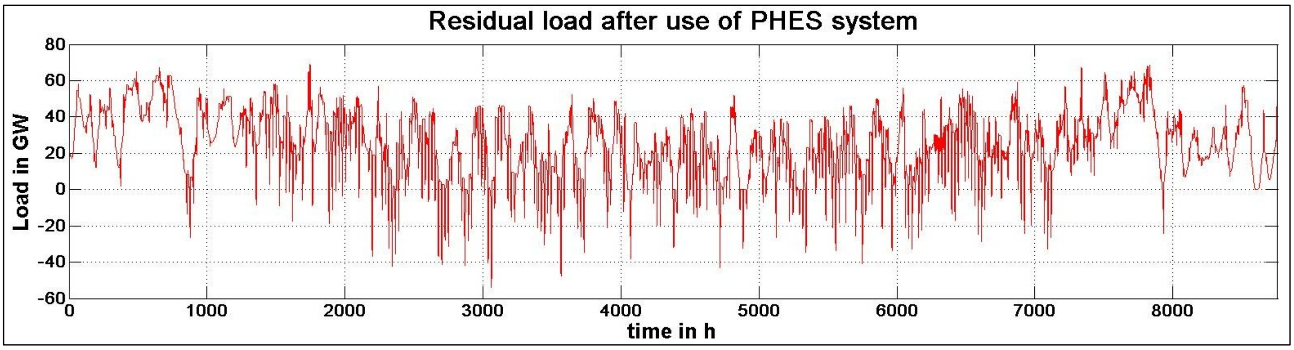

Figure 44: Residual load after the use of the Austrian and German PHES system, 2050 scenario BC (Source HSU)

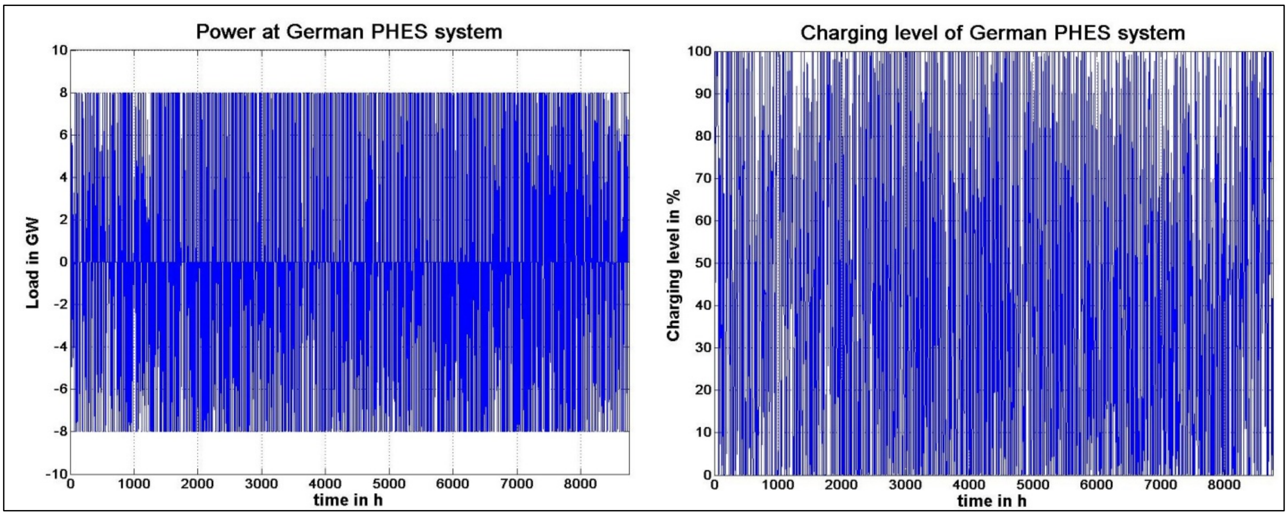

Figure 45: Power (left) and charging level (right) of the German PHES system, 2050 scenario BC (Source: HSU)

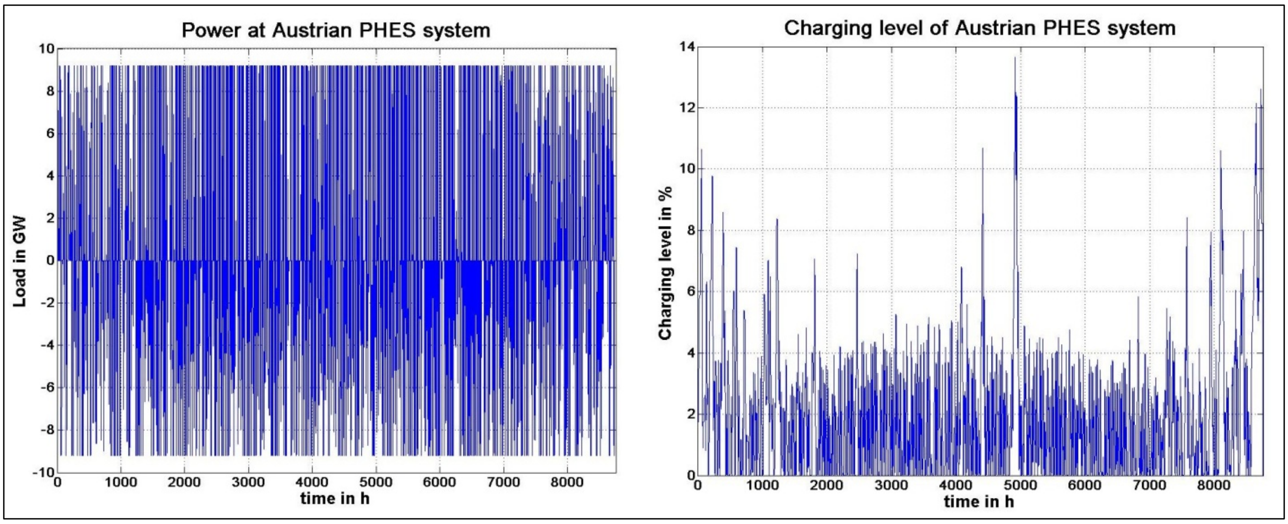

Figure 46: Power (left) and charging level (right) of the German (above) and the Austrian (below) PHES system, 2050 scenario BC (Source: HSU)

B) Scenario BC_{full}: Full exploitation of Austrian PHES system

In the 2050 scenario BC_{full} the installed charging and discharging power of the Austrian PHES system are again set to unlimited. Figure 47 presents the residual load after the use of the German and Austrian PHES system in the 2050 scenario BC_{full} - again all surpluses from RES-E are utilised.

The used power in charging and discharging mode as well as the needed capacity are shown in Figure 48 for the German and in Figure 49 for the expanded Austrian PHES system. In scenario BC_{full} the installed power of the actual Austrian PHES system is exceeded by 42 GW in charging mode and 20 GW in discharging mode. Nevertheless the capacity of the reservoirs is again just filled to maximum of less than 35%. Due to the combination of the German and the Austrian system the storage capacity needed in Austria is decreasing whereas the additionally power would increase strongly also in this scenario.

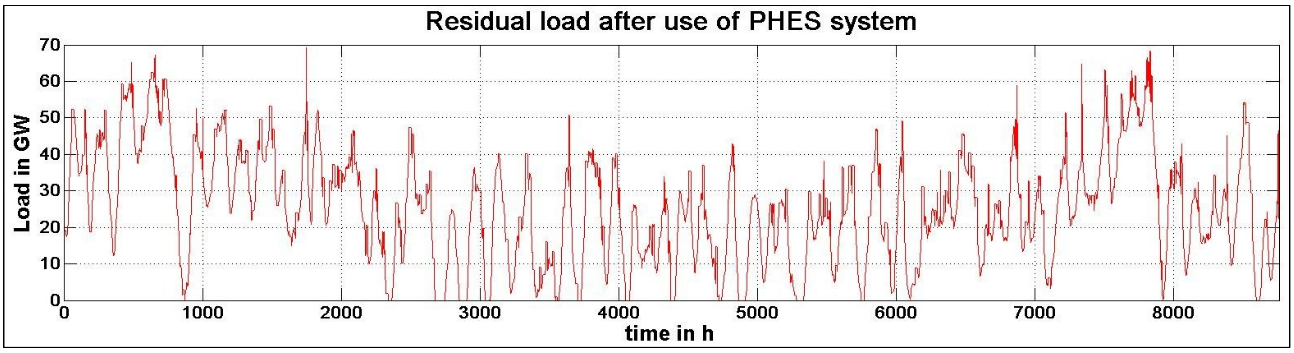

Figure 47: Residual load after the use of the Austrian and German PHES system, 2050 scenario BC_{full} (Source: HSU)

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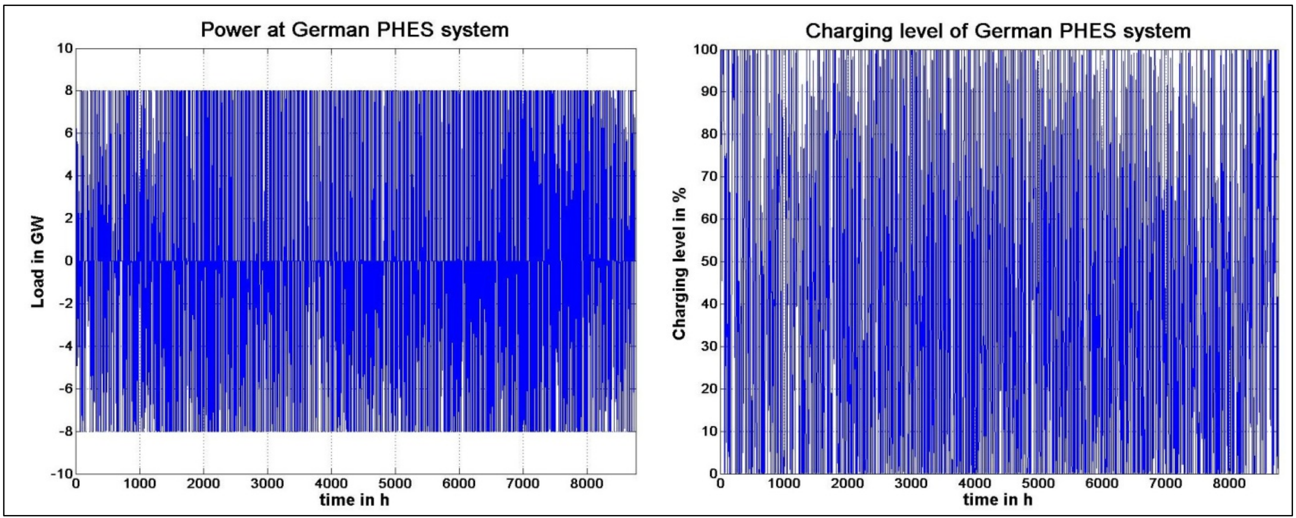

Figure 48: Power (left) and charging level (right) of German PHES system, 2050 scenario BC_{full} (Source: HSU)

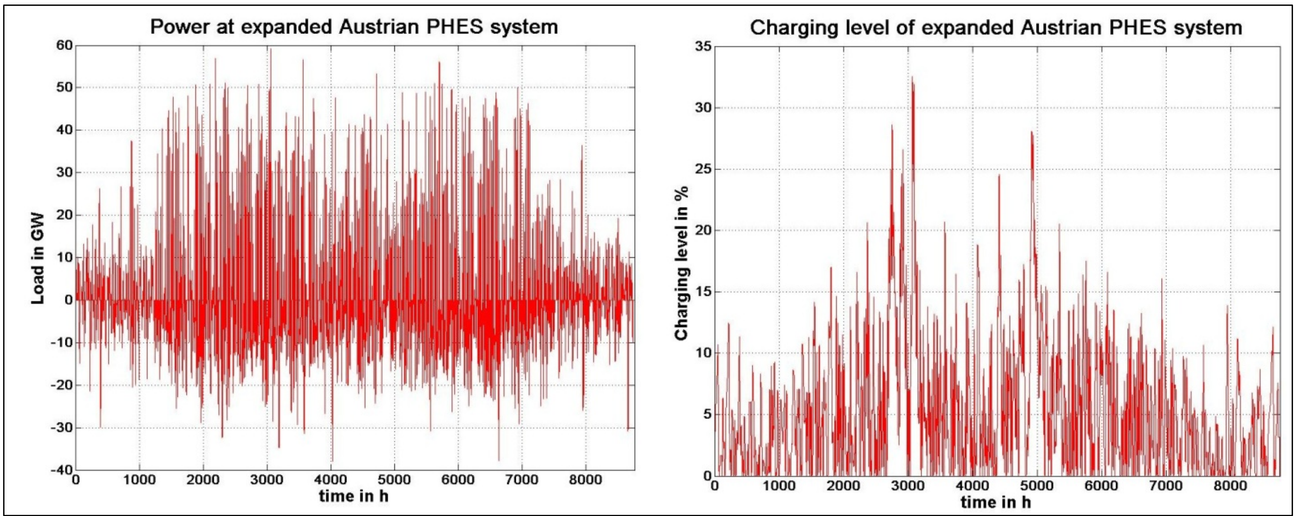

Figure 49: Power (left) and charging level (right) the expanded Austrian PHES system, 2050 scenario BC_{full} (Source: HSU)

4.3.3 Conclusions for the 2050 Scenarios AT-DE

The outcomes of the simulation are summarized in Table 18 and Table 19. Without any power expansion the capacity factor of the Austrian as well as the German system is very high due to strong fluctuations also during times of positive residual load. Especially the German system is charged and discharged completely very often and has a capacity factor of 44 % in scenario AC and 52% in scenario BC respectively. The increased capacity factor in the second scenario is caused by the higher installed PV power and the resulting higher fluctuations of the residual load.

When looking at the scenarios with full exploitation of the Austrian PHES system, it can be observed the capacity factor is falling due to highly increased installed power. The capacity factor reaches 15% in scenario AC_{full} and 19% in scenario BC_{full} respectively. As the capacity of the PHES system is not used to a high extend, the capacity factor could still be increased by

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participating in other (balancing) markets or by higher residual load smoothing.

Table 18: Overview of results for the 2050 scenarios AT-DE (I)

2050 Scenario	Country	Stored Energy [GWh]	Provided Energy [GWh]	Max. used power [GW]	
				Charge	Discharge
BC	DE	20,228.96	16,365.63	8.0	8.0
	AT	20,859.28	16,762.69	9.2	9.2
BC_{full}	DE	20,174.01	16,321.21	8.0	8.0
	AT	44,102.49	35,671.96	59.2	37.7
AC	DE	17,161.74	13,878.71	8.0	8.0
	AT	20,326.55	16,020.09	9.2	9.2
AC_{full}	DE	17,111.39	13,837.93	8.0	8.0
	AT	27,005.47	21,398.66	36.4	37.2

However the capacity factor of the expanded Austrian PHES system is higher than the one of the additionally needed PHES system in Germany to cover the surpluses just in the islanded German system. Furthermore the additionally needed power in the islanded German system is much higher than the needed expansion of turbine and pump power in the PHES facilities in Austria in the combined system.

Table 19: Overview of results for the 2050 scenarios AT-DE (II)

2050 Scenario	Additionally needed power and capacity			Additionally needed power and capacity in single German system		
	P_{charge}	$P_{discharge}$	E_{max}	P_{charge}	$P_{discharge}$	E_{max}
AC	19.17 GW	19.98 GW	0 GWh	38.79 GW	25.17 GW	1,534 GWh
BC	42.00 GW	20.51 GW	0 GWh	55.16 GW	29.04 GW	950 GWh
	Capacity factor					
	German PHES			**Austrian PHES**		
	Charge	Disch.	Total	Charge	Disch.	Total
AC	24.49%	19.80%	44.29%	25.22%	19.88%	45.10%
AC_{full}	24.42%	19.75%	44.17%	8.47%	6.57%	15.04%
BC	28.87%	23.35%	52.22%	25.88%	20.80%	46.68%
BC_{full}	28.79%	23.29%	52.08%	8.50%	10.80%	19.30%

As a final finding the difference in the used capacity of the Austrian PHES system in the single Austrian system and in the combined system with Germany has to be highlighted. Although also covering the high surpluses of renewable energies in the German system, the storage capacity used in the Austrian reservoirs is less than half. This indicates that the Austrian PHES system operates more economical when connected to the German system.

The capacity of the Austrian PHES system is big enough to store all surpluses from RES-E in all scenarios investigated. Just the installed power is not high enough. To store all surplus RES-E also from the German electricity system a high amount of pumps and turbines has to be installed (cf. Table 18).

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5 Conclusions

Already in 2011 Austria had a share of RES-E on the net electricity consumptions of more than 60%. This is mainly due to the great deployment of HPP (RoR and (P)HES in the Alps) in Austria. As hydropower is a synchronous generation there are no grid stability problems when fossil-fired power plants are shut down and the whole electricity consumption is provided by hydropower and other variable RES-E.

Despite the already high share of RES-E, the Austrian government has ambitious targets for the further development of RES-E technologies - especially for wind and solar power. While the NREAP-AT foresees only small increases of PV power, the new Austrian RES legislation (i.e. AGEA 2012) changes the RES deployment ambitions up to 2015 and 2020 for PV generation significantly – additional 2 GW of PV are envisaged until 2020. Besides the NREAP-AT two further RES-E deployment scenarios up to 2050, BAU and GREEN, are presented and analysed in this report. In the more ambitious GREEN scenario the production of renewable energies exceeds the total load demand in 2050 so that Austria is going to be net exporter of renewable energy.

To facilitate these RES-E expansion targets Austria has already a high amount of PHES systems in place, which is expected to be expanded continuously until the year 2050. Due to high electricity demand increase and only moderate increase of variable RES-E in the BAU scenario, the Austrian PHES system is capable to integrate all RES-E generation and additionally smooth the residual load. However, to be able to integrate all projected RES-E in the GREEN scenario of 2050, our analyses showed that the installed power of PHES systems has to be developed even stronger. Large amounts of surplus electricity generation from variable RES-E (especially PV) occasionally lead to high negative residual loads and therefore to an increased need in charging / pumping power of PHES systems if all future surplus RES-E generation has to be fully utilised in the Austrian electricity system. Hence, as the analysis showed, pumping power will be needed more than turbine power. However, as previously mentioned, down regulation of RES-E systems and export to neighbouring countries have not been considered in the analysis.

As the analysis of the combined system of Austria and Germany in 2050 showed, additional PHES power is also needed to integrate all future excess RES-E generation in the combined system AT-DE. However, the additionally needed power in the PHES facilities of Austria in the combined system is much lower than the one in the islanded German system. Hence, the extension of the "balancing area" by upgrading of the (cross-border) transmission grid (set to unlimited in the analysis) has the benefit of lowering ESS needs in the combined system and offers additional market participation possibilities for ESS operators.

However, in all scenarios investigated, the storage capacity of the Austrian reservoirs (2 TWh) was high enough to fully integrate all future RES-E generation – a maximum charging level of 80% was reached in the GREEN scenario in 2050. When upgrading the installed power accordingly, there is still a high storage potential left for Austrian PHES systems to participate in other (balancing) electricity markets in different countries.

6 References

APG: "APG Masterplan 2020", Austrian Power Grid AG, available at www.apg.at, 2011

Beurskens et al.: "Renewable Energy Projections as Published in the National Renewable Energy Action Plans of the European Member States", ECN-E--10-069, downloadable at http://www.ecn.nl/docs/library/report/2010/e10069.pdf, 2011

Biermayr et al.: "Innovative Energietechnologien in Österreich - Marktentwicklung 2011", report for the Austrian Federal Ministry for Transport, Innovation and Technology, downloadable at: http://www.energiesystemederzukunft.at/publikationen/view.html/id1021, 2012

E-Control: "Elektrizitätsstatistik", Energie-Control Austria, available at: http://www.e-control.at, 2012

ENTSO-E: "System Adequacy Forecast 2010 – 2025", report and scenarios, downloadable at https://www.entsoe.eu/resources/publications/system-development/ , 2010

Huber et al.: "Action plan for a dynamic RES-E policy", Report of the European research project Green-X – funded by the EC-DG Research, Vienna University of Technology, 2004

IG Windkraft: "Rekord für den Ausbau erneuerbarer Energien in Europa", press release, available at: http://www.igwindkraft.at, 2012

Karner et al.: "National Renewable Energy Action Plan 2010 for Austria (NREAP-AT)", 2010

OESG: „Ökostromgesetz 2012",75. Bundesgesetz über die Förderung der Elektrizitätserzeugung aus erneuerbaren Energieträgern (Ökostromgesetz 2012 – ÖSG 2012), available at http://www.oem-ag.at, 2011

PLATTS: „Electric Power Plant Database – Europe", www.platts.com, 2010

VERBUND-APG: "Masterplan 2009-2020 der VERBUND-Austrian Power Grid AG", 2009

Weiß: "D5.1 GERMANY – Results of the estimation of the energy storage needs of the German electricity system", part of Deliverable 5.1 of the project "stoRE", available at: www.store-project.eu, 2013

Zach et al.: "Contribution of Bulk Energy Storage in Future Electricity Systems Facilitating Renewable Energy Expansion", Deliverable 2.3 of the project "stoRE", available at: www.store-project.eu, 2012a

Zach et al.: "Report Summarizing the Current Status, Role and Costs of Energy Storage Technologies", Deliverable 2.1 of the project "stoRE", available at: www.store-project.eu, 2012b

Zach et al.: "Role of Bulk Energy Storage in Future Electricity Systems with High Shares of RES-E Generation", Deliverable 2.2 of the project "stoRE", available at: www.store-project.eu, 2012c

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