Hybrid-VPP4DSO

Deliverable 2

Work Package 2

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Electricity price scenarios and qualitative analysis of hybrid-VPP business models

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Contents

1 Introduction

1.1 Hybrid VPP4DSO approach

In different European research projects and activities first applications for virtual power plants (VPP) which focus on trading on selected power markets have been developed. These VPPs use curtailment of aggregated loads, generation and “unused” capacities like emergency power supplies as “resource” (sometimes as labelled as ‘flexibilities’), which can be delivered to different customers like transmission system operators (TSOs) or power traders. On the other hand there are technically orientated VPPs which try to manage loads and generation in distribution grids in order to keep the power quality parameters within tolerable limits. These VPPs are part of the smart grid idea, nevertheless there are no suitable business models fitting into the regulatory framework in most European countries.

According to the above mentioned background of VPPs in the European markets the main objectives of the project hybrid-VPP4DSO are the following:

Stepwise simulation-based development, evaluation and validation of a hybrid VPP concept and an implementation process of two hybrid VPP research systems to manage distribution grid issues and “normal” DR resource aggregator business with one VPP system including:

- Simulation-based validation of hybrid VPP operation concerning grid impacts (power flow simulation), techno-economic simulation of demand response (DR) resource aggregation and simulation of suitable business models.
- Technical proof of concept will be first realized at laboratory level followed by test switching of real customer loads in two distribution grid sections in Slovenia and Styria, including a security analysis of such a concept.

The project will be performed following a 4 step approach: i.) Preparing of the simulation environment including the definition and selection of the system boundaries (technical, economical and legal) and models of specific distribution network areas including a customer VPP data base (customers and generators), as well as the preselection of business models; ii.) Developing and modeling of future scenarios for generation and loads in the network areas and modeling of future scenarios including a cost benefit analysis for different market models; iii) Design and validation of a hybrid VPP aggregation concept via dynamic load flow simulations including the previous mentioned models; iv.) if the simulation-based validation of the developed hybrid VPP concept leads to promising results for a future implementation, the concept will be verified in a proof of concept in real networks.

The final result will be a validated hybrid virtual power plant concept to provide services especially for the requirements of distribution system operators (DSOs) by combining network driven and market driven approaches in one concept including a proof of concept in selected distribution network areas in Austria and Slovenia. Additionally, the most promising business case will be further evaluated regarding non-technical aspects (e.g. legal and regulatory) resulting in recommendations for possible adjustments of market rules to better enable hybrid VPPs in Austria and Slovenia.

hybrid-VPP4DSO will intensively interact with the project eBADGE, funded by the European Union in order to push the internationalization and coupling of balancing power markets in general and VPP business in particular.

1.2 Overview of electricity price scenarios and evaluation of hybrid-VPP business models approach

The work of this deliverable collects, evaluates and updates information about the potential of the future electricity generation technologies in Styria (Austria), Slovenia and Europe. The development of different scenarios of future electricity generation, demand and electricity prices under the assumption of possible market models is studied.

Starting with chapter 2 an overview of the potential of electricity generation technologies and the demand, is derived for the specific grid areas. In chapter 3 the requirements and needs of different market models in future electricity systems of the selected grid areas with different shares of variable/intermittent renewable electricity (RES-E) generation are defined for different electricity price scenarios. In chapter 4 a qualitative analysis of hybrid-VPP business models is worked out for an economic simulation of possible VPP business models.

The main objective of chapter 2 is the development and analysis of various energy scenarios for the Austrian/Styrian, Slovenian and European electricity supply and its impact on the distribution grid in the selected grid areas by the year 2020/2030. However, to make robust assessments of the future development of the electricity supply and demand in the southern part of Austria, the analysis must include neighbouring countries like Slovenia and further common market places in Europe.

Based on the scenarios from chapter 2 future electricity price scenarios are developed. These different electricity price scenarios provide the basis for an economic simulation of possible hybrid-VPP business models in deliverable 3.1.

Throughout the VPP for distribution grid services working programme the specific focus is on the future integration of new technologies (VPP) into the electricity system on distribution grid level and its behavioural characteristics in terms of improved flexibility, controllability, and observability. In particular, the VPPs for distribution grid services scenario analyses are oriented on a qualitative analysis of possible hybrid-VPP business models. More precisely, the VPP for distribution grid services approach features an in-depth qualitative analysis of the pros and cons of the hybrid-VPP business models for different stakeholders.

This requires (i) a preventive scanning of VPP ownership in order to select the most promising ones at a certain point in time in the future and (ii) the set-up of a consistent and tailor-made analysis methodology (pros, cons, reciprocal interdependency) qualified to meet the objectives in VPP for distribution grid services hybrid-VPP business models analyses.

All these data will be used as inputs for VPP business model analyses in work package 3.

2 Development of future power generation and electricity consumption scenarios

The entire European power supply is subject, since the beginning of the implementation of market-economic structures and related rules in 1999, to a continuous process of change in the energy policy, energy-economic, legislative, regulatory and structural conditions are constantly adjusted. In addition, new technological developments (e.g. electro mobility, smart grids, virtual power plants) are other factors that need to be considered for analysis of the future development of European power structures.

The uncertainties of the development of the above mentioned parameters are great challenges, especially for the system operators, as they have to fulfil a central role in the European electricity supply, both from a physical and from a market perspective. A detailed knowledge of the respective influence of the various parameters and robust statements about their possible future development helps the system operators to execute all tasks to be performed in the liberalized electricity market responsibly under increasingly difficult general conditions with corresponding pioneering technical and organizational measures.

The aim of this chapter is to develop and analyse different scenarios for the electricity supply up to year 2030. However, in order to be able to make accurate statements about the future development of the Austrian power supply must include an analysis of the Austria's neighbouring countries. Against this background, this study is based on the following two central pillars:

- Development of different scenarios of the national electricity consumption up to year 2030, with all the essential influencing parameters taken into account (e.g. economic growth, population development, e-mobility, energy efficiency, etc.).
- Development of different scenarios of the respective generation capacity in Austria and neighbouring countries up to year 2030, broken down by the respective primary energy sources (incl. renewables).

2.1 Methodology of future power generation and electricity consumption scenarios

Subsequently, the methodological approach is summarized in the development of the various scenarios of the national electricity consumption of installed power plant capacity up to year 2030 in this document.

2.1.1 Development of power plant capacities

The determination of the future development of the installed power plant capacities is broken down by primary energy source, through consideration of the decommissioning rate of existing power plants, of repowering of existing power plants, as well as the short, medium and long-term construction of new power plant capacities (see Figure 2-1 in detail)[1].

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[1] Regarding the individual power plant technologies following should be noted: 1. The currently existing hydro power capacities (run of river power plants, (pumped-) hydro storage power plants) will still exist in the future (no

As the detailed graphical illustration of the methodology in Figure 2-1 shows, to close the future gap between the existing power plant capacities (considering the decommissioning rate of the existing power plants) and the required total power generation capacities to cover future national electricity consumption with following methods:

- Short term secured addition capacities (including repowering). These are power plant projects to already planned, approved or already under construction.
- Concrete proven and quantifiable future capacities added up to 2020 (including repowering). In this category of power plant projects it is not assured at this stage, if all capacities are actually built or whether there are (often years) delays.
- Development of renewable energy sources in accordance with the different scenarios of national targets (e.g. relevant national action plans to achieve the EU 2020/2030 targets).
- Further expansion of conventional power plants by 2030, in line with national energy strategies and the existing primary-energy options (implies fundamental question of possible usage or not of nuclear power in the individual countries).

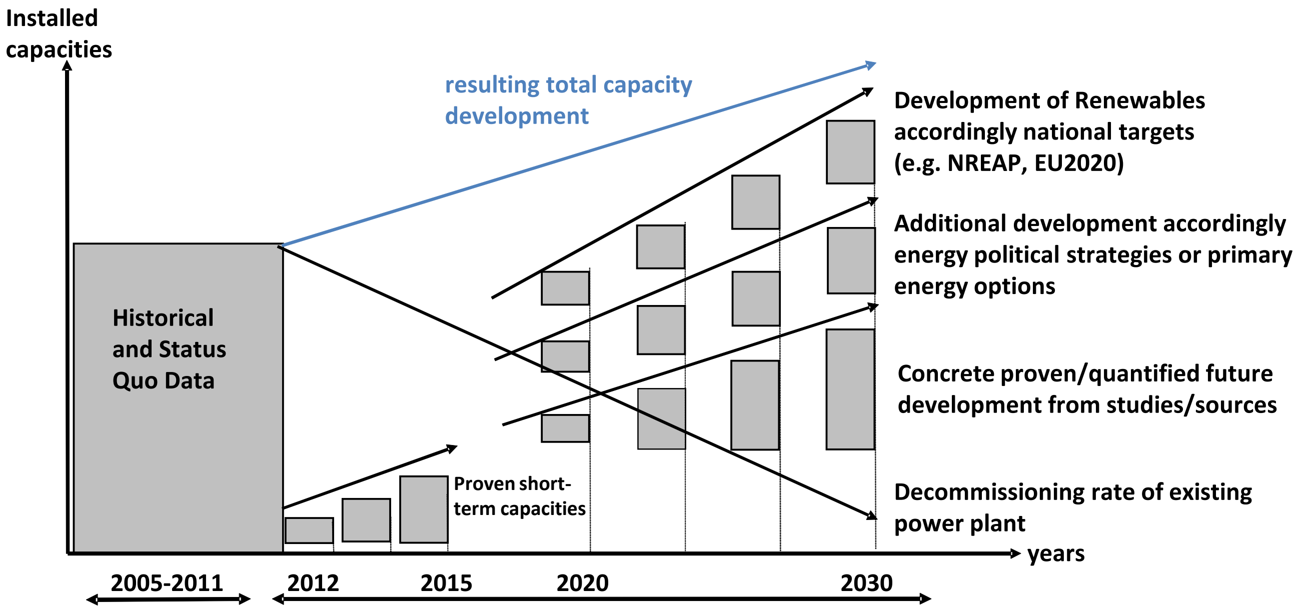

Figure 2-1 Methodology for determining the development of future power plant capacity

decommissioning) and thus are not subject of 'decommissioning rate'. In existing and newly installed pumped hydro storage power plants also includes a detailed breakdown by gross capacities for turbine operation and pump power for the pump operation. 2. The thermal power plant technologies are divided to the primary energy carriers nuclear, lignite, hard coal, gas and others (oil, mixed firing); possible future CCS (carbon capture and storage) applications does not matter up to 2030. 3. The individual renewable energy generation technologies are also broken down by the respective primary energy sources.

2.1.2 Development of electricity consumption

For the national electricity consumption trends (absolute, percentage) any essential impact parameters with increasing and decreasing effects are taken into account per country (see below Figure 2-2): Economic growth, population growth, electricity specific energy services such as E-mobility, cooling, implementation of energy efficiency measures, smart grids, etc. .

Furthermore, it is distinguished between gross and net electricity consumption development (i.e. inclusive / exclusive self-consumption of the power plants - especially pump energy - and losses) per country. An empirical data base (see list at the appropriate chapter 2.1.3) of all nationally and internationally recognized references and model results, together with own calculations are used for the empirical scaling of the various national scenarios of electricity consumption development.

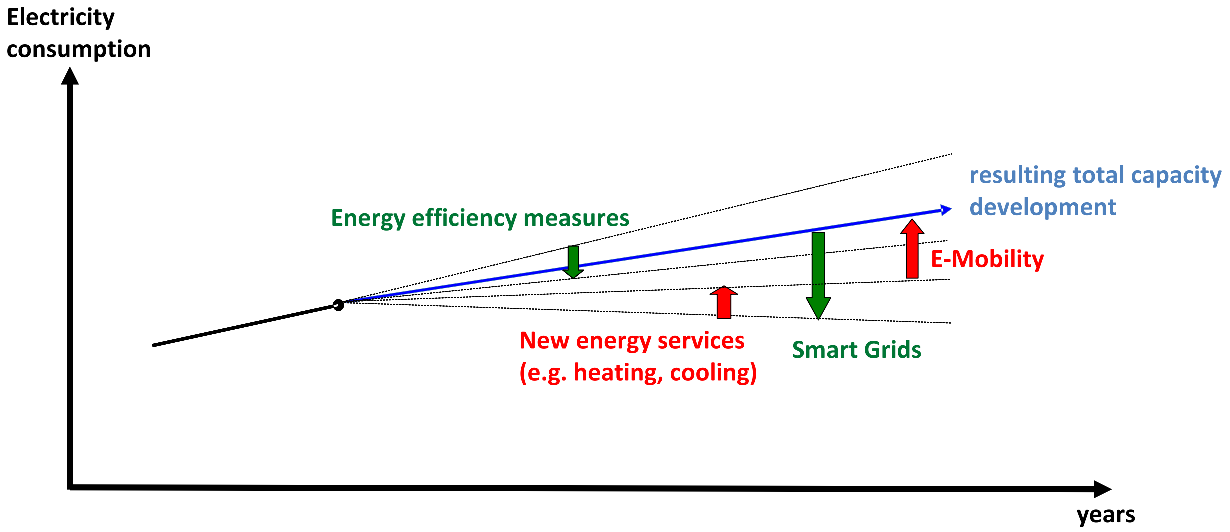

Figure 2-2 Drivers of future electricity consumption development

2.1.3 Empirical data base

The empirical scaling of the various scenarios of future national power plant capacities and electricity consumption is for example recourse to the following references:

- Platts database
- EEG power plant database
- ENTSO-E System Adequacy Forecast
- results of the model PRIMES
- NREAP 2020 (National Renewable Action plan 2020)
- etc.

The main scenario sources of the actual ENTSO-E Scenario Outlook & Adequacy Forecast (SO&AF) for 2020 und 2030 are figured out in Table 2-1 and

Table 2-2 respectively. These data are the basis for the calculation of the neighbouring countries of Austria.

Table 2-1 ENTSO-E EU2020 Scenario [7], [8]

2020	Demand (TWh)	Nuclear (MW)	Hard coal (MW)	Lignite (MW)	Gas (MW)	Oil (MW)	Other non RES (MW)	Total Hydro (MW)	Pumping (MW)	Wind (onshore) (MW)	Wind (offshore) (MW)	Solar (MW)	RES Biomass (MW)	Other RES (MW)
AT	**73,67**	**0**	**1 700**	**0**	**7 800**	**100**	**0**	**15 800**	**3 800**	**3 200**	**0**	**1 200**	**1 280**	**0**
CH	69,17	2 835	0	0	1 170	0	700	16 100	4 000	530	0	600	230	0
CZ	69,41	4 000	1 500	6 600	1 720	50	0	2 121	1 140	740	0	2 100	1 100	10
DE	562,20	8 100	28 992	19 217	32 451	3 069	3 330	14 740	10 240	43 598	9 800	51 753	8 100	298
HU	49,20	1 892	160	679	5 581	407	850	66	0	750	0	60	600	57
IT	339,00	0	10 585	0	44 692	5 057	3 980	23 851	5 815	12 900	680	24 500	4 700	730
SI	14,64	696	45	850	589	170	240	1 467	380	120	0	550	100	0
SK	30,60	2 880	200	241	1 230	0	1 030	2 680	916	150	0	550	260	0

Table 2-2 ENTSO-E Vision 3: "Green transition" [7], [8]

2030	Demand (TWh)	Nuclear (MW)	Hard coal (MW)	Lignite (MW)	Gas (MW)	Oil (MW)	Other non RES (MW)	Total Hydro (MW)	Pumping (MW)	Wind (onshore) (MW)	Wind (offshore) (MW)	Solar (MW)	RES Biomass (MW)	Other RES (MW)
AT	**91,81**	**0**	**1 212**	**0**	**7 962**	**100**	**0**	**18 821**	**4 285**	**5 500**	**0**	**3 500**	**1 750**	**0**
CH	78,60	1 165	0	0	1 170	0	700	18 644	6 872	900	0	3 000	1 300	0
CZ	82,09	5 700	300	5 210	1 980	20	0	2 200	1 140	860	0	3 620	1 100	10
DE	635,00	0	22 632	13 165	41 262	1 197	3 320	15 950	10 850	61 400	23 600	68 800	10 500	600
HU	546,10	4 152	110	0	5 163	407	720	100	0	1 000	0	200	950	90
IT	88,90	0	11 375	0	46 805	5 056	2 790	24 761	5 815	21 100	1 000	48 900	10 570	1 086
SI	51,60	1 796	159	545	787	170	0	1 999	583	240	0	1 120	0	0
SK	460,45	2 880	200	241	1 630	0	970	2 710	916	450	0	720	440	0

The assumed primary energy prices and non-fuel O&M costs for all time horizons are mentioned in Table Table 2-3 below.

Table 2-3 Assumptions concerning primary energy prices and O&M cost (in EUR/MWh), Sources: PRIMES 2013, ENTSO-E V3, EC2030 and TradeWind.

		Scenario 2020		Scenario 2030 - Base		Scenario 2030 - Efficiency	
		Cf	Cm	Cf	Cm	Cf	Cm
Variable cost components (EUR/MWh)	Nuclear	1,4	6	1,4	6	1,4	6
	Lignite	1,6	3,3	1,6	3,3	1,6	3,3
	Hard coal	10,1	3,3	8,0	3,3	8,0	3,3
	Gas	28,8	1,5	28,5	1,5	28,5	1,5
	Mixed oil/gas	60,2	5	35,6	5	35,6	5
	Light oil	60,2	5	60,2	5	60,2	5
CO2 prices (EUR/ton)		10		35		53	

Cf: fuel costs   Cm: non fuel O&M cost

2.2 Scenarios

Based on the methodology and data base above, two scenarios are developed for the year 2020 and 2030:

- Scenario Base: The 'Base' scenario is more or less a 'business as usual' scenario. There are no big changes in the power plant capacity structure and the annual demand grows with the historical average increasing rate for each country.
- Scenario Efficiency: In the 'Efficiency" scenario the EU 20/20/20 targets will be achieved by 2020. The development of renewable energy sources by 2020, takes place in the individual countries respectively with "National Renewable Energy Action Plans (NREAPs)". Up to 2030 the "Green transition" scenario from ENTSO-E is the basis for the power plant capacity structure. However the development of annual demand is lower than in the 'Base' scenario due to energy efficiency measures (e.g. Energy Efficiency Law in Austria).

Table 2-4 shows the results for Austria, Styria and Slovenia for Status Quo 2012 and for both scenarios for year 2020 and 2030. The power plant capacities are divided in following generation technologies:

- Nuclear
- Hard Coal
- Lignite
- Gas
- Oil
- Other non RES
- Hydro Run of River
- Hydro (Pump-)Storage
- Wind (onshore)
- Solar
- Other RES (e.g. biomass, biogas, geothermal).

Table 2-4 Data Overview of installed capacities (MW) and demand (TWh)for 'Base' and 'Efficiency' scenario

Scenario	2012			2020			2030 - Base			2030 - Efficiency		
Country	AT	Styria	SI	AT	Styria	SI	AT	Styria	SI	AT	Styria	SI
Annual demand - Base	62,26	10,15	12,67	73,67	12,01	14,64	91,81	14,97	19,99			
Annual demand - Efficiency				71,5	11,60					82,93	13,52	16,01
Nuclear	0	0	696	0	0	696	0	0	696	0	0	696
Hard Coal	1700	257	220	1700	257	45	1212	257	0	1212	0	0
Lignite	0	0	550	0	0	850	0	0	1200	0	0	850
Gas	5673	1024	80	7800	1243	589	9100	1650	900	7962	1400	900
Oil	250	185	170	100	0	170	100	0	170	0	0	120
Other non RES	0	0	290	0	0	240	0	0	240	0	0	100
Hydro RoR	5667	444	740	5800	490	1339	5800	500	1399	7200	630	1450
Hydro PHS	7760	205	400	10000	260	600	12000	300	600	12800	320	650
Wind Onshore	1675	83	0	3800	100	120	4500	140	240	5500	200	350
Solar	630	140	250	1200	350	550	2500	500	1120	3500	700	1500
Other RES	650	123	0	1280	180	0	1350	220	100	1750	250	120

In Figure 2-3 the cumulated power plant capacities per generation capacities are shown in the bars with scaling of the amounts in Megawatt (MW) on the left axis. Furthermore, the demands for ‘Base’ scenario (black triangles) and ‘Efficiency’ scenario (green triangles) are scaled on the right axis in Terawatthours (TWh).

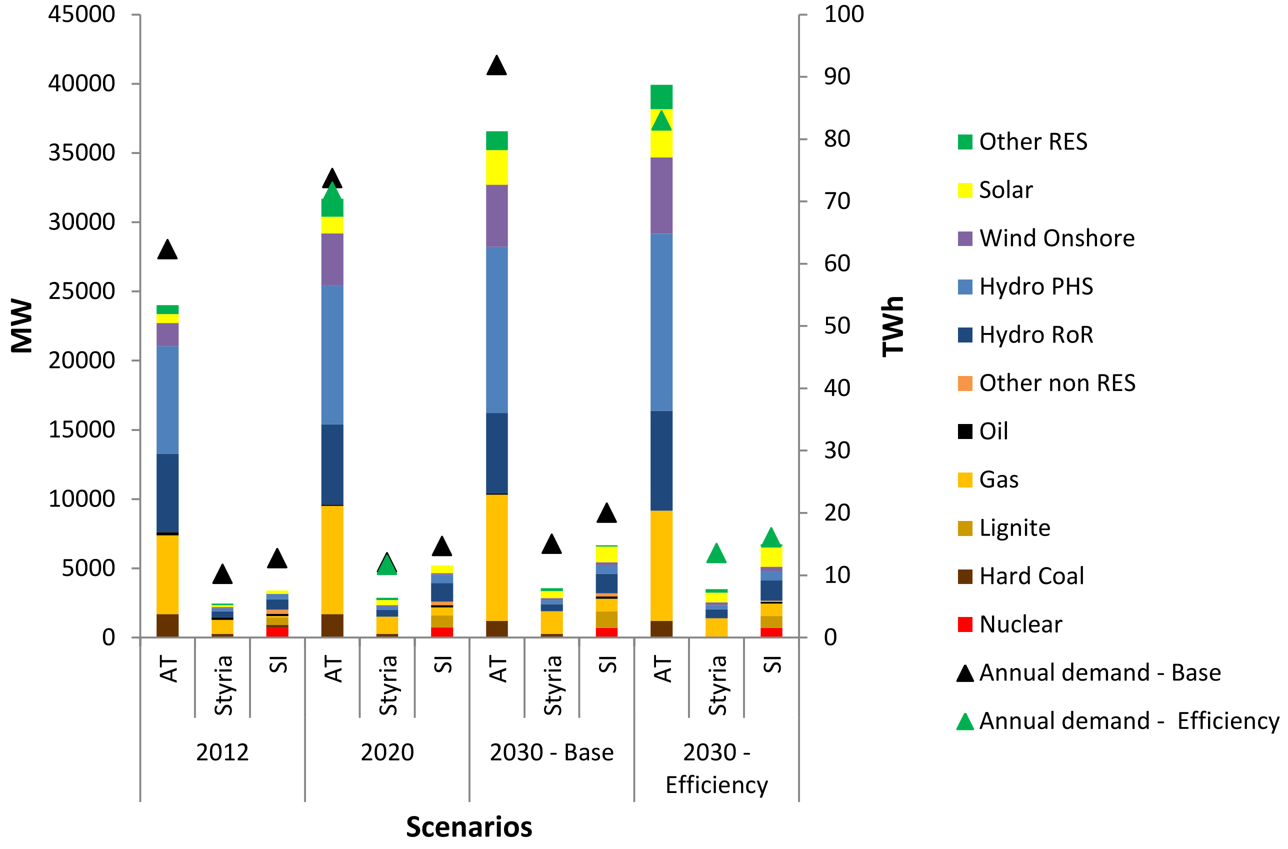

Figure 2-3 Installed capacities and annual electricity demand for Austria, Styria and Slovenia for ‘Base’ and ‘Efficiency’ Scenario up to 2030

3 Development of future electricity price scenarios

In this chapter future electricity price scenarios for 'energy only' market are modeled with own simulation tool EDisOn. Further future electricity market prices, e.g. prices of balancing market are based on historical data and results from FP7 project eBADGE. The quantitative economic analysis, to be worked out in deliverable D3 of the hybridVPP4DSO project, will include sensitivity analysis for future balancing market prices, due to the large uncertainties of future market price development in balancing markets.
Another possible electricity market can be based on different kinds of capacity mechanisms, these are more or less long time contracts and not focus for possible VPP approaches.

3.1 EDisOn market model

For the Austrian bottom-up approach a fundamental market model called EDisOn (Electricity Dispatch Optimization) has been developed in MATLAB® (for more information see [1] and [2]), to analyse in detail the further development of the Austrian electricity market and transmission grid qualified to enable the further integration of RES-E generation. EDisOn is designed as a linear programming problem and is deterministic in nature, assumes a perfect competitive market with perfect foresight, and uses an hourly resolution of a full year. Generation capacities are given exogenously. (Pumped)-hydro storage and Run-of-River (RoR) are following an annual pattern. Electricity generation of Wind and PV are considered based on historical data, but it is also possible to implement a time series based on a stochastic process. EDisOn covers the whole transmission system of Austria (220 and 380 kV-level) as well as its interconnections to neighbouring countries.

Austria is divided into 17 load and generation nodes, which correlate with the main substations within Austria, and 6 nodes in the neighbouring countries. Generation is allocated to the closest node and the load allocation is based on population figures and large industrial sites. All parallel transmission power lines (TPL) between the nodes are merged to one representative TPL, which leads to a total of 35 TPLs (see Figure 3-1below).

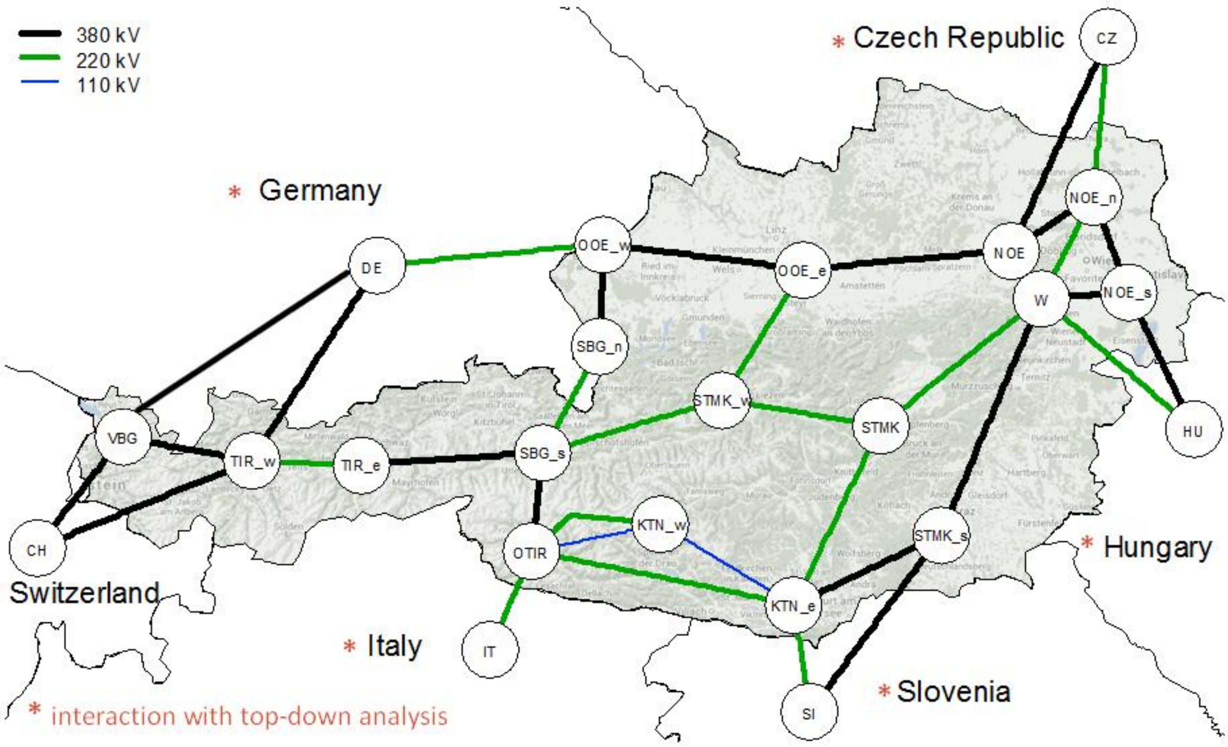

Figure 3-1: Austrian transmission grid supposed for the year 2020

The objective of the Linear Optimization Problem (LOP) model is to obtain the schedule that minimizes the total operational costs of the electricity system by considering various costs such as variable costs (e.g. fuel, O&M and CO_2 costs). There are also several technical constraints implemented, e.g. generation capacity constraints, maximum ramp rates, reservoir balance, spillage of hydro, RES-E generation technologies etc., having to be fulfilled in the whole simulation horizon. The power flows between nodes are simulated via power transfer distribution factor (PTDF) matrix. FACTS is considered as phase shifters by phase shifter distribution factors (PSDF) and also HVDC lines with DC distribution factors (DCDF) (see [3] and [4]).

Below there are all sets with the corresponding indices, parameters and decision variables of the market model listed.

H (index h)	set of time steps (hours)
I (index i)	set of nodes
$L \subset L_{AC} \dot{\cup} L_{DC}$ (index l, l_{AC}, l_{DC})	set of transmission power lines (AC and DC)
TH_i (index th_i)	set of thermal units in node i

	Description	Unit
C^{CO_2}	CO_2 prices	EUR/t CO_2
C^{WindPV}	generation costs of Wind and PV systems	EUR/MWh
C^{Hydro}	generation costs of Run of River (RoR)	EUR/MWh
$CapLines_l$	NTC-values	MW
DLR_h	Dynamic Line Rating	%
α^{max}	maximum phase shifter angle	°
$Demand_{h,i}$	demand	MWh/h
$VoLL$	Value of Lost Load	EUR/MWh
$SRMC_{h,i,th_i}$	SRMC of thermal power plants	EUR/MWh
$ThEm_{i,th_i}$	CO_2 emissions of thermal power plants	t CO_2/MWh
η^{Th}_{i,th_i}	efficiency of thermal power plants	%
$rampLimit$	ramping limit of thermal power plants	%
$ThCap^{max}_{h,i,th_i}$	max capacity of thermal power plants	MW
$KindTh_{i,th_i}$	kind of thermal power plant	Gas, Coal, Lignite, Oil, Bio, Nuclear
$HyCap^{max}_i$	max capacity of RoR	MW
η^{Hy}	efficiency of RoR	%
$Inflow_{h,i}$	natural inflow RoR	MWh/h
$PHSTuCap^{max}_i$	max turbine capacity	MW
$PHSPuCap^{max}_i$	max pump capacity	MW
η^{Tu}	efficiency of the turbine	%
η^{Pu}	efficiency of the pump	%
$PHSStor_h$	relative value of storage level	%
$PHSEn^{max}_i$	max storage level PHS	MWh
$PHSEn^{min}_i$	min storage level PHS	MWh
$InflowPHS_{h,i}$	natural inflow PHS	MWh/h
$Wind_{h,i}$	generation of wind turbines	MWh/h
$PV_{h,i}$	generation of PV systems	MWh/h
$PTDF_{l,i}$	power transfer distribution factors of the grid	
$PSDF_{l_{AC},l_{pst}}$	phase shift distribution factors of the grid	
$DCDF_{l_{AC},l_{DC}}$	DC lines distribution factors of the grid	

	Description	Unit
thP_{h,i,th_i}	generation of thermal power plants	MWh/h
$\mathrm{hyP}_{h,i}$	generation of RoR	MWh/h
$\mathrm{tuP}_{h,i}$	generation of PHS	MWh/h
$\mathrm{puP}_{h,i}$	demand for pumping	MWh/h
$\mathrm{storLev}_{h,i}$	storage level of PHS	MWh
${\mathrm{Spill}^{\mathrm{Hy}}}_{h,i}$	RoR spillage	MWh/h
${\mathrm{Spill}^{\mathrm{WindPV}}}_{h,i}$	Wind/PV spillage (RES-curtailment)	MWh/h
$\mathrm{NSE}_{h,i}$	Not Supplied Energy (NSE) at node i at time step h	MWh/h
$\mathrm{Exch}_{i,h}$	power injection in the grid at node i at time step h	MWh/h
$\mathrm{Flow}_{l,h}$	power flow on transmission line l at time step h	MWh/h
$\alpha_{l_{pst},h}$	phase shifter angle at line l_{pst} at time step h	°

3.1.1 Target function

The minimisation of total generation costs is the target function of the market model. Not only thermal generation is considered with its short run marginal costs (SRMC), but also some small amounts of RoR, PV and wind generation are taken into account. The last term in (1) is for demand, which cannot be covered. In some literature, e.g. [5], the average value of lost load (VoLL) is between 10,000 and 20,000 USD/MWh. In this analysis a VoLL of 10,000 EUR/MWh is assumed.

$$\begin{aligned}\min TotalCs \stackrel{!}{=} \sum_{i,h}\sum_{th_i} & \mathrm{thP}_{h,i,th_i} \cdot SRMC_{h,i,th_i} + \mathrm{hyP}_{h,i} \cdot C^{Hydro} \\ & + (PV_{h,i} + Wind_{h,i} - {\mathrm{Spill}^{\mathrm{WindPV}}}_{h,i}) \cdot C^{WindPV} \\ & + \mathrm{NSE}_{h,i} \cdot VoLL\end{aligned} \tag{1}$$

with $SRMC_{h,i,th_i} = C^{O\&M} + C^{fuel}_{th_i}/\eta^{Th}_{i,th_i} + C^{CO_2} \cdot ThEm_{i,th_i}/\eta^{Th}_{i,th_i}$, where the indices h describe time (hour), i the node and th_i the kind of thermal unit in node i.

3.1.2 Constraints

The following constraint is one of the most important ones. Demand in every node has to be covered by supply in every simulated hour.

$$\begin{aligned}& \forall h \in H, \forall i \in I: \\ Demand_{h,i} - \mathrm{NSE}_{h,i} = & \sum_{th_i} \mathrm{thP}_{h,i,th_i} + \mathrm{hyP}_{h,i} + Wind_{h,i} + PV_{h,i} \\ & - {\mathrm{Spill}^{\mathrm{WindPV}}}_{h,i} + \mathrm{tuP}_{h,i} - \mathrm{puP}_{h,i} - \mathrm{Exch}_{h,i}\end{aligned} \tag{2}$$

For thermal power plants there are some technical constraints, which have to be considered in market models. Thermal units are able to produce less than the maximum capacity only, which is defined in equation (3) and generation can be increased or decreased stepwise (see inequalities (4)).

$$0 \leq \mathrm{thP}_{h,i,th_i} \leq ThCap^{max}_{h,i,th_i} \qquad \forall(h,i,th_i) \tag{3}$$

$$\begin{aligned} &\forall h \geq 2, \forall(i,th_i): \\ &\mathrm{thP}_{h,i,th_i} - \mathrm{thP}_{h-1,i,th_i} \leq rampLimit \cdot ThCap^{max}_{h-1,i,th_i} \\ -&\mathrm{thP}_{h,i,th_i} + \mathrm{thP}_{h-1,i,th_i} \leq rampLimit \cdot ThCap^{max}_{h-1,i,th_i} \end{aligned} \tag{4}$$

The run of river plants can generate less than the maximum capacity only and should be equal to the natural inflow, which is calculated by using the annual average production. In this context the variable $\mathrm{Spill^{Hy}}_{h,i}$ means, that the lock of a RoR plant is open. Therefore, a certain amount of MWh is not used for electricity generation.

$$\begin{aligned} &\forall(h,i): \\ &0 \leq \mathrm{hyP}_{h,i} \leq HyCap^{max}_i \\ &\mathrm{hyP}_{h,i} + \mathrm{Spill^{Hy}}_{h,i} = Inflow_{h,i} \cdot \eta^{Hy} \end{aligned} \tag{5}$$

The pumps and the turbines of the PHS plants are limited to their technical maximum.

$$\begin{aligned} &\forall(h,i): \\ &0 \leq \mathrm{puP}_{h,i} \leq PHSPuCap^{max}_i \\ &0 \leq \mathrm{tuP}_{h,i} \leq PHSTuCap^{max}_i \end{aligned} \tag{6}$$

In Austria, the reservoir content of storage of PHS plants follows a certain annual pattern based on data of E-Control (Austrian Regulator) from 1997 to 2011 and is limited to its maximum and minimum storage level. In addition, the equations describing the storage level balance are very important (see equation (7) and (8)).

$$\begin{aligned} &\forall i \in I: \\ \mathrm{storLev}_{1,i} =& PHSstor_1 \cdot PHSEn^{max}_i - \frac{\mathrm{tuP}_{1,i}}{\eta^{Tu}} + \mathrm{puP}_{1,i} \cdot \eta^{Pu} \\ &+ InflowPHS_{1,i} \end{aligned} \tag{7}$$

$$\begin{aligned} &\text{for } h \geq 2 \text{ and } \forall i \in I: \\ &\mathrm{storLev}_{h,i} = \mathrm{storLev}_{h-1,i} - \frac{\mathrm{tuP}_{h,i}}{\eta^{Tu}} + \mathrm{puP}_{h,i} \cdot \eta^{Pu} \\ &\qquad + InflowPHS_{h,i} \end{aligned} \tag{8}$$

$$PHSEn_i^{min} \leq \text{storLev}_{h,i} \leq PHSEn_i^{max} \qquad \forall(h,i) \tag{9}$$

The exchanges - or more precisely the injections - have to be equal the sum of the flows, which are going out and coming in, compare [4]. Therefore, negative injection in a node means that demand is higher than supply and vice versa. The power flow on each TPL has to be between the lower and the upper capacity limit of each TPL and the same applies for the phase angles of the phase shifters and their maximum value, variables $\alpha_{l_{pst},h}$ and α^{max} (see equation and inequalities (10)-(12)). The power flows also have to satisfy equation (13), where the PTDF, PSDF and DCDF are respected.

$$\forall h \in H, \forall i \in I: \\ \text{Exch}_{i,h} = \sum_{l \in L} A_{l,i} \cdot \text{Flow}_{l,h} \tag{10}$$

$$\forall l \in L \subset L_{AC} \dot{\cup} L_{DC}, \forall h \in H: \\ -CapLines_l \cdot DLR_h \leq \text{Flow}_{l,h} \leq CapLines_l \cdot DLR_h \tag{11}$$

$$\forall l_{pst} \in L_{pst} \subset L_{AC}, \forall h \in H: \\ -\alpha^{max} \leq \alpha_{l_{pst},h} \leq \alpha^{max} \tag{12}$$

$$\begin{aligned} \forall l_{AC} \in L_{AC}, \forall h \in H: & \\ \text{Flow}_{l_{AC},h} = & \sum_{i \in I} PTDF_{l_{AC},i} \cdot \text{Exch}_{i,h} \\ & + \sum_{l_{pst} \in L_{pst} \subset L_{AC}} PSDF_{l_{AC},l_{pst}} \cdot \alpha_{l_{pst},h} \\ & + \sum_{l_{DC} \in L_{DC}} DCDF_{l_{AC},l_{DC}} \cdot \text{Flow}_{l_{DC},h} \end{aligned} \tag{13}$$

The remaining constraints are for considering RES-E curtailment of wind and PV and for limiting the occurrence of NSE.

$$\forall h \in H, \forall i \in I: \\ 0 \leq \text{Spill}^{\text{WindPV}}{}_{h,i} \leq Wind_{h,i} + PV_{h,i} \\ 0 \leq \text{NSE}_{h,i} \leq Demand_{h,i} \tag{14}$$

3.1.3 Calculation of the PTDF, PSDF and DCDF matrices

The matrix B_d is a symmetric L_{AC}-dimensional matrix with the susceptances of the TPLs in the diagonal entries and the remaining entries are zero. The matrix A comprises the incidence matrix; it describes which nodes are connected with each other. The PTDF, PSDF and DCDF matrices are calculated as follows (for details see [3]):

$$PTDF^{L_{AC} \times I} = (B_d \cdot A) \cdot (A^T \cdot B_d \cdot A)^{-1} \quad (15)$$

$$PSDF^{L_{AC} \times L_{pst}} = B_d - (B_d \cdot A) \cdot (A^T \cdot B_d \cdot A)^{-1} \cdot (B_d \cdot A)^T \quad (16)$$

$$DCDF^{L_{AC} \times L_{DC}} = -PTDF \cdot A_{DC}^T \quad (17)$$

The hourly based results of the different scenarios provide the basis for the calculation of the electricity system benefits (welfare, congestion rent, fossil fuel, CO_2 emissions and others). For the evaluation of the benefits the key indicators as shown in Table 3-1 are applicable (see [6]).

Table 3-1 Key indicators

Benefit/Aspect	Key indicators
Social Welfare increase	Ability of a power system to reduce congestion as a basis for an efficient market
Reliability increase	Adequate and secure supply of electricity
Resilience improvement	Ability of the system to withstand increasingly extreme system conditions
CO_2 emissions reduction	CO_2 emissions in the power system
RES-E spillage reduction	Reduce the RES-E curtailed energy
Controllability & Flexibility increase	Possibility to control power flows and different possible future development paths or scenarios
Socio-environmental impact	Public acceptance and environmental impact

3.2 Results

3.2.1 2020 Analysis

The wholesale prices of Austria and neighbouring countries for the year 2020 'Base' scenario are presented in Figure 3-2 as annual duration curves. The model results show the price differences between the different countries due to the interconnection congestions. In the used nodal pricing approach Austria has the lowest average marginal cost price of around 34 EUR/MWh. Nevertheless, Austria and Germany has in real-life a common market with the same prices on the wholesale-market any price differences can be explained with uncertainties on the used input parameters.

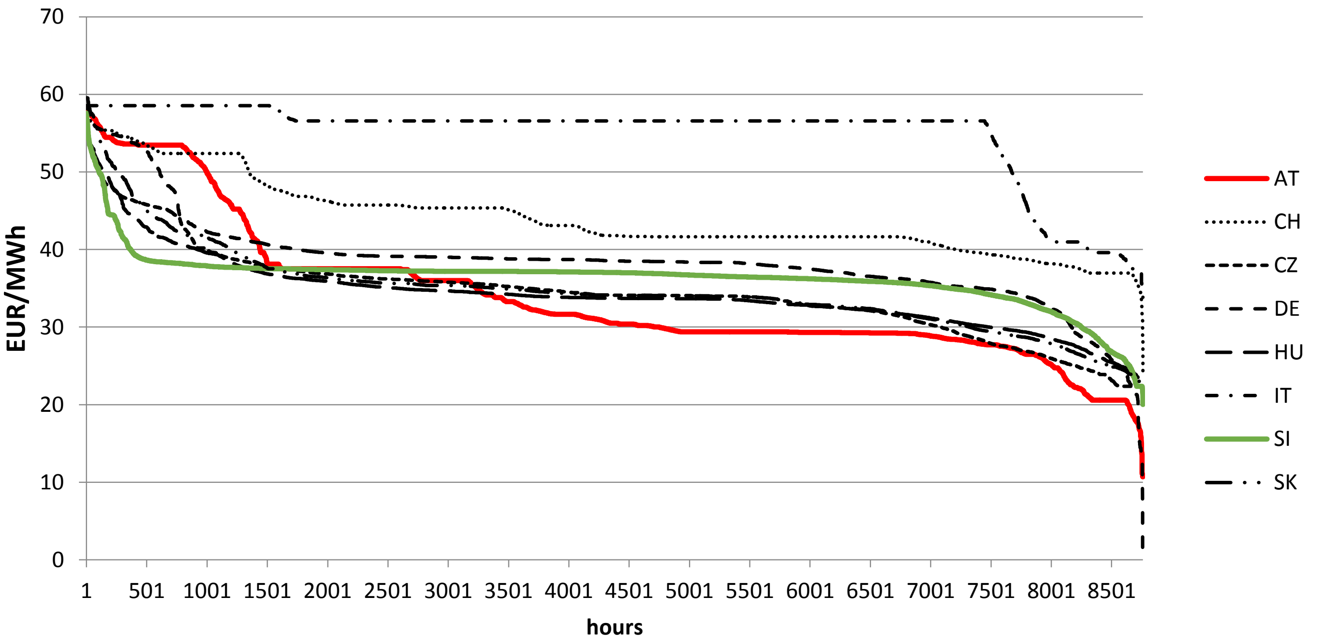

Figure 3-2 Annual duration curves of wholesale electricity prices for the year 2020 'Base'-scenario

Figure 3-3 and Figure 3-4 show the electricity price differences between the both scenarios 'Base' and 'Efficiency'. The largest prices spread between the both scenarios are during high price hours, as represented in Figure 3-3 on the left side of the annual duration curve diagram with a maximum of 12.4 EUR/MWh. The average marginal price for the 'Base' scenario is around 34 EUR/MWh and for 'Efficiency' scenario around 30 EUR/MWh for the year 2020.

For the further economic analysis in deliverable D3.1 the most relevant model result is the sequence of hourly wholesale prices as shown in Figure 3-4. The maximum price spread is in 'Base' scenario up to 16 EUR/MWh and in 'Efficiency' scenario up to 14 EUR/MWh. The value of price changes of consecutive hours is 5310 in 'Base' scenario and 4778 in 'Efficiency' scenario. Nevertheless, compared with the annual duration curve, the maximum price difference between 'Base' and 'Efficiency' scenario is 19.5 EUR/MWh.

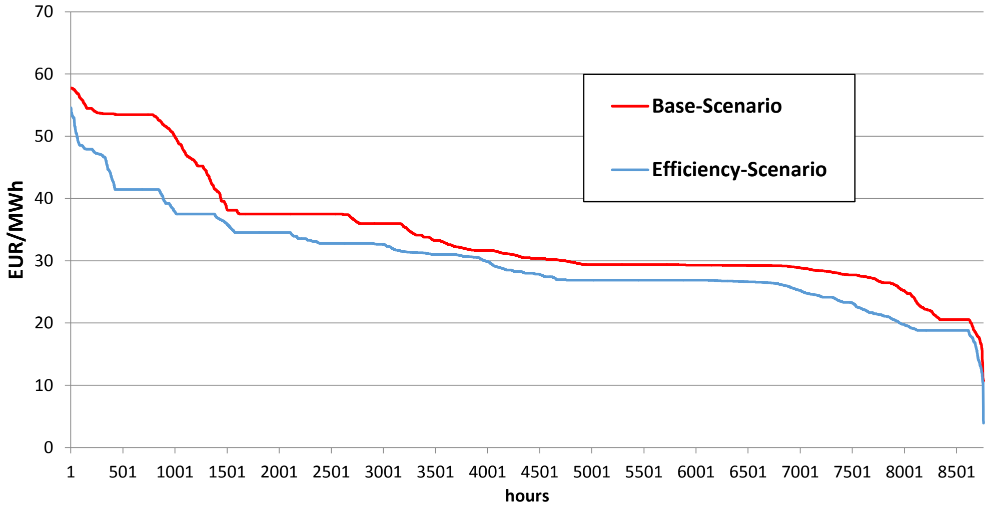

Figure 3-3 Comparison of the annual duration curves of wholesale electricity prices in Austria for 'Base' and 'Efficiency'-scenario for the year 2020

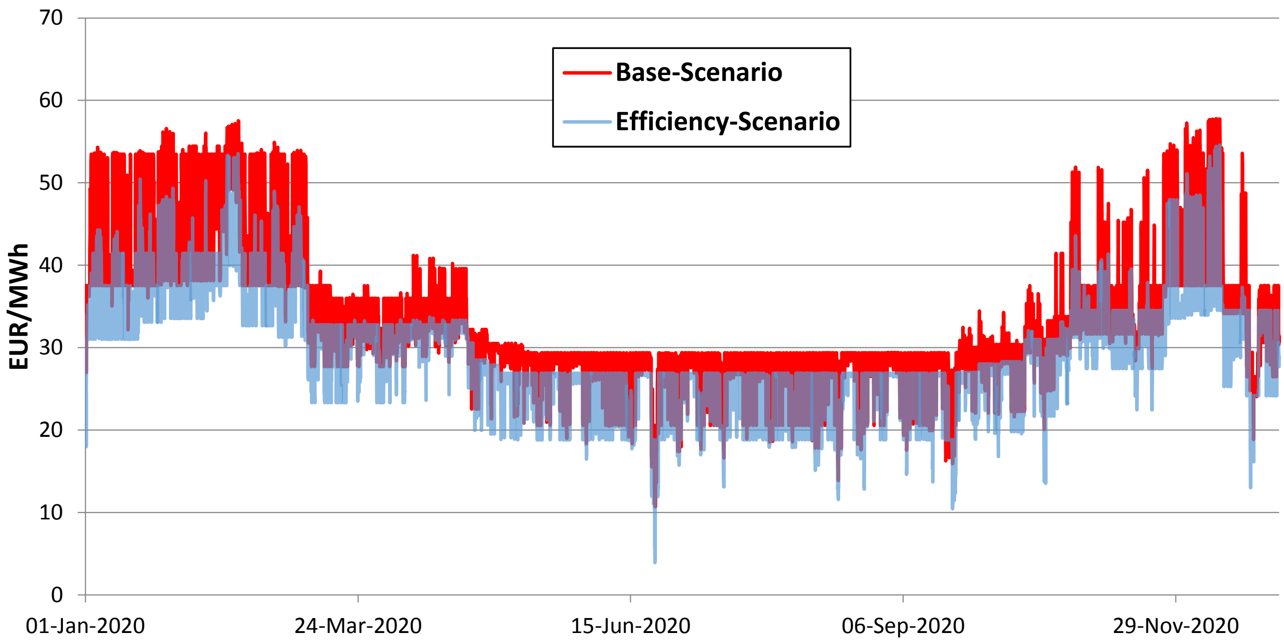

Figure 3-4 Comparison of the hourly wholesale electricity prices in Austria for 'Base' and 'Efficiency'-scenario for the year 2020

3.2.2 2030 Analysis

The wholesale prices of Austria and neighbouring countries for the year 2030 'Base' scenario are presented in Figure 3-5 as annual duration curves. Compared to the 2020 analysis in section 3.2.1 the electricity price difference between the different countries is more or less diminished due to the expansion of the European transmission grid, mostly driven by the Projects of Common Interest (PCI) support of the European Commission [9]. The model results of the average wholesale electricity prices are around 60 EUR/MWh. The increasing electricity price compared to year 2020 is mainly influenced by the higher CO2 emission price in year 2030.

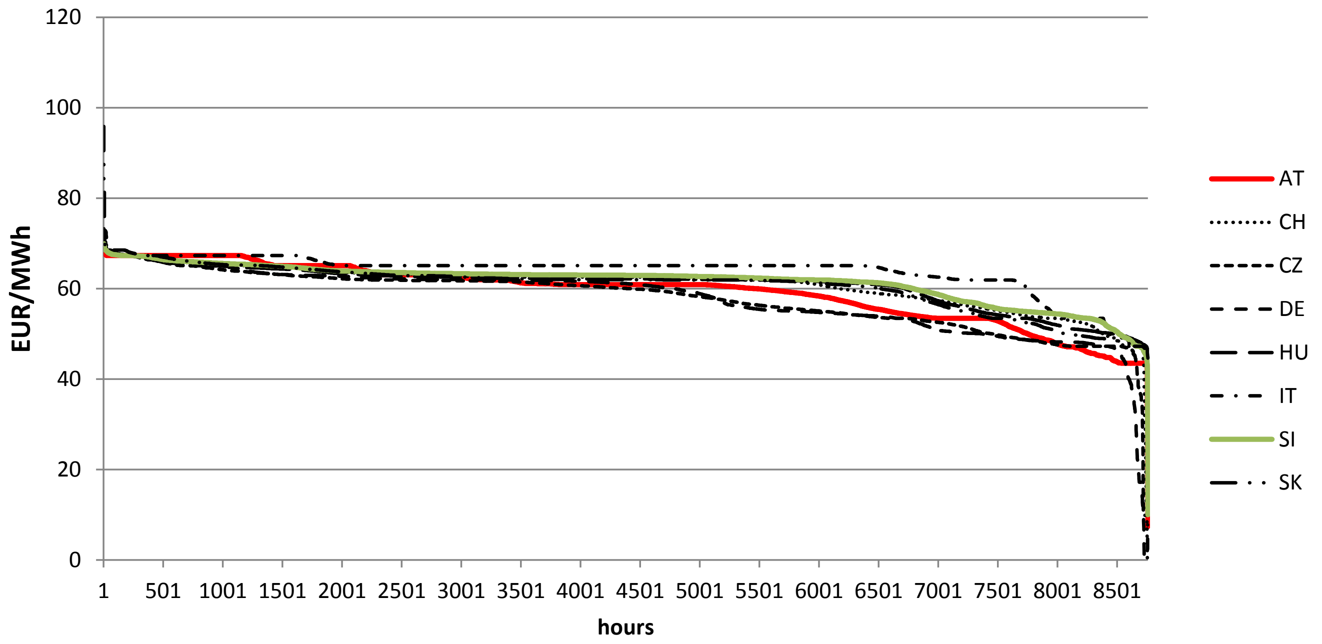

Figure 3-5 Annual duration curves of wholesale electricity prices for the year 2030 'Base'-scenario

Figure 3-6 and Figure 3-7 show the electricity price differences between the both scenarios 'Base' and 'Efficiency'. The prices spread between the both scenarios are also more or less diminished in the annual duration curve, which can be explained again due to the expansion of the European transmission grid.

For the further economic analysis in deliverable D3 the most relevant model result is the sequence of hourly wholesale prices as shown in Figure 3-7. The maximum price spread is in 'Base' scenario up to 23 EUR/MWh and in 'Efficiency' scenario up to 16 EUR/MWh, that is a little bit higher than 2020. The value of price changes of consecutive hours is 5318 in 'Base' scenario (similar as in 2020) and 6914 in 'Efficiency' scenario (50% higher as in 2020). The maximum price difference between 'Base' and 'Efficiency' scenario is around 41 EUR/MWh in 2030 and therefore 2 times higher than in 2020.

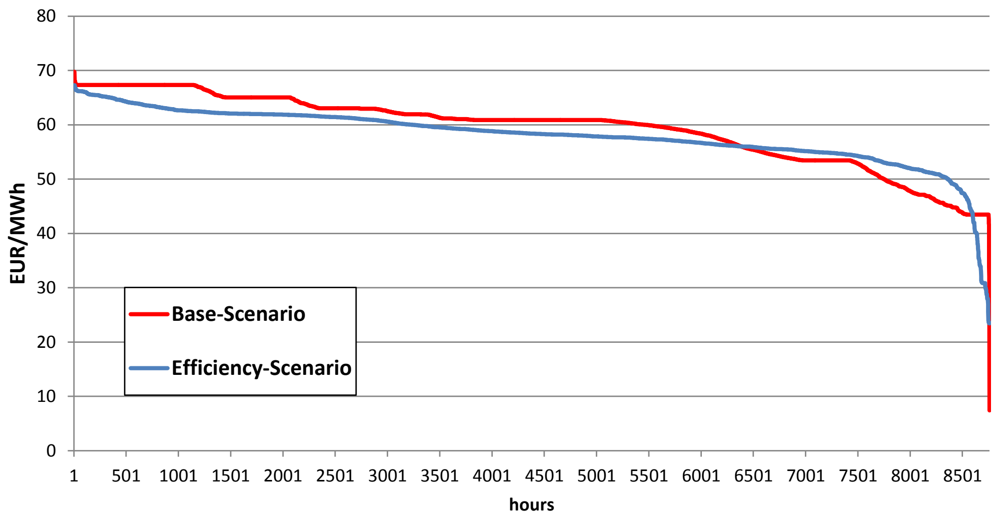

Figure 3-6 Comparison of the annual duration curves of wholesale electricity prices in Austria for 'Base' and 'Efficiency'-scenario for the year 2030

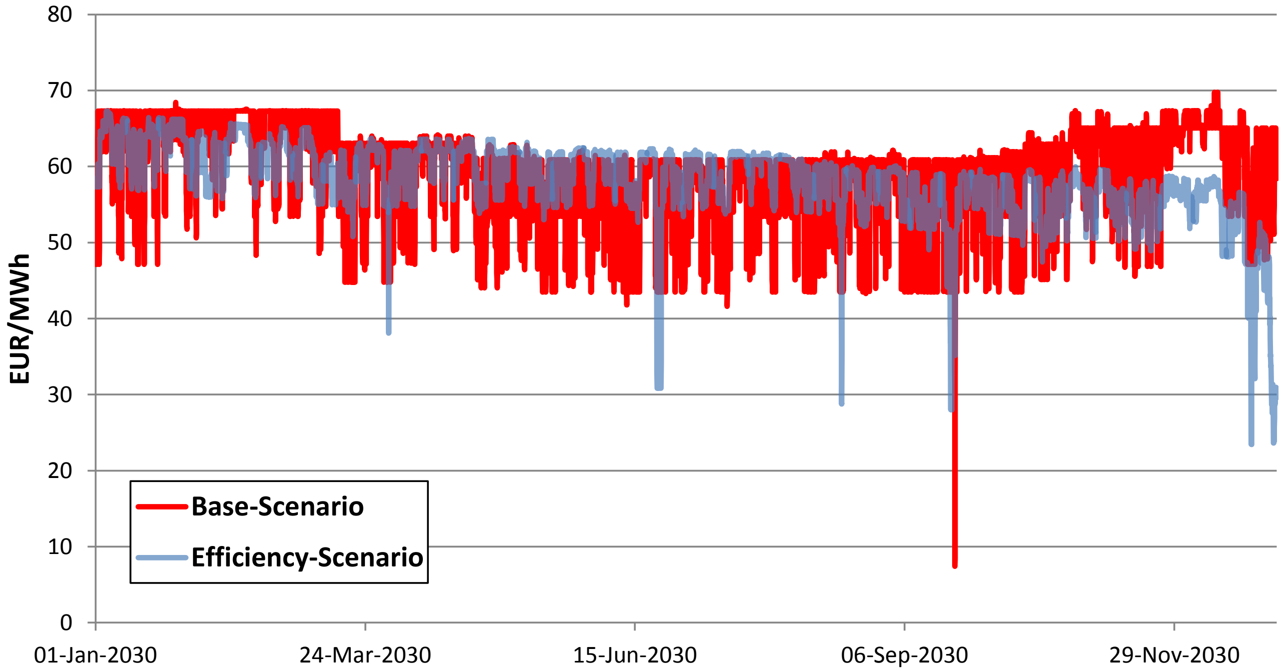

Figure 3-7 Comparison of the hourly wholesale electricity prices in Austria for 'Base' and 'Efficiency'-scenario for the year 2030

4 Qualitative analysis of hybrid-VPP business models

Based on the four business models defined in deliverable D1 of the hybrid VPP4DSO project [10] a qualitative analysis is the main topic of this chapter 4. Depending on which party is operating the VPP for a certain purpose, a different business model applies (which is in this text called 'VPP-operator'). Four different business models are considered in this project, based on the affiliation of VPPs, as follows:

- DSO
- Energy Retailer
- Independent Aggregator
- Customer VPP.

The qualitative analysis defined the evaluation criterions from deliverable D1 [10] with very positive (++), positive (+), neutral (o), negative (-) or very negative (--) assessment for each VPP-operator and the interdependencies and competition to the other stakeholders, as follows:

- DSO as competitor without VPP.
- Energy Retailer as competitor without VPP.
- Aggregator as competitor with 'market'-VPP.
- hybrid-VPP-participant with flexible load and/or generation.
- Other customers.

The weighting of the evaluation criterions is uniformly distributed. The reason for this is a better comparability of the different assessment of the different VPP-owner and their different technical and economic objective functions.

4.1 DSO

The assessment for the DSO as VPP-operator and owner is shown in Table 4-1 and has the highest technical benefit to solve grid problems with the hybrid-VPP, due to the priority to operate the VPP as a 'Grid-VPP' (see D1 [10]). Negative from a technical point of view is the geographical limitation of the VPP, because the DSO is limited on its own distribution grid area. To operate a VPP by a DSO the organisational issues like system complexity and the existing customer pool is no problem for the DSO, but he has no information about the participating VPP facilities and no knowledge about energy trading and markets. The regulatory restriction that a DSO is not allowed for energy trading and to operate a VPP as a 'Market-VPP' (see D1 [10]) is very negative for the regulatory evaluation criterion and therefore also for the monetary criterion to get revenues on energy markets. However for the monetary grid view the DSO has very positives assessment as hybrid-VPP-operator, except for the end-users grid costs, because these grid costs are apportioned in grid tariffs for the DSOs. The DSO can achieve a green image, even he has no political targets to fulfil energy efficiency measures or to increase RES share in the energy system. Finally the DSO can develop new tariff structures.

For the other defined market participants like a DSO without VPP, the most evaluation criterions have no influence if another DSO operates a hybrid-VPP. He has only the disadvantages that he cannot use the possibility of a hybrid-VPP for minimizing grid cost investments and to develop a green image and new tariff structures.

The energy retailer which is not participating in the hybrid-VPP profits especially that the DSO as hybrid-VPP-operator can solve grid problems. Therefore he has monetary benefits for energy trading, but he cannot so easily increase his existing customer pool or achieve political aims due to the competition with the hybrid-VPP.

An aggregator with a market-VPP has the similar assessment of the evaluation criterions like the energy retailer without VPP. The markedly differences are in political criterions, which are positive due to the own operation of a VPP, but are negative in case of financing new information and communications technologies (ICT) and structure investments.

The hybrid-VPP participant has the similar assessment as the hybrid-VPP operator. In case the DSO is the operator he has also not the possibility to get revenues by energy trading on the one hand. On the other hand he has positive effect that he can reduce costs for grid requirements.

Other customers have positive evaluation criterions mostly in case of technical and monetary grid issues and to support the fulfilment of political aims.

Summarized, the DSO as hybrid-VPP owner and the other market participant are barely positive evaluated. Exception is the DSO as competitor, which is not positive.

Table 4-1 Qualitative analysis of evaluation matrix for hybrid-VPP business model 'DSO'

active hybrid-VPP		VPP-owner	Stakeholders					
		Affiliation of VPP - DSO	DSO (comp. without VPP)	Energy Retailer (comp. without VPP)	Aggregator (comp. with market-VPP)	hybrid-VPP-participant (flex. load/gen)	Other Customers	Total
Technical	Solution of grid problems	++	o	++	++	++	++	++
	Data safety and security	o	o	o	o	+	o	+
	Geographical limitation / limitation in participating units							
	> geographical limitaion	-	o	o	o	-	o	o
	> limitation in participating units	+	o	o	o	o	o	+
Organisational	High system complexity	++	o	o	o	++	o	+
	Existing information / know-how							
	> information about own facilities	--	o	o	o	-	o	o
	> know-how about trading / energy markets	--	o	o	o	-	o	o
	Existing customer pool	+	o	-	--	o	o	o
Regulatory	Compliance with regulatory framework	--	o	o	o	--	o	o
Political	Fullfilment of political framework conditions e.g. climate targets							
	> share of RES	o	o	-	+	+	++	+
	> energy efficiency	o	o	-	+	+	++	+
Monetary	Possibility to get revenues by business cases - market view							
	> energy only market	--	o	+	+	--	o	o
	> balancing market	--	o	+	+	--	o	o
	> minimizing imbalance costs	--	o	o	o	--	o	o
	Possibility to get revenues by business cases - grid view							
	> minimizing connection costs for customer	o	o	o	o	++	o	+
	> minimizing grid investments for the DSO	++	-	+	+	++	++	++
	> energy provision during failures	++	-	+	+	++	++	++
	> Minimizing grid tariffs charged by DSO / TSO	o	o	+	+	+	+	+
	Low investment costs: ICT, infrastructure, etc.	++	o	o	--	+	o	+
	Avoided grid enhancement	+	-	++	++	++	++	++
Other	Green image	++	--	o	o	++	o	+
	New tariff structures / products	++	--	o	o	++	o	+
Total		+	o	+	+	+	+	+

4.2 Energy Retailer

The assessment for the energy retailer as VPP-operator and owner is shown in Table 4-2 and has the highest technical benefit to solve grid problems with the hybrid-VPP, due to the opportunity to operate the VPP as a 'Grid-VPP' (see D1 [10]) and with no geographical limitation. Negative from a technical point of view is the data safety and security of the VPP, because the energy retailer has to develop new data structures to get the grid data from DSOs and VPP participants. To operate a VPP by an energy retailer the organisational issues like system complexity and the existing customer pool is no problem for the energy retailer and he has also various information about the participating VPP facilities and much knowledge about energy trading and markets. There are no regulatory restrictions if an energy retailer operates a hybrid-VPP. Therefore it is very positive for the monetary criterion to get revenues on energy markets and for the monetary grid view the energy retailer has also positives assessment as hybrid-VPP-operator, except for investment costs for ICT and other technical infrastructures. The energy retailer can achieve a green image and can fulfil political targets like energy efficiency measures or to increase RES share in the energy system. Finally the energy retailer can develop new tariff structures and products.

For the other defined market participants like a DSO without VPP, most evaluation criterions have no influence if the energy retailer operates a hybrid-VPP. He has only the advantages that he can use the possibility of a hybrid-VPP for minimizing grid cost investments and to develop also new tariff structures.

The energy retailer without VPP and competitor of the energy retailer with hybrid-VPP has very negative influence in comparison of monetary benefits for energy trading and he cannot so easily increase his existing customer pool or achieve political aims due to the competition with the energy retailer with hybrid-VPP.

An aggregator with a market-VPP has the similar assessment of the evaluation criterions like the energy retailer without VPP. The markedly differences are in political criterions, which are not so negative due to the own operation of a VPP, but are very negative in case of financing new ICT and structure investments and in case of existing customer pool due to the competition with the energy retailer with hybrid-VPP.

The hybrid-VPP participant has the similar assessment as the hybrid-VPP operator.

Other customers have positive evaluation criterions mostly in case of support the fulfilment of political aims.

Summarized, the energy retailer as hybrid-VPP owner and the participant of this hybrid-VPP are very positive evaluated. The other market participant like DSO and other customers are barely positive evaluated. Energy retailer and aggregators with market-VPP as competitor are neutrally evaluated.

Table 4-2 Qualitative analysis of evaluation matrix for hybrid-VPP business model 'Retailer'

active hybrid-VPP		VPP-owner	Stakeholders					
		Affiliation of VPP - Retailer	DSO	Energy Retailer (comp. without VPP)	Aggregator (comp. with market-VPP)	hybrid-VPP-participant (flex. load/gen)	Other Customers	Total
Technical	Solution of grid problems	++	+	+	+	++	+	++
	Data safety and security	-	o	o	o	-	o	o
	Geographical limitation / limitation in participating units							
	> geographical limitaion	++	o	o	o	++	o	+
	> limitation in participating units	+	o	o	o	+	o	+
Organisational	High system complexity	+	o	o	o	+	o	+
	Existing information / know-how							
	> information about own facilities	+	o	o	o	++	o	+
	> know-how about trading / energy markets	++	o	o	o	++	o	+
	Existing customer pool	++	o	-	--	o	o	o
Regulatory	Compliance with regulatory framework	++	o	o	o	++	o	+
Political	Fullfilment of political framework conditions e.g. climate targets							
	> share of RES	+	o	-	+	+	++	+
	> energy efficiency	+	o	-	+	+	++	+
Monetary	Possibility to get revenues by business cases - market view							
	> energy only market	++	o	-	-	++	o	+
	> balancing market	++	o	--	-	++	o	+
	> minimizing imbalance costs	++	o	--	-	++	+	+
	Possibility to get revenues by business cases - grid view							
	> minimizing connection costs for customer	o	o	o	o	+	o	+
	> minimizing grid investments for the DSO	+	+	o	o	+	+	+
	> energy provision during failures	+	o	o	o	+	o	+
	> Minimizing grid tariffs charged by DSO / TSO	+	o	+	+	+	+	+
	Low investment costs: ICT, infrastructure, etc.	-	o	o	--	-	o	o
	Avoided grid enhancement	+	+	+	+	+	+	+
Other	Green image	++	o	-	o	++	o	+
	New tariff structures / products	++	+	o	o	++	o	+
Total		++	+	o	o	++	+	+

4.3 Independent Aggregator

The assessment for an independent aggregator as VPP-operator and owner is shown in Table 4-3 and has the highest technical benefit to solve grid problems with the hybrid-VPP, due to the opportunity to operate the VPP as a 'Grid-VPP' (see D1 [10]) and with no geographical limitation. Very negative from a technical point of view is the data safety and security of the VPP, because the aggregator has to develop totally new data structures to get the grid data from DSOs, energy retailers and VPP participants. Organisational issues like system complexity and the existing customer pool could be problem for the aggregator, in the case it operates a VPP. Besides that the aggregator also has no information about the participating VPP facilities and no historical knowledge about energy trading and markets. There are no regulatory restrictions that an independent aggregator operates a hybrid-VPP. Therefore it is very positive for the monetary criterion to get revenues on energy markets and for the monetary grid view the aggregator has also positives assessment as hybrid-VPP-operator, except for investment costs for ICT and other technical infrastructures. The independent aggregator can achieve a green image and can fulfil has political targets like energy efficiency measures or to increase RES share in the energy system. Finally the independent aggregator can develop new tariff structures and products.

For the other defined market participants like a DSO without VPP, the most evaluation criterions have no influence if the independent aggregator operates a hybrid-VPP. He has only the advantages that he can use the possibility of a hybrid-VPP for minimizing grid cost investments and to develop also new tariff structures.

The energy retailer without VPP has very negative influence in comparison of monetary benefits for energy trading and he cannot so easily increase his existing customer pool or achieve political aims due to the competition with the independent aggregator with hybrid-VPP.

An aggregator with a market-VPP and competitor of the aggregator with hybrid-VPP has the similar assessment of the evaluation criteria like the energy retailer without VPP. The markedly differences are in political criterions, which are positive due to the own operation of a VPP, but are very negative in case of financing new ICT and structure investments and in case of existing customer pool, the same situation like the aggregator with hybrid-VPP. Compared with the aggregator with hybrid-VPP the green image and development of new tariff structures is negative for an aggregator with market-VPP.

The hybrid-VPP participant has the similar assessment as the hybrid-VPP operator.

Other customers have positive evaluation criterions mostly in case of support the fulfilment of political aims.

Summarized, the independent aggregator as hybrid-VPP owner and the participant of this hybrid-VPP are positive evaluated, also the other market participant like DSO and other customers are barely positive evaluated. Energy retailer and aggregators with market-VPP as competitor are neutrally evaluated.

Table 4-3 Qualitative analysis of evaluation matrix for hybrid-VPP business model 'Aggregator'

active hybrid-VPP		VPP-owner	Stakeholders					
		Affiliation of VPP - Aggregator	DSO	Energy Retailer (comp. without VPP)	Aggregator (comp. with market-VPP)	hybrid-VPP-participant (flex. load/gen)	Other Customers	Total
Technical	Solution of grid problems	++	+	+	+	++	+	++
	Data safety and security	--	o	o	o	--	o	o
	Geographical limitation / limitation in participating units							
	> geographical limitaion	++	o	o	o	++	o	+
	> limitation in participating units	+	o	o	o	+	o	+
Organisational	High system complexity	-	o	o	o	o	o	o
	Existing information / know-how							
	> information about own facilities	+	o	o	o	++	o	+
	> know-how about trading / energy markets	+	o	o	o	+	o	+
	Existing customer pool	--	o	-	--	o	o	o
Regulatory	Compliance with regulatory framework	++	o	o	o	++	o	+
Political	Fullfilment of political framework conditions e.g. climate targets							
	> share of RES	++	o	-	+	+	++	+
	> energy efficiency	++	o	-	+	+	++	+
Monetary	Possibility to get revenues by business cases - market view							
	> energy only market	++	o	-	-	++	o	+
	> balancing market	++	o	--	-	++	o	+
	> minimizing imbalance costs	+	o	--	-	++	+	+
	Possibility to get revenues by business cases - grid view							
	> minimizing connection costs for customer	o	o	o	o	+	o	+
	> minimizing grid investments for the DSO	+	+	o	o	+	+	+
	> energy provision during failures	+	o	o	o	+	o	+
	> Minimizing grid tariffs charged by DSO / TSO	+	o	+	+	+	+	+
	Low investment costs: ICT, infrastructure, etc.	--	o	o	--	-	o	o
	Avoided grid enhancement	+	+	+	+	+	+	+
Other	Green image	++	o	-	-	++	o	+
	New tariff structures / products	++	+	o	-	++	o	+
Total		+	+	o	o	+	+	+

4.4 Customer VPP

The assessment for a single customer as VPP-operator and owner is shown in Table 4-4 and has the highest technical benefit to solve grid problems with the hybrid-VPP, due to the opportunity to operate the VPP as a 'Grid-VPP' (see D1 [10]). Very negative from a technical point of view is the limitation in participating units of the VPP, because the customer is limited on its own flexible generation and loads. To operate a VPP by a single customer the organisational issues like system complexity could be problem for the customer and he has no historical knowledge about energy trading and markets. There are no regulatory restrictions that a customer operates a hybrid-VPP. Therefore it is very positive for the monetary criterion to get revenues on energy markets and for the monetary grid view the customer has also positives assessment as hybrid-VPP-operator, except for investment costs for ICT and other technical infrastructures. The customer can achieve a green image and can fulfil has political targets like energy efficiency measures or to increase RES share in the energy system. Finally the customer can support the development of new tariff structures and products.

For the other defined market participants like a DSO without VPP, the most evaluation criterions have no influence if the customer operates a hybrid-VPP. He has only the advantages that he can use the possibility of a hybrid-VPP for minimizing grid cost investments, reduce energy provision during failures and to develop also new tariff structures.

The energy retailer without VPP has very negative influence in comparison of monetary benefits for energy trading and he cannot so easy increase his existing customer pool or achieve political aims due to the competition with the customer with hybrid-VPP.

An aggregator with a market-VPP and competitor of the customer with hybrid-VPP has the similar assessment of the evaluation criterions like the energy retailer without VPP. The markedly differences are in political criterions, which are positive due to the own operation of a VPP, but are very negative in case of financing new ICT and structure investments and negative in case of existing customer pool.

The hybrid-VPP participant has the similar assessment as the hybrid-VPP operator.

Other customers have positive evaluation criterions mostly in case of support the fulfilment of political aims.

Summarized, the customer as hybrid-VPP owner and the participant of this hybrid-VPP are positive evaluated, also the other market participant like DSO and other customers are barely positive evaluated. Energy retailer and aggregators with market-VPP as competitor are neutral evaluated.

Table 4-4 Qualitative analysis of evaluation matrix for hybrid-VPP business model 'Customer'

active hybrid-VPP		VPP-owner	Stakeholders					
		Affiliation of VPP - Customers	DSO	Energy Retailer (comp. without VPP)	Aggregator (comp. with market-VPP)	hybrid-VPP-participant (flex. load/gen)	Other Customers	Total
Technical	Solution of grid problems	++	+	+	+	++	+	++
	Data safety and security	+	o	o	o	+	o	+
	Geographical limitation / limitation in participating units							
	> geographical limitaion	+	o	o	o	+	o	+
	> limitation in participating units	--	o	o	o	--	o	o
Organisational	High system complexity	-	o	o	o	-	o	o
	Existing information / know-how							
	> information about own facilities	++	o	o	o	++	o	+
	> know-how about trading / energy markets	-	o	o	o	-	o	o
	Existing customer pool	+	o	--	-	++	o	o
Regulatory	Compliance with regulatory framework	++	o	o	o	++	o	+
Political	Fullfilment of political framework conditions e.g. climate targets							
	> share of RES	++	o	-	+	++	++	+
	> energy efficiency	++	o	-	+	++	++	+
Monetary	Possibility to get revenues by business cases - market view							
	> energy only market	++	o	-	-	++	o	+
	> balancing market	++	o	--	-	++	o	+
	> minimizing imbalance costs	++	o	--	-	++	+	+
	Possibility to get revenues by business cases - grid view							
	> minimizing connection costs for customer	++	o	o	o	++	o	+
	> minimizing grid investments for the DSO	+	+	o	o	++	+	+
	> energy provision during failures	+	+	o	o	+	++	+
	> Minimizing grid tariffs charged by DSO / TSO	+	o	+	+	+	+	+
	Low investment costs: ICT, infrastructure, etc.	--	o	o	--	--	o	-
	Avoided grid enhancement	+	+	+	+	+	+	+
Other	Green image	++	o	-	++	++	o	+
	New tariff structures / products	+	+	o	+	+	o	+
Total		+	+	o	o	+	+	+

4.5 Comparison of hybrid-VPP business models

4.5.1 VPP-owner

A direct comparison of all evaluation criterions between the 4 VPP-owner is shown in Table 4-5 as a qualitative assessment and in Figure 4-1 a more detailed illustration per unit. The total results of the assessment from VPP-owner show that an energy retailer has the highest benefit to operate a hybrid-VPP, followed by customer and aggregator. Due to the regulatory restriction, that a DSO is not allowed for energy trading and to operate a VPP as a 'Market-VPP', the DSO as VPP-owner has the lowest benefit. If the regulatory restriction is no problem for the DSO to operate a hybrid-VPP also as market-VPP, the totals result of the assessment is in the same range as for aggregator or customer (see Figure 4-2).

Table 4-5 Comparison of the qualitative analysis of evaluation matrix for hybrid-VPP owner

active hybrid-VPP		VPP-owner			
		DSO	Retailer	Aggregator	Customers
Technical	Solution of grid problems	++	++	++	++
	Data safety and security	o	-	--	+
	Geographical limitaion	-	++	++	+
	Limitation in participating units	+	+	+	--
Organisational	High system complexity	++	+	-	-
	Information about own facilities	--	+	+	++
	Know-how about trading / energy markets	--	++	+	-
	Existing customer pool	+	++	--	+
Regulatory	Compliance with regulatory framework	--	++	++	++
Political	Share of RES	o	+	++	++
	Energy efficiency	o	+	++	++
Monetary	Energy only market	--	++	++	++
	Balancing market	--	++	++	++
	Minimizing imbalance costs	--	++	+	++
	Minimizing connection costs for customer	o	o	o	++
	Minimizing grid investments for the DSO	++	+	o	o
	Energy provision during failures	++	+	+	+
	Minimizing grid tariffs charged by DSO / TSO	o	+	+	+
	Low investment costs: ICT, infrastructure, etc.	++	-	--	--
	Avoided grid enhancement	+	+	+	+
Other	Green image	++	++	++	++
	New tariff structures / products	++	++	++	+
Total		+	++	+	+

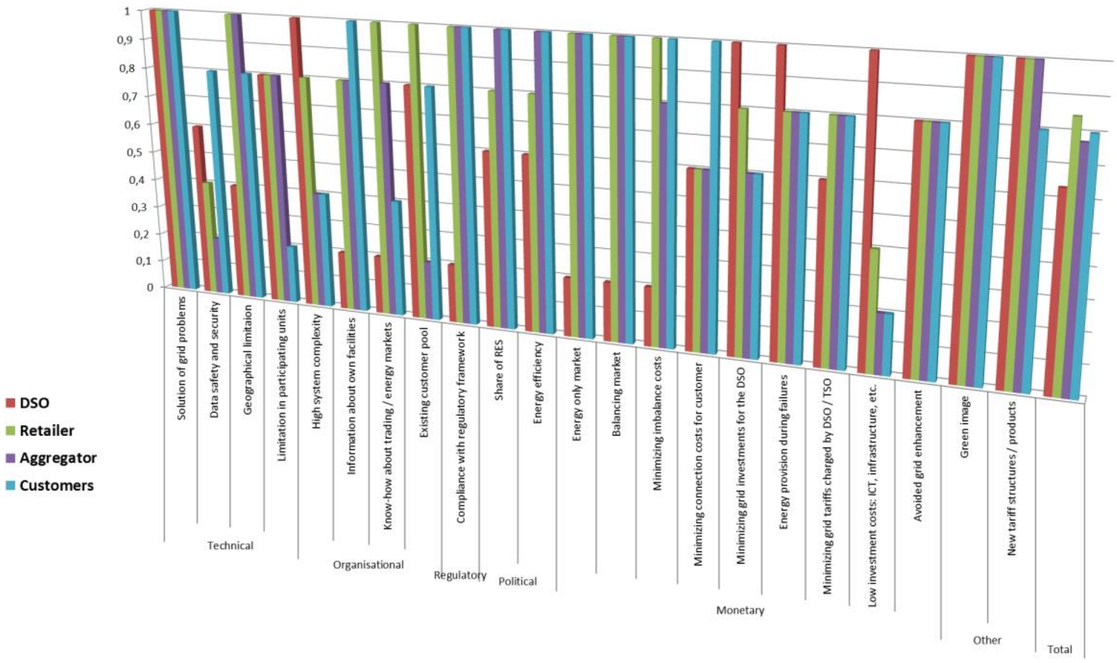

Figure 4-1 Comparison (per unit) of the qualitative analysis of evaluation criterions for hybrid-VPP owner

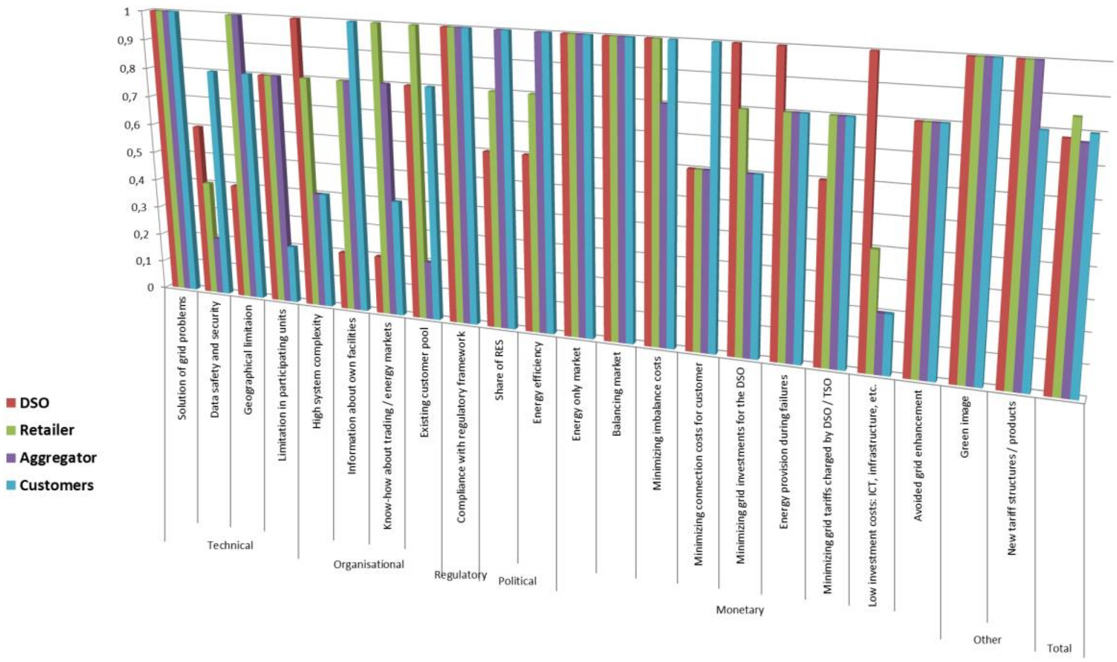

Figure 4-2 Comparison (per unit) of the qualitative analysis of evaluation criterions for hybrid-VPP owner with no regulatory restriction for DSO

4.5.2 VPP-owner and other market participants

The summarized comparison of all evaluation criterions between the four VPP-owner and the interdependencies to the other market participants is shown in Table 4-6 as a qualitative assessment and in Figure 4-3 a more detail illustration per unit. The total summarized results of the assessment from VPP-owner show that all 4 business models are positively evaluated, also similar in the per unit figure. In the case with the regulatory restriction for the DSO, the DSO has the lowest assessment, but without the regulatory restriction the DSO has the highest assessment. Nevertheless the overall summarized results lead to no preferred business model in general.

Table 4-6 Comparison of the summarized qualitative analysis of evaluation matrix for hybrid-VPP owner and other market participants

active hybrid-VPP		VPP-owner			
		DSO	Retailer	Aggregator	Customers
Technical	Solution of grid problems	++	++	++	++
	Data safety and security	+	o	o	+
	Geographical limitaion	o	+	+	+
	Limitation in participating units	+	+	+	o
Organisational	High system complexity	+	+	o	o
	Information about own facilities	o	+	+	+
	Know-how about trading / energy markets	o	+	+	o
	Existing customer pool	o	o	o	o
Regulatory	Compliance with regulatory framework	o	+	+	+
Political	Share of RES	+	+	+	+
	Energy efficiency	+	+	+	+
Monetary	Energy only market	o	+	+	+
	Balancing market	o	+	+	+
	Minimizing imbalance costs	o	+	+	+
	Minimizing connection costs for customer	+	+	+	+
	Minimizing grid investments for the DSO	++	+	+	+
	Energy provision during failures	++	+	+	+
	Minimizing grid tariffs charged by DSO / TSO	+	+	+	+
	Low investment costs: ICT, infrastructure, etc.	+	o	o	-
	Avoided grid enhancement	++	+	+	+
Other	Green image	+	+	+	+
	New tariff structures / products	+	+	+	+
Total		+	+	+	+

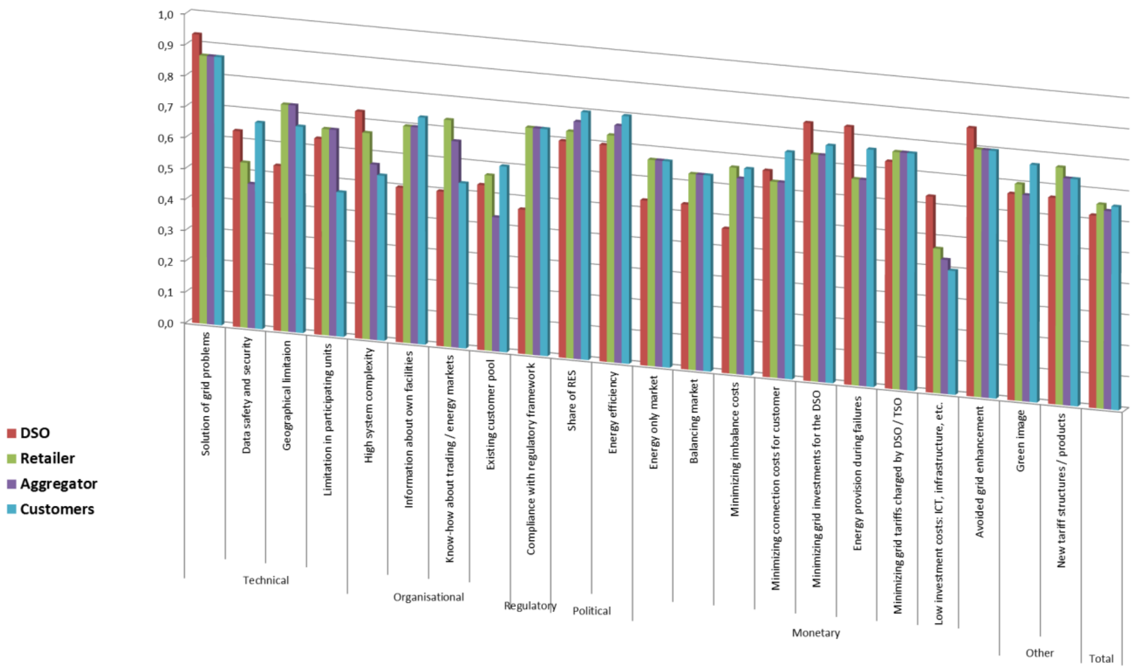

Figure 4-3 Comparison (per unit) of the summarized qualitative analysis of evaluation criterions for hybrid-VPP owner and other market participants

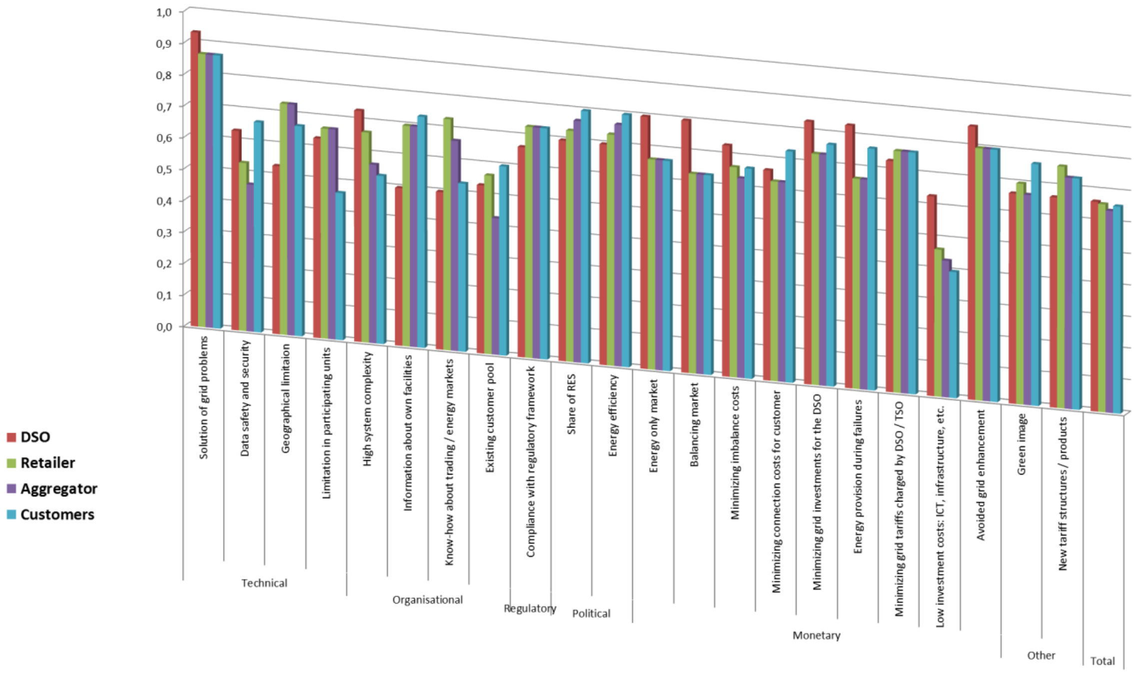

Figure 4-4 Comparison (per unit) of the summarized qualitative analysis of evaluation criterions for hybrid-VPP owner and other market participants with no regulatory restriction for DSO

5 Conclusion

The two developed scenarios ‘Base’ and ‘Efficiency’ are the basis for the development of future electricity price scenarios. The ‘Base’ scenario is more or less a ‘business as usual’ scenario. There are no big changes in the power plant capacity structure and the annual demand grows with the historical average increasing rate for each country. The ‘Efficiency” scenario has a high share of RES and the development of annual demand is lower than in the ‘Base’ scenario due to energy efficiency measures (e.g. Energy Efficiency Law in Austria).

The results of the used EDisOn market model show for different hourly electricity prices for energy-only market and the possible price differences between both scenarios. On the one hand the average electricity prices are in ‘Efficiency’ scenario lower than in ‘Base’ scenario. On the other hand the more relevant parameter for operation of a hybrid-VPP on energy-only market, are the price changes between the possible demand response times. Due to the higher share on RES in ‘Efficiency’ scenario, the volatility and price changes are higher in this scenario than in ‘Base’ scenario.

Other relevant electricity prices for different energy markets (e.g. balancing market) are not modelled especially. For the further quantitative economic analysis in deliverable D3 these prices will be analysed with historical trends and Monte Carlo approach.

To find out the critical parameter for the quantitative economic analysis, different business models and associated evaluation criterions from D1 [10] are qualitatively evaluated. The data safety and security and the limitation in participating units are the most relevant technical criterion. Organisational criterions mainly affect the information about own facilities and the know-how about energy trading. The compliance to the regulatory framework is important for the business model where the DSO is owner and operator of the hybrid-VPP. The influence of the monetary parameter depends mainly on this criterion by the DSO business model. For the other business model the ICT and infrastructure investment costs could be the most critical monetary parameters. These mentioned parameters are particularly discussed in the further quantitative economic analysis.

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