Ea Energy Analyses

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post 2030 Baltic electricity market

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Ea Energy Analyses
Gammeltorv 8, 6 tv.
1457 Copenhagen K
Denmark
www.eaea.dk

This report was made by Ea Energy Analyses for Elering AS the Estonia TSO.

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Introduction

The purpose of this report the analysis of different scenarios for the future of Estonian energy system and more in general to define a post 2030 Baltic electricity market study.

Context of the Study

As the EU strives to become the first carbon neutral continent by 2050, the Baltic Sea region could become a large source renewable generation, including from offshore wind. While the wind resource is favorable, most of the Baltic Sea is far from the large load centers in Central Europe, meaning that to maximize the offshore wind potential sitting in the Baltic Sea, the transmission system will also need heavy investment. In this context the Baltic Sea Countries' TSOs aim to co-operate to develop a marine energy network and market. This study should provide insight into the economic performance parameters, impact and perspective of **various generation, storage, and transmission projects** in the region's energy system, with an end goal of mapping a **viable and economically optimal pathway** to enable a decarbonized electricity system, with adequate security of supply of electricity.

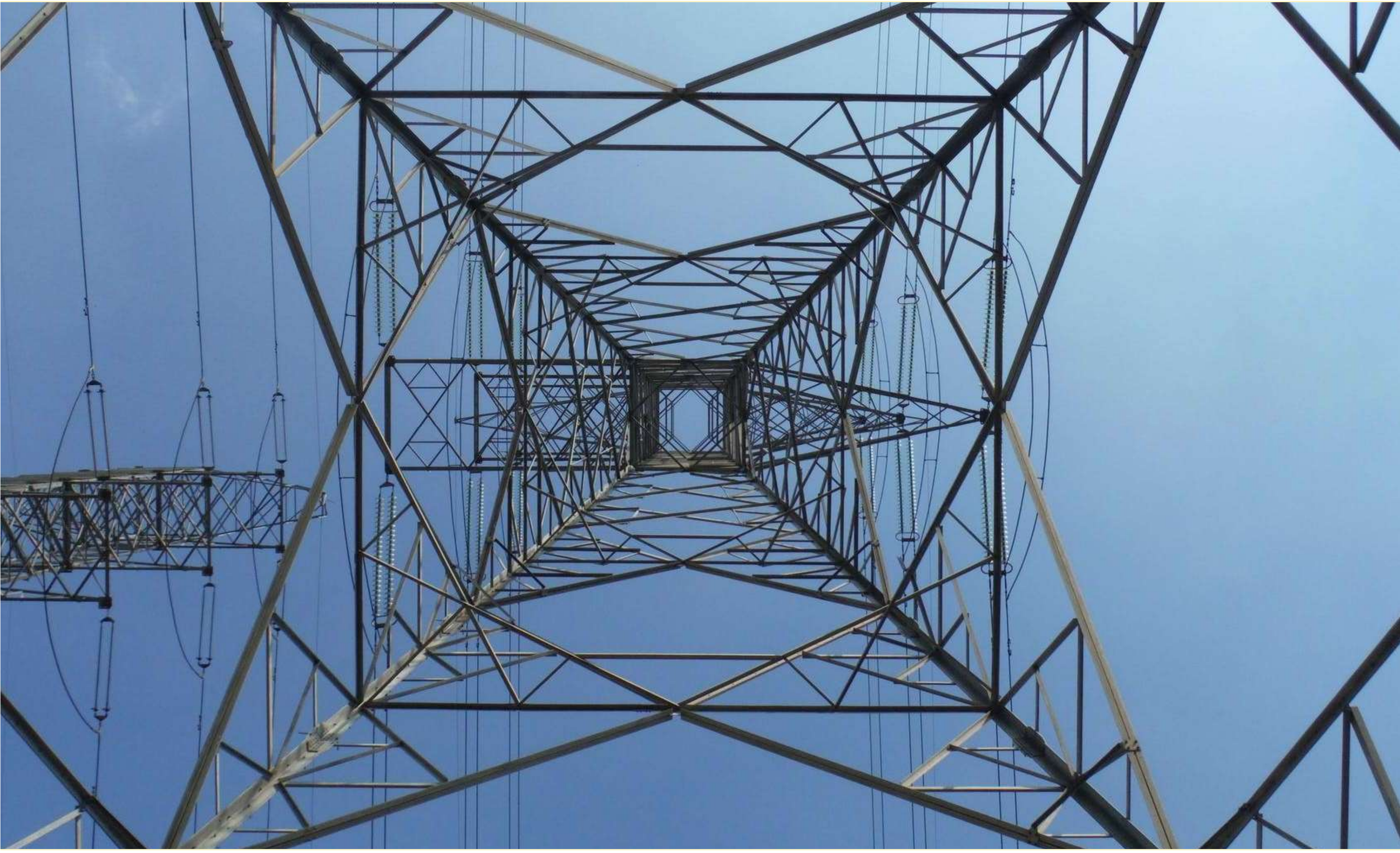
Energy Modelling using Balmorel

The primary tool used to conduct this work is the energy system model called Balmorel. The optimal dispatch is determined based on inputs as hourly demand, existing generation and transmission capacities, fuel, and generation costs.

The geographical scope of the model, for the current study, will include 18 European Countries: Estonia, Latvia, Lithuania, Finland, Sweden, Norway, Denmark, Poland, Germany, the Netherlands, Belgium, Luxemburg France, Italy, Switzerland, Austria, Czech Republic, and Great Britain. The information regarding demand and generation are provided by region whether the transmission capacity is given between the latter.

Balmorel results for this study include:

- Yearly and hourly electricity generation.
- Fuels and other operations and maintenance costs (O&M).
- Capital costs.
- Total costs.
- Investment costs.
- Emissions.
- Congestion rent.
- Hydrogen demand and generation.



Scenarios Under Investigation

The European Balmorel energy system model is utilized to generate a Reference Scenario (Current Best Estimate), a benchmark useful to analyse and understand which investment pathways are most economically viable and which are the no-regret decisions that can be made today. In this study, three core pathways are defined, and these will be the starting point of other 14 different scenarios. The study compares a total of 45 scenarios, where each of the scenarios is compared with the relative reference pathway. The three scenario pathways are considered as three starting points; hence, the model will optimize the investment in the Estonian heating system accordingly. Therefore, the capacity in the Estonian heat sector can vary between pathways, adjusting the optimal heating mix accordingly to the power system. On the other hand, the different power generation capacities in the Estonian energy system are not considered affecting the other European Countries, hence remain unvaried in the three pathways.

Current Best Estimate

The specifics of this pathway scenario are outlined in the following, the Current Best Estimate (CBE) pathway is considered the base of the entire study.

Rapid Development

The Rapid Development (RD) pathway considers the addition of wind capacity in the Estonian energy system. More specifically a more rapid development of onshore wind and the addition of offshore wind capacity reaching 3000 MW in 2050.

Rapid Development + Storage

The Rapid Development + Storage pathway start from the same development of the RD pathway but foresees the addition of flexibility measures in the Estonian energy system.

Current Best Estimate (Reference Scenario)

Overview

Current Best Estimate scenario acts as the reference scenario used to compare back to all the other scenarios. The main inputs to the European Balmorel model are listed in the following. The energy system resulting from the inputs is also described.

> "...this scenario represents the most expected path for the Baltic energy system to meet future electricity demand, which is going to be compared with the other scenarios."

The Current Best Estimate scenario will be based on TYNDP's modelling results along with other technology assumptions. TYNDP (Ten Years Network Development Plan) is a plan designed by ENTSOG and ENTSOE that provides an overview of the European energy infrastructure and its future developments, and it maps the integrated gas network according to a range of development scenarios.

The Global Ambition (GA) scenario is one of the three scenarios outlined in the TYNDP to reflect the increasing uncertainties towards 2050. Global Ambition (GA) illustrates a pathway to achieve carbon neutrality by 2050 and at least 55 % emission reduction in 2030. The main drivers in this scenario are the development of a wide range of renewable and low-carbon technologies (many being centralized) and the use of global energy trade as a tool to accelerate decarbonization.

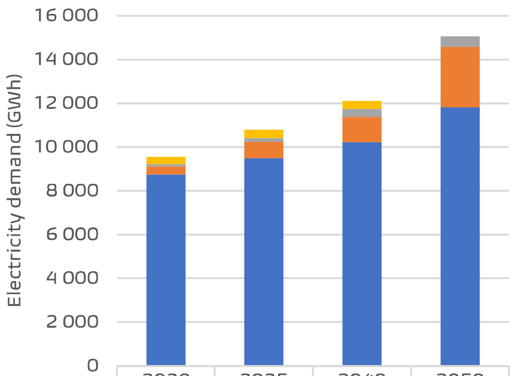
The GA scenario's output data is used as reference dataset. Several policies are defined to follow the capacity expansion and to achieve the TYNDP's GA capacity expansion results. In other words, this scenario represents ENTSOE vision most likely path for European, Baltic, and more specifically for the Estonian energy system, to meet future electricity demand respecting the climate goals.

The main inputs to any large-scale energy system model are energy demand, energy supply (generation technologies and fuel prices), and energy transmission (high-voltage transmission capacity). The Current Best Estimate scenario is simulated for 2030, 2035, 2040 and 2050 with hourly time resolution and relaxed unit commitment (to reduce the run times). The original TYNDP's geographical division is maintained in the analysis with the regional bidding zones representing the existing market.

Key Inputs

The electricity demand in the TYNDP's methodology is split into four main different categories: Classic, Electric Vehicles, Residential and Tertiary. In the analysis conducted with the Balmorel model Classic, Residential and Tertiary sectors demands are unified in the Classic demand the electricity demand to district heating (DH) demand depends on the electricity price and the heat sector capacities, therefore, the latter will vary among pathways. The yearly demand is then adjusted adding to the Balmorel profile a demand for EVs that is considered fixed (not depending by the electricity price) and an electricity demand for hydrogen generation (P2X demand). **Figure 1** depicts the yearly total demand for Estonia in the CBE pathway case. The Classic demand sees an almost constant increase in the period considered, around 1.6 TWh every ten years, however the most consistent increase regards the EVs charging expected to reach almost 3 TWh in 2050. The P2X demand is also fixed, however the share of hydrogen generated, and therefore the electricity demand to generate it depends on the electricity price.

The information regarding generation capacity (expect Estonia, Latvia, Lithuania, and Finland which are based on National Trends till 2035), electricity and heat demand, transmission capacity, demand response and CO2 prices are retrieved from the ENSTO-e and TYNDP'22 global ambition data. The hourly profiles of non-dispatchable energy sources (wind and solar), hydro and hourly demand are attained from ENTSO-e data and the climate year considered for the analysis is 1995. The year 1995 is a representative year to test the adequacy of the electricity system being the historical climatic year of highest residual demand based on Distributed Energy RES capacity and demand profile.



	2030	2035	2040	2050
P2X	349	383	381	
DH	89	162	374	475
EV	365	754	1 143	2 771
Classic	8 744	9 480	10 216	11 808

Figure 1:Total electricity demand in Estonia (GWh).

Flexibility is also considered in the model with six different Demand Side Response (DSR) bands, based once again, on TYNDP's data. The six bands are characterized by specific activation price and no limitation of duration, the values considered for the bands are reported in **Table 1**. The demand side response is modelled as a certain amount of demand that can be "unserved" with the payment of the activation price.

Table 1: DSR bands considered based on TYNDP.

Band	Activation price (EUR21/MWh)
DSR Band 1	250
DSR Band 2	500
DSR Band 3	900
DSR Band 4	1500
DSR Band 5	3500
DSR Band 6	4800

The years simulated are 2030, 2035, 2040, and 2050. The model is not allowed to invest in electricity generation capacity and/or transmission line expansion; however, in the pathways the Estonian heat sector is optimized in response of the power sector capacities. The development of generation and transmission capacity follow the TYNDPs perspective on all the European Countries apart from Estonia. The model optimizes the hourly dispatch to meet the electricity demand in said years, defining which technology will generate and the amount of electricity transferred among regions.

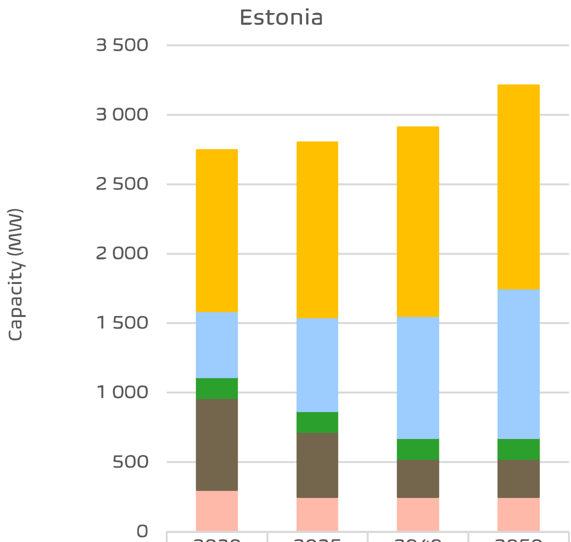
TYNDP's capacity expansion results provide regional capacity by fuel and technology type. The fuels included in the analysis are coal, natural gas, biogas, nuclear, shale, onshore and offshore wind, solar, hydro, waste, biomass, and other fuels. The latter are allocated to specific fuel category based on the comparison of the Balmorel model and TYNDP runs. **Figure 2** shows the electricity generation capacities for Estonia and for the Baltic Countries retrieved from TYDNPs projection.

The increasing generation capacity, considering the context of the ongoing energy transition, is required to meet the raising total electricity demand of the energy system. Furthermore, the price per MW of technologies such as wind (onshore and offshore), solar PV, and battery storage decreases towards 2050 to a much higher degree compared to other technologies. The limited lifetime of the existing plants, in many cases ending before 2050, has also an influence on the variation of the generation capacity mix. The growth in demand, the falling costs of new generation technologies and the ageing of existing generation system, along with the European climate neutrality goal, can be seen as the main factors influencing the alteration in the generation mix towards 2050.

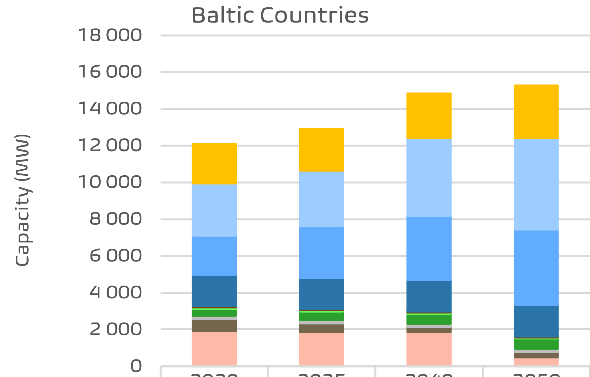
These factors are considered reflected in the TYNDPs scenario. Furthermore, the Baltic Countries have a certain amount of generation capacity utilized as reserve capacity. According to the data provided, the reserve capacities in the three Countries are the one listed in **Table 2**. In Appendix it is possible to see the total installed capacity on a Country level, divided by the four years considered and the generating fuel.

Table 2: Defined reserves for Baltic Countries.

Country	Reserve Capacity (MW)
Estonia	250
Lithuania	400
Latvia	50



	2030	2035	2040	2050
Solar	1 160	1 260	1 360	1 460
Onshore wind	476	676	876	1 076
Biomass	150	150	150	150
Shale	660	466	274	274
Gas	300	250	250	250



	2030	2035	2040	2050
Solar	2 144	2 277	2 445	2 881
Onshore wind	2 832	3 032	4 233	4 961
Offshore wind	2 120	2 796	3 472	4 112
Hydro	1 720	1 720	1 720	1 720
Waste	67	66	66	41
Biogas	94	55	55	55
Biomass	360	471	541	566
Other	187	187	187	187
Shale	660	466	274	274
Gas	1 899	1 849	1 849	482

Figure 2:Generation capacity development in the Current Best Estimate scenario, for Estonia (left) and Baltic Countries (right).

Another key input influencing the future electricity generation is the CO2 price or CO2 tax on emissions. In **Table 3** shows the CO2 prices used in the model for each of the year analysed. The CO2 prices utilized in the simulation of the model are retrieved once again from the TYNDP 2022 projections.

Table 3: CO2 prices in the simulated years.

Year	CO2 price (EUR21/ton)
2030	78
2035	100.5
2040	123
2050	168

Natural gas use is not limited to a maximum use, but the use of synthetic fuels is included in the models' assumptions. Bio-methane, synthetic-methane, and hydrogen use in power generation are seen as requirements and constrained to a minimum fuel use to generate electricity. This assumption follows once again the ENTSO-E and TYNDPs perspective. The optimization decides the share of these fuels although the minimum total requirement, as sum of these fuels, must be met. The fuel prices of the synthetic fuels cited, follow also the TYNDP projections, the latter can be seen in **Figure 3** .As depicted, the fuel costs are characterized by a common decrease towards 2050, the price projections do not consider the current gas crisis and assumes better natural gas availability in the years simulated, therefore also the natural gas price is considered decreasing towards 2050.

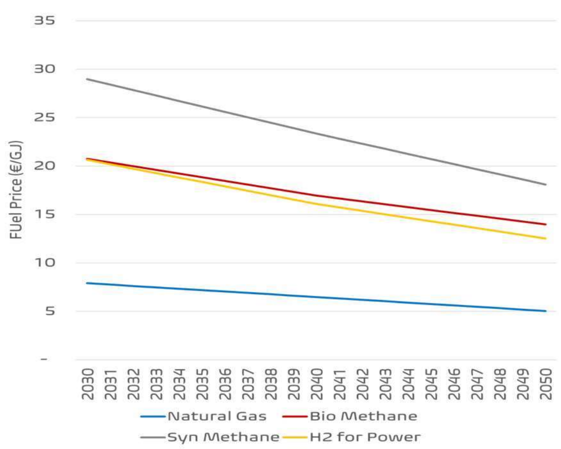


Figure 3: TYNDP's fuel prices projections.

Key Results

Figure 4 shows the optimal electricity generation by fuel in the years considered for Estonia and for all the Baltic Countries. The decade from 2030 to 2050 shows a clear increase of generation from wind and solar PV. For the Baltic Countries the development and increase in generation regards mainly wind onshore and offshore. In Estonia the electricity generation from onshore wind more than doubles from 2030 to 2050, in Latvia and Lithuania the increase in generation of onshore and offshore wind is similar and goes from around 9 TWh in 2030 to around 16 TWh in 2050. If the onshore generation in the Baltics also considers the contribution of Estonian plants, the offshore development regards only Latvia and Lithuania since in the CBE pathway no offshore capacity development is predicted in Estonia. Fossil fuels generation sees an overall decrease in all the Baltics. The electricity generation from gas is constantly decreasing towards 2050 no electricity generated from gas in Estonia from 2035, due to the use of the 250 MW of gas capacity as reserve. The gas generation in the Baltics decreases of more than ten times during the same period. Similar trend is seen also for the electricity generated from shale in Estonia with decreasing generation until 2040. In 2050 the increasing electricity demand requires the increment of generation from shale, compared to 2040, and around 120 GWh of electricity are still generated from shale.

Figure 5 shows the CO2 emission from power generation in Estonia towards 2050, the emissions from heat generation are not included in the chart. As a result of the decreasing generation from fossil fuels it is possible to see how the overall CO2 emissions in Estonia decrease till 2040, it appears that the increasing electricity demand between 2040 and 2050 results in higher generation from shale, with consequent higher CO2 emissions. The emissions from natural gas are 0 already in 2035, due to the 250 MW natural gas power capacity used as strategic reserve and, hence, not generating electricity in the regular functioning of the Estonian energy system.

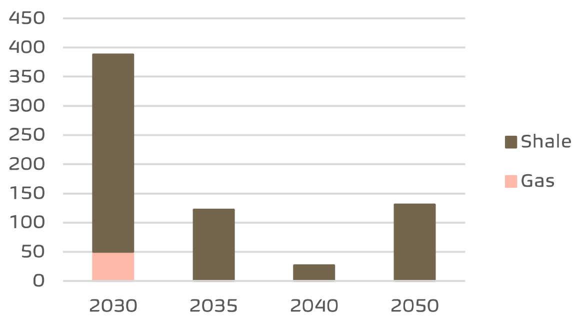
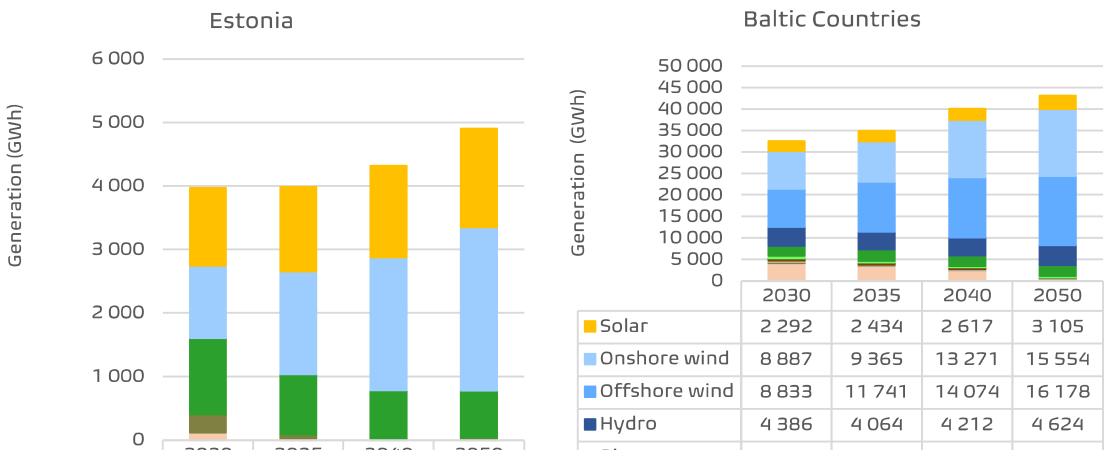


Figure 5: CO2 emissions in the Baltic Countries.



	2030	2035	2040	2050
Solar	1 229	1 336	1 444	1 554
Onshore wind	1 138	1 616	2 095	2 573
Biomass	1 199	946	766	737
Shale	286	87	14	38
Gas	116			

	2030	2035	2040	2050
Solar	2 292	2 434	2 617	3 105
Onshore wind	8 887	9 365	13 271	15 554
Offshore wind	8 833	11 741	14 074	16 178
Hydro	4 386	4 064	4 212	4 624
Biomass	2 304	2 675	2 448	2 523
Biogas	608	350	285	325
Waste	544	512	458	174
Other	265	264	263	258
Shale	286	87	14	38
Gas	4 113	3 414	2 397	310

Figure 4: Yearly electricity generation by fuel in the Baltic Countries (left) and all the Countries (right).

The increased generation from renewables has an influence on the electricity prices in Estonia and in the Baltics. Overall, the TYNDP capacity development projections see an increase of renewable capacity in all European Countries, with related higher share of renewable electricity generated. This trend influences the average yearly electricity prices towards 2050. Table 5 shows the evolution of the average electricity price in the European Countries, and more specifically in the modelled bidding zones. The average prices register a notable decrease in all the Countries in the model. Overall, it is possible to see a less differentiated price in 2050 compared to 2030 in the whole Europe. This result can be interpreted with less hours of congestion in the interconnectors between regions. The Estonian average electricity price decreases substantially towards 2050, however the expected raise of electricity demand keeps the contraction of the price to a lower value compared to other Countries.

The decreasing average electricity prices in all the regions considered in the model is a result of the increasing penetration of variable renewables (VRE). VRE penetration expresses the ratio between variable renewable electrical power output, and the total electrical load served. For what concern the Estonian case the value of wind and solar penetration are reported in Table 4.

If, on one hand, the penetration of wind continuously increases towards 2050, on the other hand the penetration of solar remains almost constant towards 2050. The electricity generated from solar source remain around one third of the total, showing a proportional increase in electricity generated from solar and total electricity generation in Estonia.

Table 4: Estonia VRE penetration.

Year	Wind penetration	Solar penetration
2030	29%	31%
2035	41%	34%
2040	49%	33%
2050	52%	32%

Table 5: Average electricity prices (€/MWh) in the modelled regions.

Region	2030	2035	2040	2050
AT	74	59	46	34
BE	77	59	43	34
CH	79	72	54	41
CZ	81	67	50	38
DE	87	71	51	40
DK_E	54	48	41	29
DK_W	55	41	28	20
EE	67	63	50	50
FI	42	47	37	27
FR	57	38	32	27
GB	83	62	44	35
IT	72	63	57	29
LT	62	57	44	35
LV	65	59	44	43
LX	77	62	51	40
NL	76	56	39	29
NO_N	32	36	38	36
NO_M	34	37	37	37
NO_S	60	60	38	37
PL	83	67	48	35
SE_N1	29	37	35	29
SE_N2	25	35	36	29
SE_M	25	34	33	26
SE_S	39	41	41	30

The value factor, intended as the ratio of market value of the technology (average revenue per MWh in a certain year), and the average wholesale electricity market price, is a good indicator to express the renewables technology potential. The value factor can in fact be an indicator of the potential of further development of non-dispatchable renewables, being the latter available in certain hours of the years, a high development of these technology can manifest the phenomenon of the so-called "self-cannibalization effect". This effect occurs when the penetration of renewables in the hours when the latter are generating is high enough to drive the electricity price to low values compared to the rest of the years (when there is no availability of sun or wind).

Table 6 shows the Estonian value factor of Onshore wind and Solar towards 2050. The decreasing value factor of wind related with the high wind penetration suggest a potential for storages, that decrease the difference in electricity price between hours with high and low renewable electricity generation. Furthermore, the high value factor of solar suggest untapped potential for the technology and the limited number of hours in which solar generation is the driver of the electricity price in 2030, in 2050 the value factor of solar is decreasing showing once again the potential for storages.

Table 6: Value factor for VRE Estonia.

Year	Onshore Wind	Solar
2030	0.83	1.03
2035	0.81	0.99
2040	0.78	1.00
2050	0.76	0.82

Figure 6 depicts the variation of the price duration curve in Estonia for the simulated years. The first visible outcome is the progressive diminishing of the average electricity price towards 2050, furthermore, it is possible to see how the curves tend to reduce their slope with increasing hours with same price approaching the last simulated year. This is evident if comparing the price duration curve in 2030 and the one in 2050.

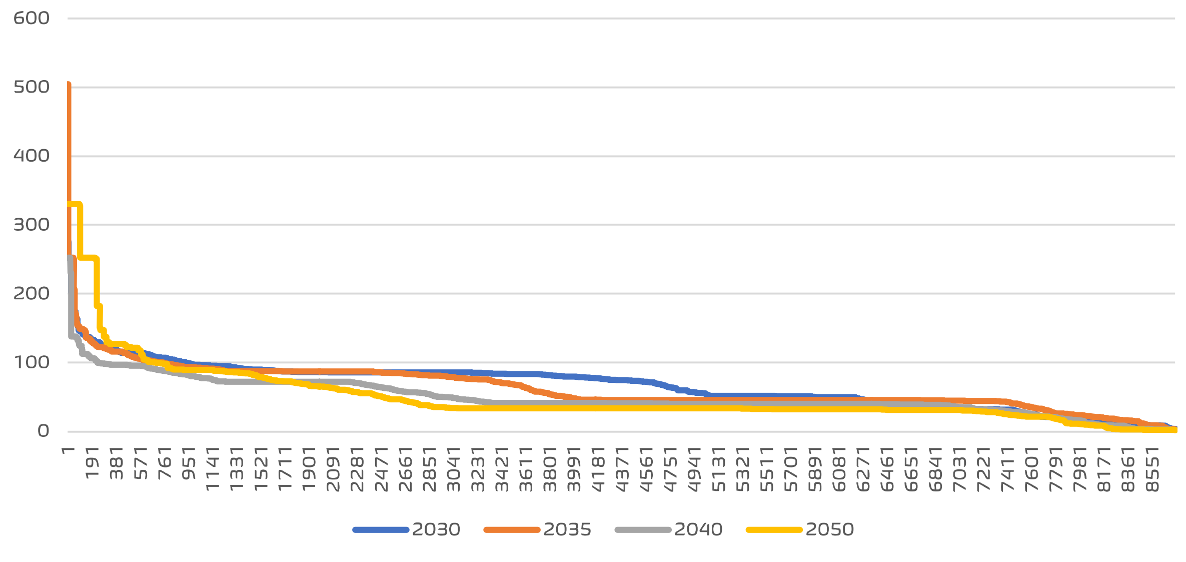


Figure 6: Estonian price duration curve in 2030, 2035, 2040 and 2050.

Table 7 reports the number of hours with electricity price above 100 €/MWh and below 10 €/MWh. This table helps to have more specific insights regarding the electricity prices, not easily detectable from the curves. Overall, it is possible to see how the number of hours with high electricity price tend to decrease towards 2040, however this number increases substantially in 2050. This can be justified by the high increase of electricity demand in Estonia from 2040 to 2050, where the generation of renewables occurs just in certain hours of the year driving the average electricity price to low value in certain hours. Furthermore, in 2050 also the number of hours with low electricity price raises substantially due to the mentioned increase of generation from renewable sources. As already indicated by the s slope of the price duration in 2050, these outcomes suggest a potential high value of storages for the Estonian energy system.

Table 7: Electricity price data in Estonia.

Year	Hours above 100 €/MWh	Hours below 10 €/MWh
2030	931	290
2035	755	228
2040	246	598
2050	719	682

Figure 7 shows the total yearly electricity net flow between the Baltics and the neighboring Countries for the years 2030 and 2050. The figure must be interpreted with a net export if the column is above the x-axis and a net import if the column is below.

The CBE pathways results indicate that Estonia is a net importer of electricity from Finland in 2030 and will substantially increase the imports from Latvia in 2050. This raise of export from Latvia to Estonia can be explained by the rapid upturn of electricity generation from offshore wind in Latvia that will export part of the low-price generated electricity to Estonia. Lithuania from exporter of electricity to Poland will import electricity in 2050 and increase the exports to Latvia. This trend is also reflected in the average electricity price for the three Baltic Countries with Lithuania having the lower average electricity price in 2030 and 2050.

Examining the interconnection use between Baltic and neighboring Countries. The following tables show the flow, in both directions, between the Baltic and the interconnected Countries. Furthermore, in the tables it is also shown the utilization rate and the number of congested hours in each interconnector, intended as the ratio between the total flow and the total yearly available capacity.

[redacted]

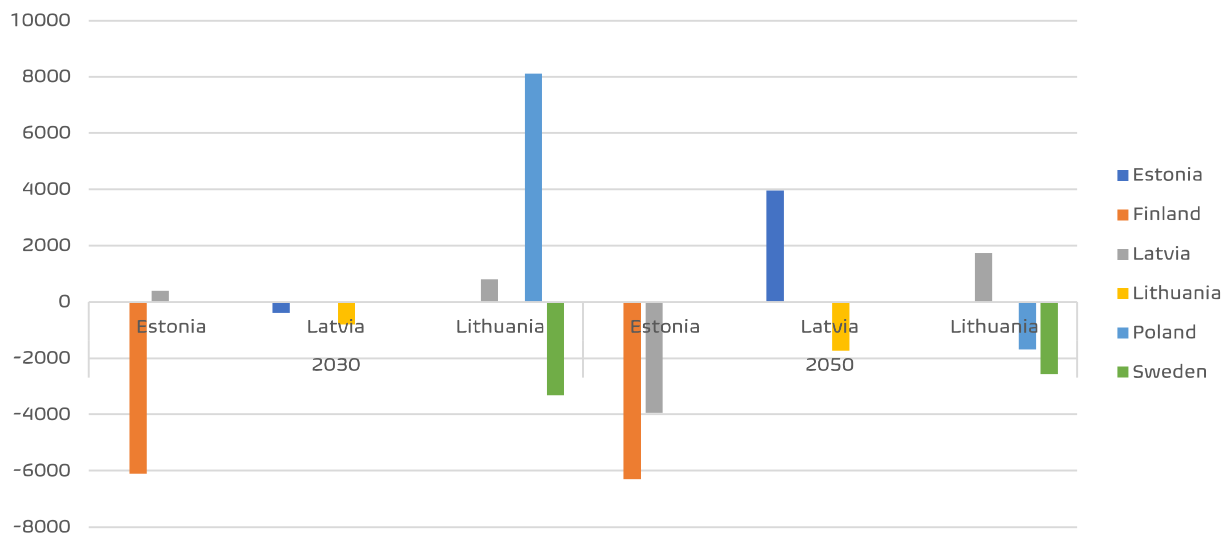


Figure 7: Net flow between Baltic, Finland, and Sweden – 2030 and 2050 (TWh).

[redacted]

[redacted]

The hydrogen demand from the TYNDP, sum of direct, indirect and hydrogen demand for power generation is introduced in the Balmorel model. The demand of hydrogen is defined as regional level for each Country. For each Country, hence, a specific area is modelled, and the national development of hydrogen demand follow once again the ENTSO-E projections. This demand is covered by a certain share of produced hydrogen while the remaining is covered by imports.

The production through electrolysis occurs if the electricity marginal price is below a certain threshold that corresponds to the cost of importing hydrogen from extra-European Countries (values from TYNDP 22). These costs are reported in **Table 12.** This modelling approach follows the reasoning of the TYNDPs for which extra-European Countries will be able to guarantee high production of hydrogen at low costs.

Table 11 shows the hydrogen demand and the share of produced and imported hydrogen for Estonia. The price cap in 2030 results in a reduction of the local hydrogen generation of 51% compared to the ENTSO-e data. The increasing electricity demand and the decreasing hydrogen costs are the two-factor influencing the hydrogen generation in Estonia. The cost of hydrogen generated also considers the CAPEX and OPEX related to the investment in electrolysers, for this reason the model does not see optimal the investment in electrolyser capacity after 2030. Due to the limited lifetime of the electrolysers the capacity installed in 2030 cannot generate hydrogen in 2050. No investment is considered beneficial in 2050 and the entire hydrogen demand is covered by imports.

Table 12: Levelised cost of Hydrogen (€/kg H2).

Year	Eur22
2030	2.05
2035	1.99
2040	1.93
2050	1.50

[redacted]

Table 11: Hydrogen production in the Baltic countries and effect of price cap.

Year	H2 demand (GWh)	H2 produced	H2 imported
2030	480	54%	46%
2035	933	30%	70%
2040	2.136	13%	87%
2050	1.918	0%	100%

Scenario Pathways

Overview

The Rapid Development pathway and the Rapid Development + Storage pathway will function as the two main scenarios to be compared with the reference (Current Best Estimate). These two pathway scenarios differ from the reference by including a more rapid growth of RES towards 2050 and for the introduction of storages and higher flexibility measures into the Estonian energy system in the case of the RDS pathway. Furthermore, the model is allowed to invest in the Estonian heat sector, so that the capacity in the latter can differ from the CBE pathway if economically optimal.

Rapid Development Pathway

Rapid Development (RD) Pathway differs from the CBE pathway for the capacity development of wind source technologies in Estonia. More specifically, the development of onshore wind sees a more rapid expansion, reaching the capacity seen in 2050 (1076 MW) in CBE already in 2040. After 2040 the onshore wind capacity remains constant until 2050. Furthermore, the Rapid Development pathway considers 1000 MW of offshore wind by 2030 growing to 3000 MW in 2050.

Rapid Development + Storage Pathway

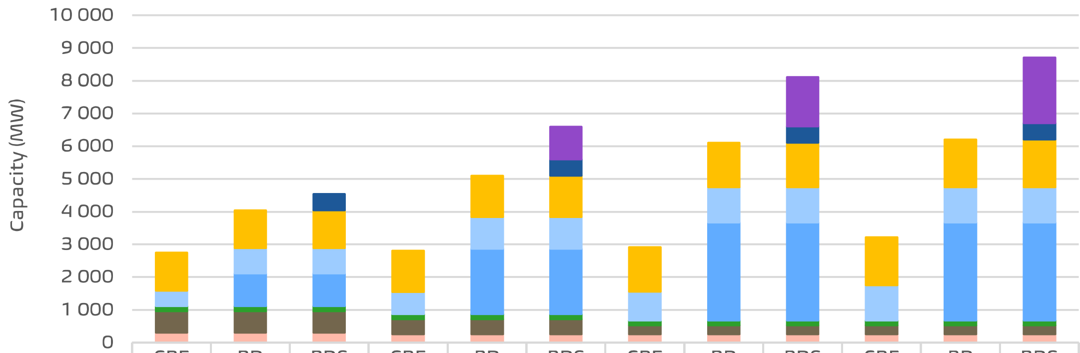
The Rapid Development + Storage pathway follows the same trend in wind technologies (onshore and offshore) development as the RD Pathway and on top of this assumes the adoption of additional storage and flexibility measures. More precisely, it anticipates higher Demand Side Management or Demand Side Response (DSR) capacity, up to 250 MW, the installation of battery storage capacity (up to 2000 MW in 2050) and the construction of the Paldiski pumped-hydro storage plant, 500 MW capacity, operating from 2030.

The purpose of examining these pathways is to compare the effect of a more rapid increase of capacity and generation from RES (wind) with the reference case. All the other assumptions regarding the Estonian, Baltics and other European Countries remain unvaried, where, once again the goal is to reflect the TYNDPs perspective of future development of the European energy system.

Key Inputs

As mentioned in the chapter introduction the inputs changing in the pathways regard the electricity generation and storage capacity in Estonia. **Figure 9** displays the installed power capacity in Estonia in the years simulated. The capacity development in the other Baltic Countries is not considered to be affected by the capacity development of Estonia and remain therefore the same for the three pathways.

In the RD and RDS pathways the variable RES (wind and solar) reach a share of the total power capacity in Estonia of nearly 90% in 2050. To give an overall perspective of distinction between the pathways, the figure also accounts for the capacity of electric batteries and pumped hydro storages, even if these are not generating technologies per se.



	CBE	RD	RDS	CBE	RD	RDS	CBE	RD	RDS	CBE	RD	RDS
		2030			2035			2040			2050	
Electric						1 000			1 500			2 000
Pumped hydro			500			500			500			500
Solar	1 160	1 160	1 160	1 260	1 260	1 260	1 360	1 360	1 360	1 460	1 460	1 460
Onshore wind	476	776	776	676	976	976	876	1 076	1 076	1 076	1 076	1 076
Offshore wind		1 000	1 000		2 000	2 000		3 000	3 000		3 000	3 000
Biomass	150	150	150	150	150	150	150	150	150	150	150	150
Shale	660	660	660	466	466	466	274	274	274	274	274	274
Gas	300	300	300	250	250	250	250	250	250	250	250	250

Figure 9: Power capacity development in Estonia for the three pathways considered.

Key Results

Figure 11 compares the outcomes of the two alternative pathways with the CBE reference in terms of electricity generation by fuel in Estonia. A notable difference is the total electricity generated in Estonia in 2030. The CBE pathway the Estonian energy system generates around 4 TWh, while in the RD and RDS pathways generates almost 9 TWh. This increase is due to the higher installed capacity of onshore wind technologies and investment in offshore wind, resulting in almost 4.5 TWh of electricity generated offshore. Meanwhile, natural gas does not generate from 2035, because as for the CBE pathway also in RD and RDS the 250 MW of capacity are used as strategic reserve. Shale generation is reduced in the pathways compared to the CBE, with a slightly higher generation in the RDS pathway in comparison with the RD. This trend continues to 2050, with offshore electricity generation exceeding 10 TWh in the RD and RDS pathways. Furthermore, comparing the two pathways, the RDS pathway, thanks to its storage capacity, generates slightly more electricity than the RD pathway in all years analysed, decreasing the dependency on imports.

Another interesting output to be compared between the two pathways and the CBE is the resulting CO2 emissions in Estonia. **Figure 10** shows the resulting kTons of CO2 emitted by electricity generation in Estonia. In 2030 it is possible already to see a decrease in emission from natural gas and shale, from RD and RDS in comparison with CBE. The RDS pathway results in higher emissions compared to the RD pathway due to the higher total generation and more specifically from shale being the only emitting fuel used for power generation. Already in 2040, the resulting emissions from the RD and RDS pathway appear comparable still with lower emissions compared to the CBE pathway.

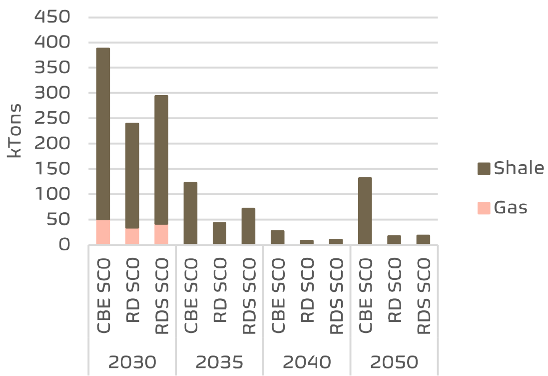
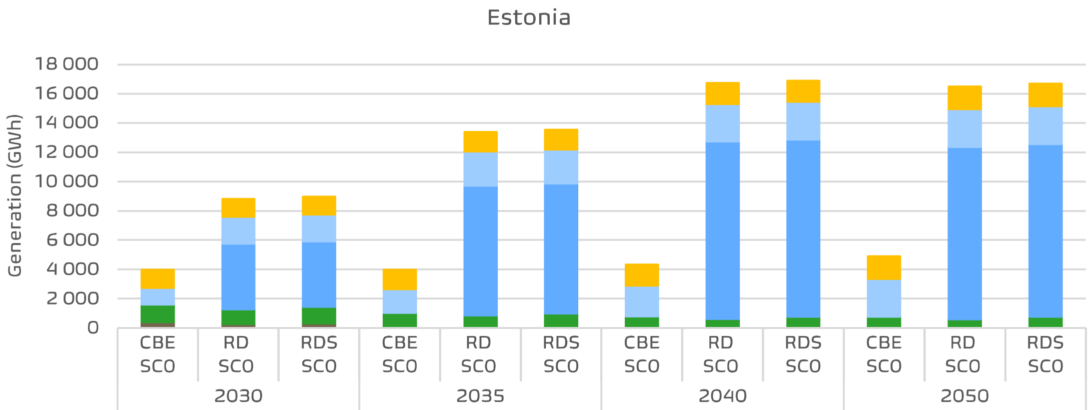


Figure 10: CO2 emissions in Estonia in the three pathways.



	CBE SCO 2030	RD SCO 2030	RDS SCO 2030	CBE SCO 2035	RD SCO 2035	RDS SCO 2035	CBE SCO 2040	RD SCO 2040	RDS SCO 2040	CBE SCO 2050	RD SCO 2050	RDS SCO 2050
Solar	1 229	1 229	1 229	1 336	1 336	1 336	1 444	1 444	1 444	1 554	1 554	1 554
Onshore wind	1 138	1 855	1 855	1 616	2 334	2 334	2 095	2 573	2 573	2 573	2 573	2 573
Offshore wind		4 463	4 463		8 873	8 875		12 113	12 111		11 780	11 801
Biomass	1 199	1 020	1 128	946	813	926	766	609	756	737	576	744
Shale	286	171	208	87	46	65	14	7	12	38	16	20
Gas	116	84	105					0				

Figure 11: Electricity generation by fuel in Estonia for the three pathways considered.

The increased generation from renewable sources in Estonia is expected to also have a high influence on the average electricity price in Estonia and in the neighboring Countries. Table 13 reports the average electricity price in the Baltics for the three pathways. The average price in the Baltics decreases already in 2030 in both the pathways showing how the increased renewable capacity in Estonia influences all the Baltic Countries and Finnish electricity price.

More specifically, the effect in Estonia is a decrease respectively of 13 and 14 €/MWh for RD and RDS pathway on the average electricity price in 2030, the decrease reaches 19 €/MWh for the RD and the RDS pathway in 2050. These results show the high influence of the of the increased wind capacity on the Estonian energy system. Furthermore, the storages have an effect of decreasing the average electricity price not just in Estonia but also in other neighboring Countries. The effect of these new technologies on the variability of the electricity price is also examined.

Table 13: Electricity price in the Baltic Countries in the three pathways.

Region	2030	2035	2040	2050
EE				
CBE	67	63	50	50
RD	54	48	35	31
RDS	53	47	34	31
FI				
CBE	42	47	37	27
RD	39	43	35	27
RDS	38	42	35	27
LT				
CBE	62	57	44	35
RD	58	53	41	33
RDS	58	53	41	32
LV				
CBE	65	59	44	43
RD	56	51	36	31
RDS	56	50	36	31

Table 14 accounts for the number of hours for the year 2030 and 2050 below 10 €/MWh (low price) and above 100 €/MWh (high price) in the three pathways evaluated. The first noticeable result is the high increase of number of low-price hours and the substantial decrease of high price hours comparing the reference pathway CBE with RD and RDS pathway. This predictable outcome is a result of increased generation from onshore and offshore wind that drives the hourly electricity price down decreasing the imports and the generation from expensive thermal power sources. Comparing the results of the RD and RDS pathway it is evident that already by 2030, the battery and pumped hydro storage capacity influence the number of hours with low and high prices. Considering the number of hours at a high price, in 2030 this goes from 612 to 400 decreasing of more than 30%, in 2050 the effect of the expansion of renewables capacity decreases significantly the hours at high price with 400 hours in the RD pathway and 238 hours in the RDS pathway. The number of hours at low prices are instead similar in the two with higher number in the RD in 2030. The effect of the storage is expected to flatten the price duration decreasing the variability of the price throughout the year but not necessarily increasing the number of hours with low price.

Table 14: Electricity price data for the pathways in 2030 and 2050.

	2030			2050		
N. of hours	CBE	RD	RDS	CBE	RD	RDS
>100	931	634	447	719	219	169
<10	290	720	719	682	2646	2677

To better understand the effect of the higher renewable and storage capacities in Estonia on the electricity price, the price duration curves of the three pathways are compared for the year 2030 and 2050. **Figure 12** shows the price duration curves in 2030 (on the top) and in 2050 (on the bottom). A first clear result is the lower electricity price in the RD and RDS pathways compared to the CBE in almost all the hours of the year both in 2030 and in 2050. Furthermore, comparing the RD and the RDS price curve it is evident in both the years how storage decreases electricity prices in high price hours, furthermore in the 2030 curve is possible to see higher electricity prices of the RDS pathway compared to the RD in lower price hours. The effect of storage also decreases the peak price in the year. In 2030 the peak price in Estonia is respectively 275, 252 and 243 €/MWh for CBE, RD and RDS pathway. In 2050 the peak prices registered are 330, 176 and 151 €/MWh for the same pathways.

Error! Reference source not found. shows the net electricity transferred Between the Baltics and the neighboring Countries in 2030 and 2050. Already in 2030 comparing the three pathways is possible to see how Estonia considerably reduces the import from Finland in RD and RDS pathway and becomes net exporter to Latvia. Comparing RD and RDS is possible to detect the cause of the increased electricity generation in the RDS compared to RD. This increase in generation appears to be related to the slight increase in export to Latvia and the reduction of imports from Finland. The system, hence, modifies the yearly generation and dispatch of electricity considering optimal the augmentation of export and the reduction of imports. In 2050, Estonia reduces sensibly the imports from Finland and consistently decreases the import from Latvia. The differences between RD and RDS are not easily detectable from the graph and the transfer from and to each of the Baltic Countries are more specifically analyzed in the following.

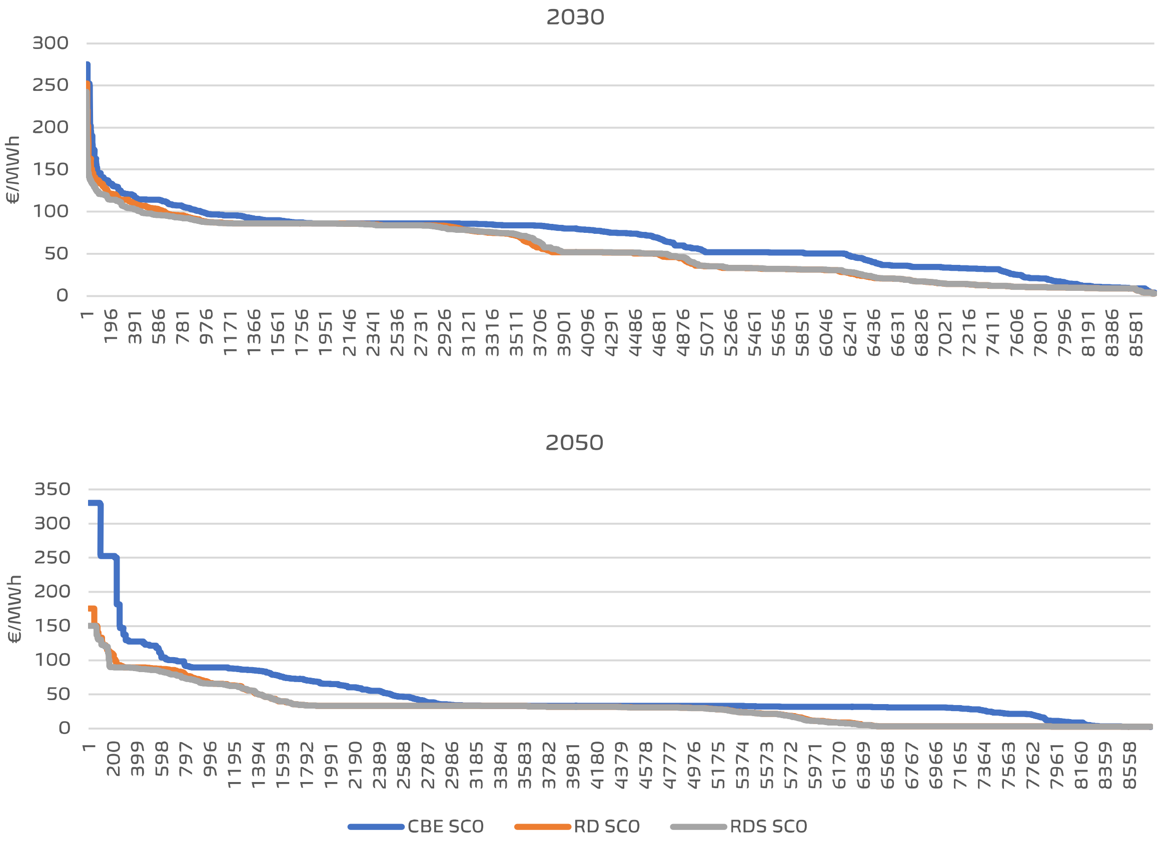


Figure 12: Price duration curve in 2030 and 2050 for the three pathways.

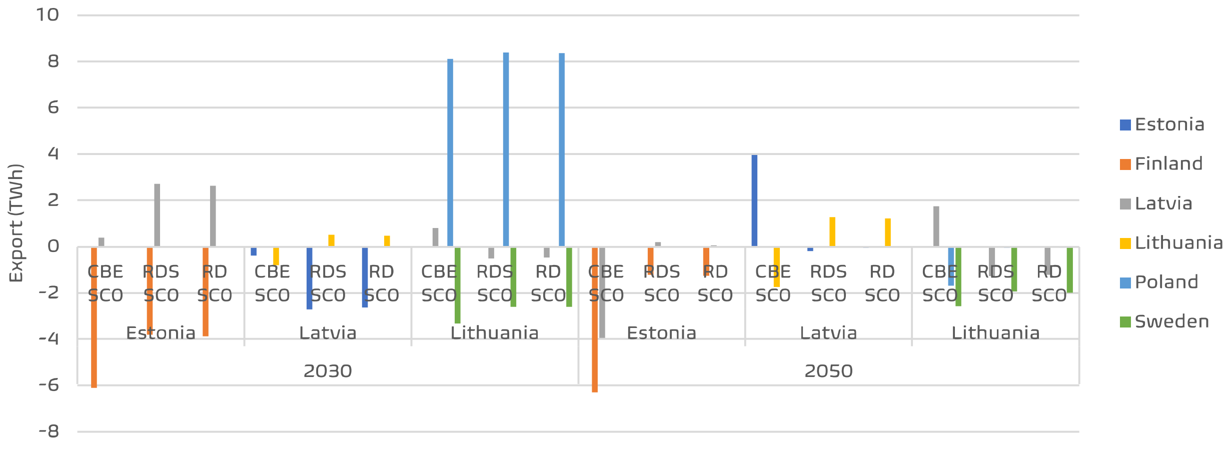


Figure 13: Net flow of the Baltic Countries in 2030 and 2050.

The increased generation capacity in Estonia influences also in Latvia which in RD and RDS pathways and increases the imports from Estonia and export to Lithuania. The flow, the utilization rate and the congestion hours of each Latvian interconnector is shown in the following for 2030 and 2050.In RD and RDS pathways, Lithuania imports from Latvia exceeds the export as effect of the increased import of the Latvia from Estonia. Furthermore, the effect of the higher RES capacities in Estonia on Lithuania is a reduction of the imports from Sweden and an augmentation of the export to Poland in 2030. In 2050 comparing the outcome of the Lithuanian imports from Latvia increase even more evidently and in comparison, with the CBE pathway where it was importing electricity from Poland becomes a net exporter Estonia.

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[redacted]

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The hydrogen generated in Estonia is increased in the pathways due to higher generation of electricity at low price that decreases the need for import of hydrogen. The fixed hydrogen import cost makes the generation of the latter economically profitable just in hours with low electricity price, in the other hours the model considers optimal to import hydrogen to satisfy the demand that it is considered constant at each hour. The high costs related to the investment in hydrogen storage is also a reason why even with high penetration of renewables, the hydrogen demand is not totally satisfied by generated hydrogen. The effect of storage is limited, and it doesn't appear to significantly affect the hydrogen generation. Table 18 shows the demand, generation and import of hydrogen in the pathways in the years simulated. In the two pathways the share of hydrogen generated is significant and exceed 80% in 2040.

Table 18: Hydrogen demand, imports, and generation for the three pathways.

Year	H2 demand (GWh)	H2 generated (GWh)	H2 imported (GWh)	H2 generated (%)	H2 imported (%)
2030					
CBE	480	238	242	50%	50%
RD	480	353	127	73%	27%
RDS	480	348	132	72%	28%
2035					
CBE	933	264	669	28%	72%
RD	933	708	225	76%	24%
RDS	933	706	227	76%	24%
2040					
CBE	2.136	263	1.873	12%	88%
RD	2.136	1.768	368	83%	17%
RDS	2.136	1.767	368	83%	17%
2050					
CBE	1.918	0	1.918	0%	100%
RD	1.918	1.426	492	74%	26%
RDS	1.918	1.426	492	74%	26%

Scenarios Analysis

Overview

The analyses conducted predicts the effect of fourteen possible scenarios that will be a combination of technology solutions comprising additional generation capacity in Estonia and/or additional transmission capacity between the Baltics and neighbouring Countries.

Power capacity

The modification in the scenarios of the power capacity in the Estonian energy system refer to an additional dispatchable generation capacity (gas turbine) of 250 MW, or the addition of an offshore wind park in the Baltic Sea in radial or meshed configuration. More specifically, in case of a meshed configuration (interconnection with both Estonia and Latvia) the power capacity of offshore wind park is 700 MW, in case instead of radial connection, hence with the park connected just to Estonia the wind park capacity is 1000 MW. The power capacities of the scenarios must be considered additional to the capacity of each of the pathway. In Figure

Transmission capacity

The added transmission in the different scenarios regards the increased transmission capacity between Estonia, where with increased transmission is intended higher transmission availability in both directions, hence increasing the potential import and export. Scenario 12 includes also then establishment of a new transmission line between Latvia and Sweden (+700 MW from 2035). These investment in transmission lines regard the connection between Estonia and Finland where a third HVDC interconnector is added (+700 MW from 2030), Estonia and Latvia where a fourth interconnector HVDC is added (+700 MW from 2030) and the connection with the offshore wind park, in the scenarios including the new power capacity, with increased transmission capacity equal to the power capacity of the offshore wind park.

Scenarios description

The characteristics of the fourteen scenarios are in the following descripted with the addition to the Estonian energy system.

Scenario 1 (SC1): addition of 250 MW of additional gas turbine capacity.

Scenario 2 (SC2): addition of 700 MW inter-connector between Estonia and Finland.

Scenario 3 (SC3): addition of 700 MW inter-connector between Estonia and Latvia.

Scenario 4 (SC4): addition of 700 MW capacity of offshore wind connected to Estonia (700 MW connection) and Latvia (700 MW connection) bidirectionally (with total additional connection Estonia-Latvia 700 MW).

Scenario 5 (SC5): addition of 700 MW inter-connector between Estonia and Finland, addition of 700 MW interconnector between Estonia and Latvia.

Scenario 6 (SC6): addition of 700 MW interconnector between Estonia and Finland, addition of 700 MW capacity of offshore wind connected to Estonia (700 MW connection) and Latvia (700 MW connection) bidirectionally (with total additional connection Estonia-Latvia 700 MW).

Scenario 7 (SC7): addition of 250 MW of additional gas turbine capacity, addition of 700 MW inter-connector between Estonia and Finland.

Scenario 8 (SC8): addition of 250 MW of additional gas turbine capacity, addition of 700 MW inter-connector between Estonia and Latvia.

Scenario 9 (SC9): addition of 250 MW of additional gas turbine capacity, and addition of 700 MW capacity of offshore wind connected to Estonia (700 MW connection) and Latvia (700 MW connection) bidirectionally (with total additional connection Estonia-Latvia 700 MW).

Scenario 10 (SC10): addition of 250 MW of additional gas turbine capacity, addition of 700 MW interconnector between Estonia and Finland and addition of 700 MW interconnector between Estonia and Latvia.

Scenario 11 (SC11): addition of 250 MW of additional gas turbine capacity, addition of 700 MW interconnector between Estonia and Finland and addition of 700 MW capacity of offshore wind connected to Estonia (700 MW connection) and Latvia (700 MW connection) bidirectionally (with total additional connection Estonia-Latvia 700 MW).

Scenario 12 (SC12): addition of 250 MW of additional gas turbine capacity, addition of 700 MW interconnector between Estonia and Finland, addition of 700 MW capacity of offshore wind connected to Estonia (700 MW connection) and Latvia (700 MW connection) bidirectionally (with total additional connection Estonia-Latvia 700 MW), and addition of a new interconnector 700 MW between Latvia and Sweden.

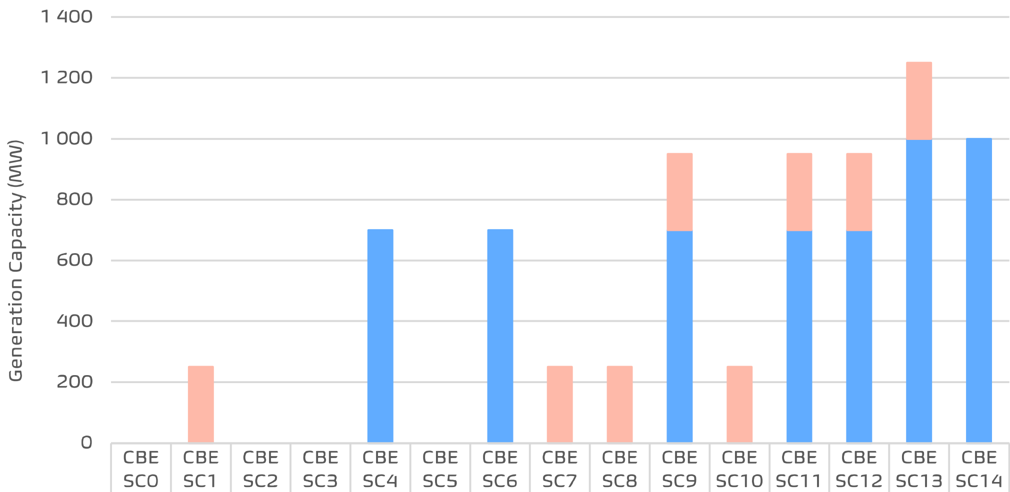
Scenario 13 (SC13): addition of 250 MW of additional gas turbine capacity, addition of 700 MW interconnector between Estonia and Finland, addition of 700 MW interconnector between Estonia and Latvia and addition of 1000 MW capacity of offshore wind connected to Estonia (1000 MW connection).

Scenario 14 (SC14): addition of 1000 MW capacity of offshore wind connected to Estonia (1000 MW connection).

Table 19 shows the combination of the power and transmission solutions included in each scenario, as already mentioned these are added to the existing power and transmission capacity of each pathway. **Figure 15** shows the additional generation capacity of each scenario.

Table 19: Power and transmission capacity included in the scenarios (*connected with 1000 MW transmission to Estonia).

	SC0*	SC1	SC2	SC3	SC4	SC5	SC6	SC7	SC8	SC9	SC10	SC11	SC12	SC13	SC14
Dispatchable generation		x						x	x	x	x	x	x	x	
EE-FI inter-connector			x			x	x	x			x	x	x	x	
EE-LV inter-connector				x	x	x	x		x	x	x	x	x		
Offshore wind park (700 MW)					x		x			x		x	x		
Offshore wind park 1000 MW*														x	x
LV-SE inter-connector													x		



	CBE SC0	CBE SC1	CBE SC2	CBE SC3	CBE SC4	CBE SC5	CBE SC6	CBE SC7	CBE SC8	CBE SC9	CBE SC10	CBE SC11	CBE SC12	CBE SC13	CBE SC14
Gas		250	0	0	0	0	0	250	250	250	250	250	250	250	0
Offshore wind		0	0	0	700	0	700	0	0	700	0	700	700	1 000	1 000

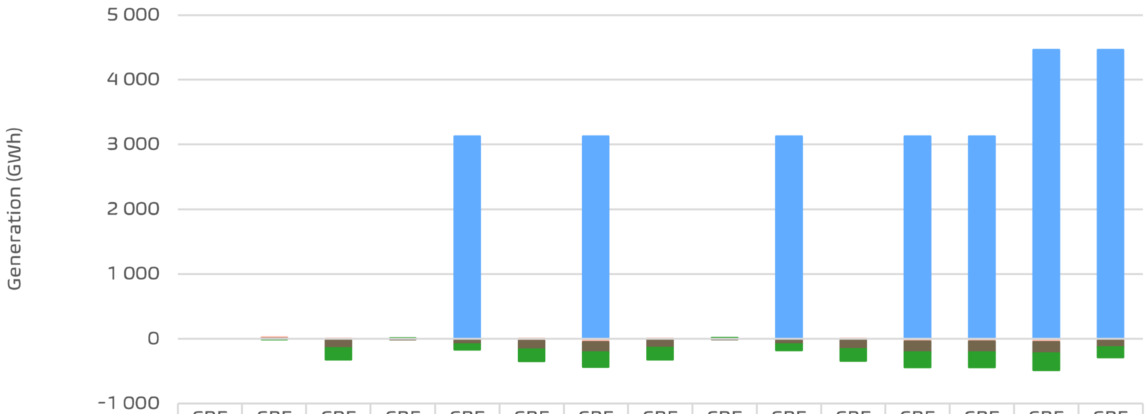
Figure 15: Added generation capacity (MW) by fuel. difference with CBE SC0 in 2030.

Key results

The results of the fourteen scenarios of each of the pathway are compared with SC0 scenario. For each scenario it is analysed and shown the effect on the Estonian energy system in terms of resulting electricity generation, difference in net flow, increased or decreased use of the interconnectors and effect on the yearly electricity prices in Estonia, Latvia, Lithuania, and Finland. In the following the result of the reference of each pathway are referred as Scenario 0 (SC0).

CBE pathway scenarios – electricity generation

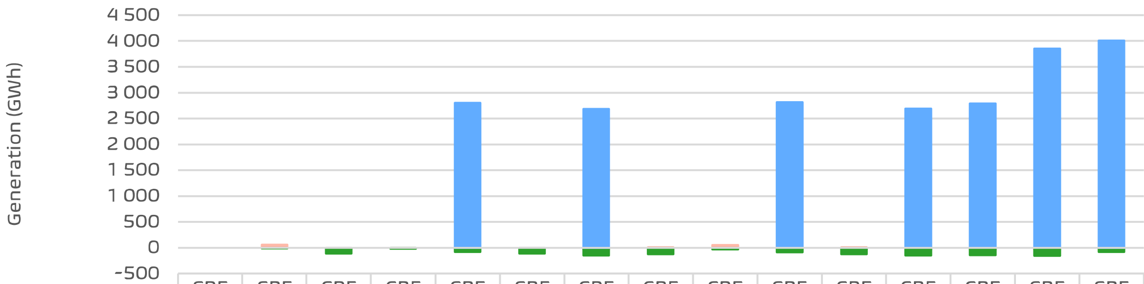
Figure 16 shows the electricity generation by fuel in Estonia for 2030 for each of the scenarios analysed. As it is possible to see in SC1 the higher natural gas capacity affects the generation with an increase in electricity generation from gas and a decrease of electricity generation from shale. In SC2 the increased transmission capacity between Estonia and Finland results in a lower generation from thermal capacities due to the increase in electricity imports from Finland. In SC3, on the other hand, the increased transmission capacity between Latvia and Estonia affects biomass, shale, and gas generation. In SC4, SC6 can be seen how the integration of the 700 MW of offshore wind (meshed configuration) influences the total Estonian generation, marginally decreasing the generation from shale biomass and gas. The reduced generation from biomass and gas is more marked in SC6 where the additional interconnection capacity to Finland plays a role. Comparing SC1 and SC7 it is possible to see how the increased dispatchable capacity has a lower influence in SC7 due to the increased interconnection capacity with Finland. In case of connection with Latvia the higher dispatchable capacity has instead a higher effect with an overall increase of generation from biomass, shale, and gas. SC9 has similar output of SC4, whether SC11 and SC12 have similar effect of SC6, showing how the increased dispatchable capacity and the interconnector between Sweden and Latvia don't significantly influence the Estonian generation mix. In SC13 and SC14 the additional generation capacity from the offshore wind park increases substantially the total generation in Estonia, the presence of interconnection allows to further decrease the generation from thermal plants. In 2030 the curtailment of offshore wind is limited to around 4GWh in scenario 13 and 14, the two scenarios with radial wind offshore configuration.



	CBE SC0	CBE SC1	CBE SC2	CBE SC3	CBE SC4	CBE SC5	CBE SC6	CBE SC7	CBE SC8	CBE SC9	CBE SC10	CBE SC11	CBE SC12	CBE SC13	CBE SC14
Solar		0	0	0	0	0	0	0	0	0	0	0	0	0	0
Onshore wind		0	0	0	0	0	0	0	0	0	0	0	0	0	0
Offshore wind		0	0	0	3 127	0	3 127	0	0	3 127	0	3 127	3 127	4 464	4 464
Biomass		-1	-178	4	-86	-182	-229	-180	2	-95	-179	-234	-234	-259	-157
Shale		-10	-118	-3	-64	-135	-160	-127	-14	-77	-138	-167	-167	-175	-107
Gas		20	-29	-8	-21	-31	-52	-16	9	-12	-25	-44	-44	-53	-27

Figure 16: Electricity generation (GWh) by fuel. difference with CBE SC0 in 2030.

Figure 17 shows how in 2050 the gas generation remains low even in the scenarios with additional gas turbine capacity, the higher generation is seen in SC1 where 60 GWh of generation are coming from this source. The low generation from dispatchable sources is due to the synthetic fuel requirements, the high costs of gas and the CO2 tax, and where the gas capacity is available the generation from shale decreases. The trend described for 2030 still takes place in 2050. The availability of additional interconnection results in lower generation from biomass and shale. In regards of the curtailment of offshore wind generation, the scenarios are compared to understand which additional technology influences it. It must be stated that the curtailment reaches a significant amount (above 10 GWh/year) just from 2040, showing how the capacity development in the neighboring Countries makes more profitable to import electricity or that the capacity development of other renewables (sun and onshore wind) satisfies the electricity demand in Estonia. Comparing SC4 and SC6 it appears that the higher interconnection between Estonia and Finland increases sensibly the electricity curtailed. The same trend appears comparing SC13 and SC14, where the additional connection between Estonia and Finland increases the curtailed of 30% (596 GWh in SC13 and 457 GWh in SC14). The additional dispatchable capacity of gas turbine does not appear to have an influence on the hours of curtailment.



	CBE SC0	CBE SC1	CBE SC2	CBE SC3	CBE SC4	CBE SC5	CBE SC6	CBE SC7	CBE SC8	CBE SC9	CBE SC10	CBE SC11	CBE SC12	CBE SC13	CBE SC14
Solar		0	0	0	0	0	0	0	0	0	0	0	0	0	0
Onshore wind		0	0	0	0	0	0	0	0	0	0	0	0	0	0
Offshore wind		0	0	0	2 803	0	2 684	0	0	2 802	0	2 682	2 780	3 843	4 011
Biomass		-5	-98	-20	-71	-98	-125	-105	-24	-75	-105	-126	-120	-130	-69
Shale		-6	-22	-1	-19	-22	-32	-26	-5	-22	-26	-32	-32	-32	-14
Gas		60	0	0	0	0	0	13	54	14	13	12	12	10	0

Figure 17: Electricity generation by fuel. Difference with CBE SC0 in 2050.

CBE pathway scenarios – electricity price

The effects of the scenarios on the electricity price are also analyzed. **Figure 18** shows the price duration curves for the CBE scenarios in 2030 and 2050. It is possible to see from the chart how the curve with lower prices throughout the year appears to be the one of SC13. the combination of higher interconnection with Finland and additional offshore wind capacity (radial configuration), seems therefore to have the highest impact on the Estonian electricity price. **Table 20** shows the average electricity price in Estonia for each scenario in all the years simulated. The highest average electricity price is found in the SC0; hence, it appears that each additional measure would have an impact reducing the Estonian electricity price. As already mentioned, the lowest prices are found in SC13 till 2040 in 2050 the lowest price is found in SC6. In SC6 the scenario foresees additional offshore wind capacity (in meshed configuration in this case) and additional interconnector capacity to Finland. The reason behind SC6's lower average electricity price in 2050 can be found by the supplementary connection with Latvia given by the meshed offshore wind configuration. Even if the offshore wind capacity added to the Estonian system in SC6 is lower than SC13, the 700 MW additional connection to Latvia result in a lower average Estonian electricity price in 2050. The additional capacity of offshore wind in radial configuration (SC14) still has a high impact. In general, the addition of offshore wind capacity, also in meshed configuration, and the higher interconnection with Finland are the options impacting the most the electricity price. The higher interconnection with Latvia (SC3) has higher influence towards 2050 then in the early years simulated, on the other hand the disposal of dispatchable capacity does not impact the electricity price in 2050. The addition of an interconnector between Latvia and Sweden (SC12 vs SC11) influences the price in 2040 and 2050 increasing the Estonian electricity price.

Table 20: Average electricity prices in CBE scenarios.

€/MWh	2030	2035	2040	2050
CBE SC0	67	63	50	50
CBE SC1	66	62	49	50
CBE SC2	56	56	44	37
CBE SC3	66	62	49	48
CBE SC4	59	58	46	41
CBE SC5	58	55	44	37
CBE SC6	52	51	41	34
CBE SC7	55	55	44	37
CBE SC8	66	62	49	45
CBE SC9	59	57	46	40
CBE SC10	58	55	43	37
CBE SC11	52	51	41	34
CBE SC12	52	52	42	35
CBE SC13	45	49	40	33
CBE SC14	55	56	44	39

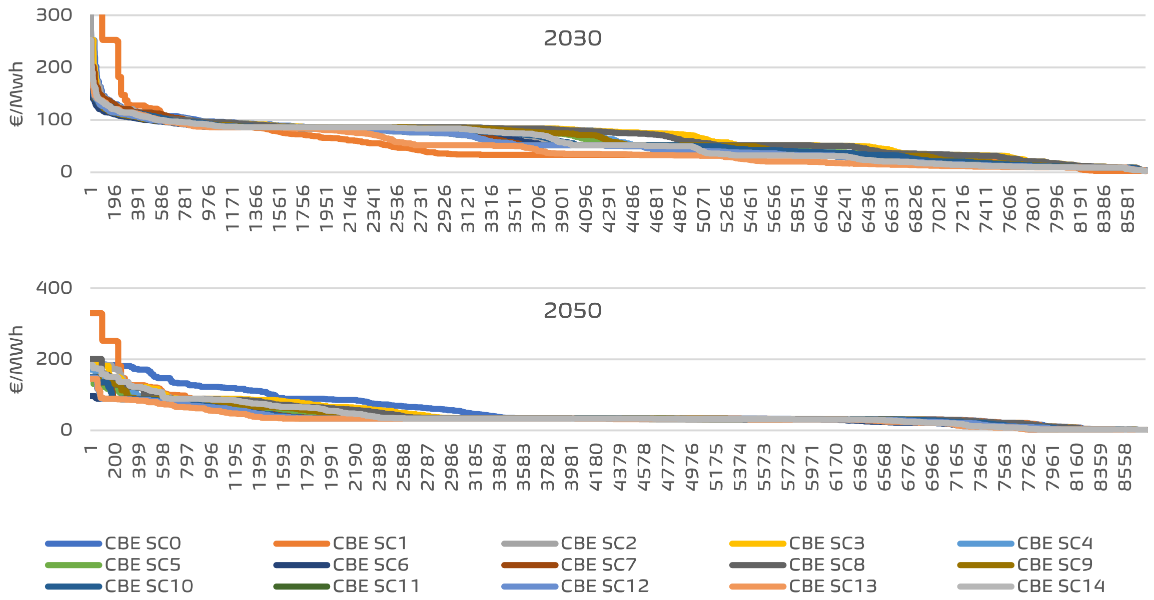


Figure 18: CBE scenarios price duration curves in 2030 (on top) and 2050 on the bottom.

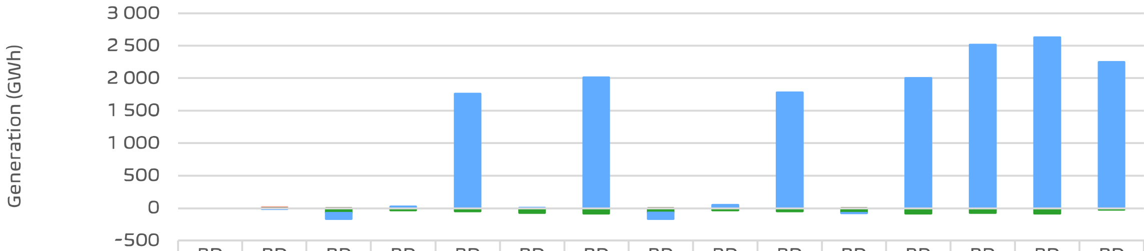
RD pathway scenarios – electricity generation

Figure 19 shows the electricity generation by fuel in Estonia for 2030 for each of the scenarios analysed for the RD pathway. The additional dispatchable generation capacity (SC1) has lower impact compared to the CBE results, this is due to the higher generation offshore capacity that limits the hours in which the gas turbine is generating electricity. In SC2 the increased transmission capacity between Estonia and Finland results in a lower generation from thermal capacities due to the increase in electricity imports from Finland, and the curtailed offshore electricity decreases of 1 GWh. The increased transmission capacity between Latvia and Estonia has almost no effect on Estonian generation, and the already limited curtailment of offshore wind generated is slightly reduced. The additional offshore capacity reaching a total of 1700 MW in 2030, in case of the meshed configuration and 2 GW in case of radial, increases the generation from offshore wind and further reduced the already limited generation from thermal plant. These results suggest that the higher availability of wind capacity will be translated in higher export and/or reduced import. The curtailment is still limited in 2030 and the highest curtailment is reached once again in SC14 with 143 GWh of offshore wind generation curtailed, less than 2% of the offshore generation. In case of higher interconnection with Finland (SC13) the curtailment is instead below 1% of the offshore wind generation.

	RD SC0	RD SC1	RD SC2	RD SC3	RD SC4	RD SC5	RD SC6	RD SC7	RD SC8	RD SC9	RD SC10	RD SC11	RD SC12	RD SC13	RD SC14
Solar		0	0	0	0	0	0	0	0	0	0	0	0	0	0
Onshore wind		0	0	0	0	0	0	0	0	0	0	0	0	0	0
Offshore wind		0	1	2	3 108	4	3 125	1	2	3 108	3	3 125	3 125	4 446	4 387
Biomass		-1	-96	9	-38	-92	-128	-99	9	-38	-95	-128	-128	-145	-82
Shale		-5	-57	-2	-28	-64	-81	-62	-3	-28	-66	-83	-83	-87	-47
Gas		9	-31	-2	-17	-31	-40	-25	1	-14	-29	-34	-34	-36	-24

Figure 19: Electricity generation by fuel. Difference with RD SC0 in 2030.

Figure 20 shows the results in 2050, in regards of the curtailment of offshore wind generation, the scenarios are compared to understand which additional technology influences it. The curtailment reaches a significant amount (above 10 GWh/year) just from 2040, showing how the capacity development in the neighboring Countries could increase their degree of self-sufficiency decreasing the Estonian exports, increasing the curtailment. In 2050, comparing SC4 and SC6 the higher interconnection with Finland significantly increases the curtailment of electricity generated from offshore wind technologies. The curtailment varies from around 3100 GWh to more than 3500 GWh, showing how in some hours is beneficial importing electricity from Finland rather from the offshore wind park. A similar trend to what was seen in CBE scenarios, is found comparing SC13 and SC14. The additional capacity given by SC13 and SC14 added to the already high offshore capacity of the RD pathway results in high curtailment in the Estonian energy system. If in fact, the curtailment is around 15% of the electricity generated by offshore wind in RD SC0 (1.726 GWh curtailed and 11.675 GWh generated), this measure exceeds the 25% in SC13 and reaches almost 30% in SC14. This indicates that the high generation from the offshore wind plants cannot be totally integrated in the Estonian energy system and suggests the requirement of storages.



	RD SC0	RD SC1	RD SC2	RD SC3	RD SC4	RD SC5	RD SC6	RD SC7	RD SC8	RD SC9	RD SC10	RD SC11	RD SC12	RD SC13	RD SC14
Solar		0	0	0	0	0	0	0	0	0	0	0	0	0	0
Onshore wind		0	0	0	0	0	0	0	0	0	0	0	0	0	0
Offshore wind		0	-97	27	1 761	0	2 014	-95	39	1 768	-5	2 004	2 514	2 630	2 250
Biomass		-6	-55	-22	-38	-56	-67	-55	-22	-38	-56	-68	-56	-68	-19
Shale		-5	-16	-10	-10	-16	-16	-16	-10	-10	-16	-16	-16	-16	-4
Gas		15	0	0	0	0	0	0	13	10	0	0	0	0	0

Figure 20: Electricity generation by fuel. Difference with RD SC0 in 2050.

RD pathway scenarios – electricity price

The effects of the scenarios on the electricity price are also analyzed. Figure 21 shows the price duration curves for the RD scenarios in 2030 and 2050. It is possible to see from the chart how once again the price duration, with lower prices throughout the year, appears to be the one of SC13. From the 2030 curve it is possible to compare the curves of SC13 and SC14 where the effect of the additional connection to Finland is mainly lowering the electricity price in hours of relatively high price. From the 2050 curves comparing once again the curves of the two scenarios is clearer the effect also in low-price hours. The additional interconnection behaves as "storage" decreasing the price in high-price hours and increasing it in low-price hours. Table 21 shows the average electricity price in Estonia for each RD scenario in all the years simulated. The highest average electricity prices are found again in the SC0 scenario. One clear outcome is that towards 2050 the yearly electricity prices of the scenario differentiate less to SC0 showing how the development of wind capacity of the RD pathway are already highly influencing the electricity prices. In 2040 and 2050 the lower electricity price is found in SC6. This outcome highlights once again the influence of the higher interconnection between Estonia and Latvia. As it was found in the CBE scenarios, the interconnection between Sweden and Latvia (SC12) increases the Estonian electricity price showing on average higher electricity prices in Southern Sweden compared to Latvia.

Table 21: Average electricity prices in RD scenarios.

€/MWh	2030	2035	2040	2050
RD SC0	54	48	35	31
RD SC1	54	48	34	31
RD SC2	45	45	33	29
RD SC3	56	48	34	31
RD SC4	50	44	32	29
RD SC5	48	45	33	29
RD SC6	44	41	31	26
RD SC7	45	45	33	29
RD SC8	55	48	34	31
RD SC9	50	44	32	29
RD SC10	47	44	33	29
RD SC11	44	41	31	26
RD SC12	44	43	33	28
RD SC13	40	40	30	25
RD SC14	45	41	30	28

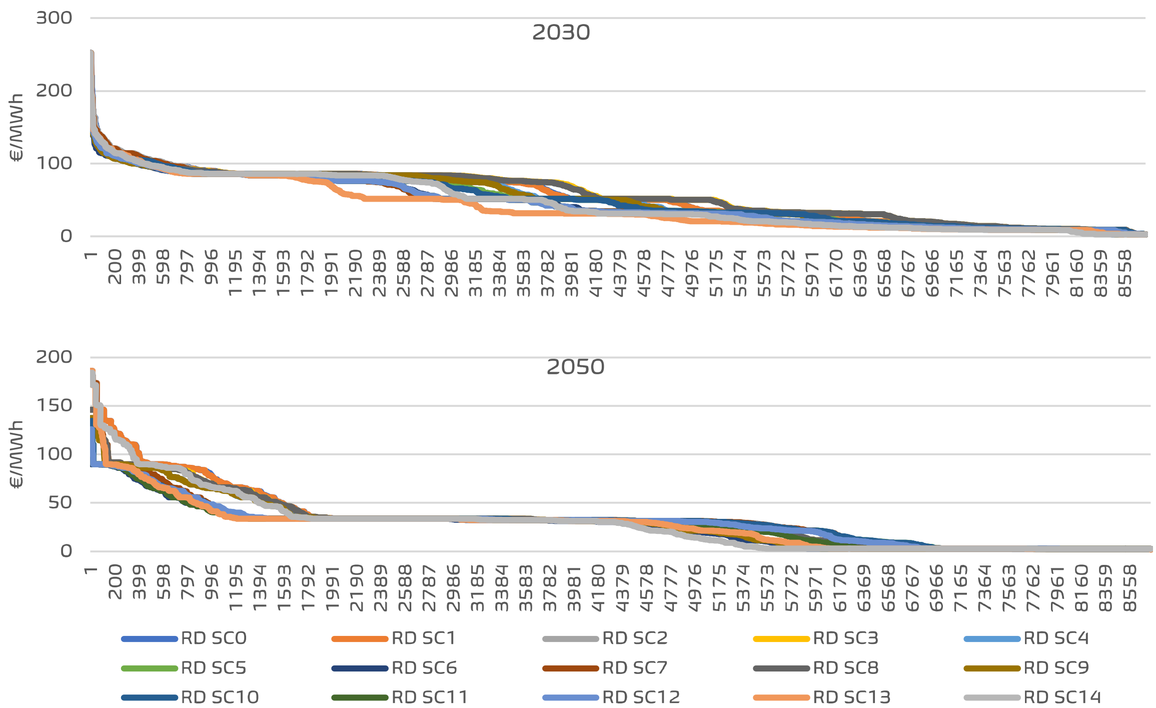
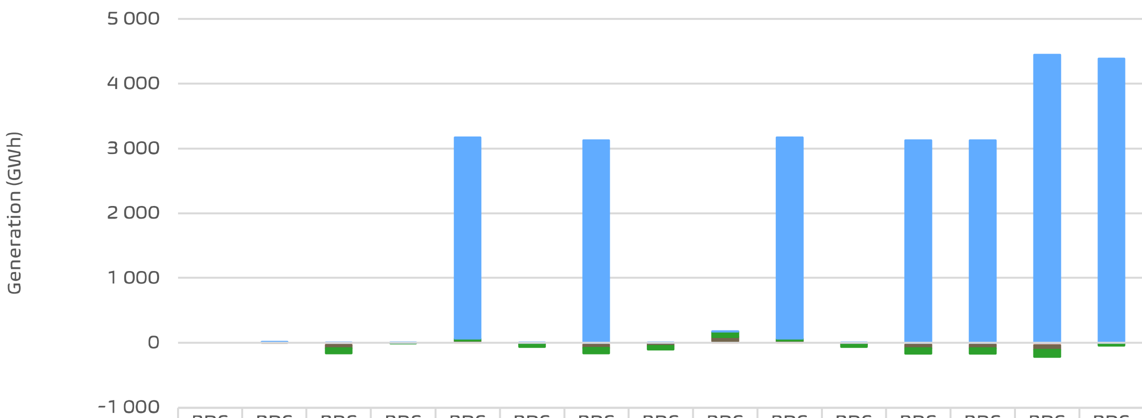


Figure 21: RD scenarios price duration curves in 2030 (on top) and 2050 (on the bottom).

RDS pathway scenarios – electricity generation

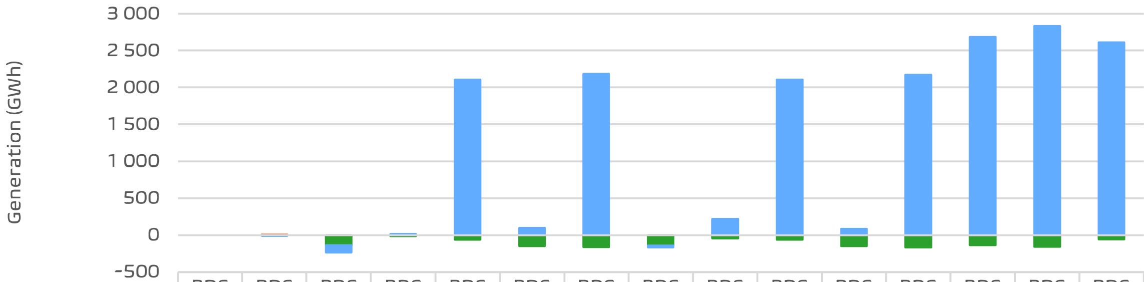
Figure 22 shows the electricity generation by fuel in Estonia for 2030 for each of the RDS scenarios analysed. The additional dispatchable capacity (SC1) has the lowest effect compared to the other pathways, showing how the presence of storage decreases the need of dispatchable thermal capacity in the system. In SC2, as occurs for the CBE and RD case, the increased transmission capacity between Estonia and Finland results in a lower generation from thermal capacities due to the increase in electricity imports from Finland. In SC4 and SC9 can be seen how the effect of the integration of the 700 MW of offshore wind (meshed configuration) in presence of storage capacity in the Estonian energy system. Differently from the RD scenarios the addition of dispatchable capacity (SC9) do not increases the generation from gas in comparison to the scenario without the additional gas turbine capacity (SC4). The main difference between RD SC9 and RDS SC9 is the not decreased generation from biomass and shale, it appears hence that in presence of storages the system prefers to generate from CHP plants that can also satisfy the heat demand and store the electricity generated. It appears that overall, the same trend analysed for RD scenarios occurs also in the RDS scenarios with the main difference regarding the phenomenon cited for SC9 happening for all the scenarios with additional gas capacity, lower generation from gas compared to RD scenarios. The curtailment of offshore wind generation in 2030 is substantially unvaried compared to the RD scenarios.



	RDS SC0	RDS SC1	RDS SC2	RDS SC3	RDS SC4	RDS SC5	RDS SC6	RDS SC7	RDS SC8	RDS SC9	RDS SC10	RDS SC11	RDS SC12	RDS SC13	RDS SC14
Solar		0	0	0	0	0	0	0	0	0	0	0	0	0	0
Onshore wind		0	0	0	0	0	0	0	0	0	0	0	0	0	0
Offshore wind		0	1	2	3 108	4	3 125	1	2	3 108	3	3 125	3 125	4 446	4 387
Biomass		4	-80	-4	32	-35	-85	-56	84	32	-37	-87	-87	-109	-25
Shale		3	-49	-4	30	-17	-51	-31	65	30	-18	-53	-53	-67	-11
Gas		0	-34	-2	3	-11	-29	-18	22	3	-12	-31	-31	-42	-11

Figure 22: Electricity generation by fuel. Difference with RDS SC0 in 2030.

Figure 23 shows how in 2050 the curtailment of offshore wind generation for the RDS scenarios is less than each respective RD scenario. In 2050, hence, the role of storages is more noticeable and the generation from offshore is increased on average of almost 200 GWh a year. The increased generation is especially conspicuous in the scenarios where additional offshore capacity is available without the increased interconnection with Finland (SC4 SC9 and SC14), where effect of the storage is decreasing the curtailment of almost 400 GWh. Regarding the generation of thermal units, each additional capacity, in terms of generation or interconnection capacity decreases the generation from biomass and shale. The additional generation dispatchable capacity SC1 does not appear to have a significant influence on Estonian generation in 2050, the resulting generation from the gas turbine is below 20 GWh.



	RDS SC0	RDS SC1	RDS SC2	RDS SC3	RDS SC4	RDS SC5	RDS SC6	RDS SC7	RDS SC8	RDS SC9	RDS SC10	RDS SC11	RDS SC12	RDS SC13	RDS SC14
Solar		0	0	0	0	0	0	0	0	0	0	0	0	0	0
Onshore wind		0	0	0	0	0	0	0	0	0	0	0	0	0	0
Offshore wind		-2	-103	17	2 104	97	2 185	-22	220	2 105	84	2 172	2 683	2 833	2 609
Biomass		-5	-114	-11	-53	-129	-143	-122	-36	-53	-130	-145	-117	-138	-52
Shale		-3	-20	-3	-9	-20	-20	-20	-9	-9	-20	-20	-20	-20	-6
Gas		17	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 23: Electricity generation by fuel. Difference with RDS SC0 in 2050.

RDS pathway scenarios – electricity price

The effects of the scenarios on the electricity price are also analyzed. Figure 24 shows the price duration curves for the RDS scenarios in 2030 and 2050. It is possible to see from the chart how once again the price duration with lower prices throughout the year appear to be the one of SC13. From the 2030 curve it is possible to compare of the curve of SC13 and SC14 where the effect of the additional connection to Finland mainly lowers the electricity price in hours of relatively high price. From 2050's figure, comparing once again the curves of the two scenarios the effect also in low-price hours is clear. The additional interconnection behaves as "storage" decreasing the price in high-price hours and increasing it in low-price hours. Table 22 shows the average electricity price in Estonia for each RD scenario in all the years simulated. The highest average electricity prices are found again in the SC0 scenario. One clear outcome is that towards 2050 the yearly electricity prices of the scenario differentiate less to SC0 showing how the development of wind capacity of the RD pathway are already highly influencing the average electricity price. In 2040 and 2050 the lower electricity price is found in SC6. This outcome highlights once again the influence of the higher interconnection between Estonia and Latvia. As it was found in the CBE scenarios, the interconnection between Sweden and Latvia (SC12) increases the Estonian electricity price showing on average higher electricity prices in Southern Sweden compared to Latvia.

Table 22: Average electricity prices in RDS scenarios.

€/MWh	2030	2035	2040	2050
RDS SC0	53	47	34	31
RDS SC1	53	47	34	31
RDS SC2	44	44	33	28
RDS SC3	55	48	34	31
RDS SC4	52	48	33	28
RDS SC5	49	46	35	28
RDS SC6	45	44	32	26
RDS SC7	45	46	35	28
RDS SC8	57	52	37	31
RDS SC9	52	48	33	28
RDS SC10	49	46	35	28
RDS SC11	45	44	32	26
RDS SC12	45	44	34	28
RDS SC13	40	41	31	25
RDS SC14	46	44	31	27

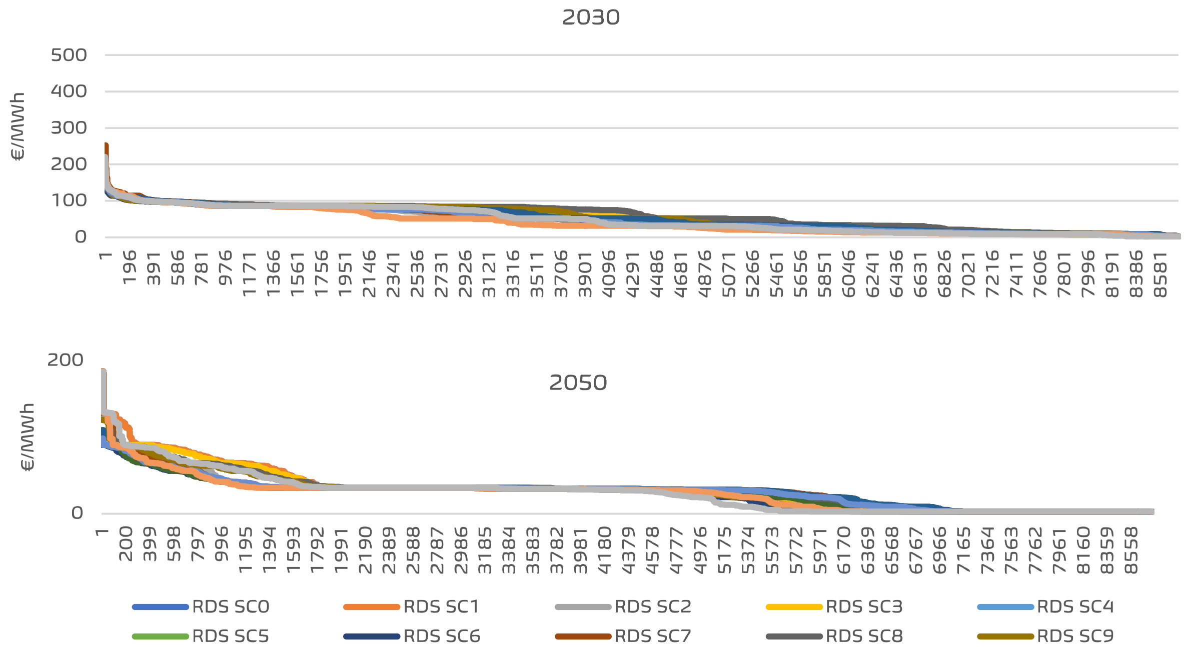


Figure 24: RDS scenarios price duration curves in 2030 (on top) and 2050 (on the bottom).

Sensitivity Analysis: Climate Years

Overview

In the following section, the focus will be shifted to a comprehensive sensitivity analysis centred on climate years within the Estonian energy system. This analysis aims to present the impact of climate variations on electricity generation technologies and, more broadly, on the resilience of the Estonian and Baltic region energy infrastructure.

The analysis undertaken in the previous sections has been rooted in the climate year 1995 and the latter will be addressed as reference year in the following. Acknowledging the dynamic nature of climate patterns and their potential influence on energy systems, the analysis now extends to multiple scenarios specifically, scenarios 0, 1, 2, 4, 13, and 14 in the three pathways CBE, RD and RDS. It will be placed particular emphasis on climate years 2009 and 2012.

These specific years have been identified by Elering as significant for the Estonian energy system, representing a year with high and low VRE potential. For a thorough examination, each of the cited scenarios will be scrutinized across the three pathways. The investigation will span the years 2030, 2035, 2040, and 2050, providing a comprehensive understanding of the long-term implications of climate variability.

The influence of the climate year will regard not just Estonia, but all the modelled Countries, and the PV wind onshore and wind offshore power generation will be influenced by the climate year conditions. This approach aims to assess which is the climate years impact to individual technologies and to the overall resilience of the Estonian energy system.

Figure 25 shows the capacity factor curve for a wind onshore technology for the years 1995, 2009, 2012. To maintain an understandable chart just the first the effects of climate years on the VRE technologies. As it is possible to see other than the average capacity variation, also the variability is a factor to consider and to test the robustness of Estonian energy system. The data utilized for the climate years are real data and refer to measurements in different areas of Europe.

Each area has been allocated a specific wind speed and solar irradiation for the two years considered. As actual data are employed pertaining to the climate conditions of different countries, it's important to note that the data lack homogeneity. A year characterized as "bad" due to low Variable Renewable Energy (VRE) potential in one country may conversely be deemed favorable for another region.

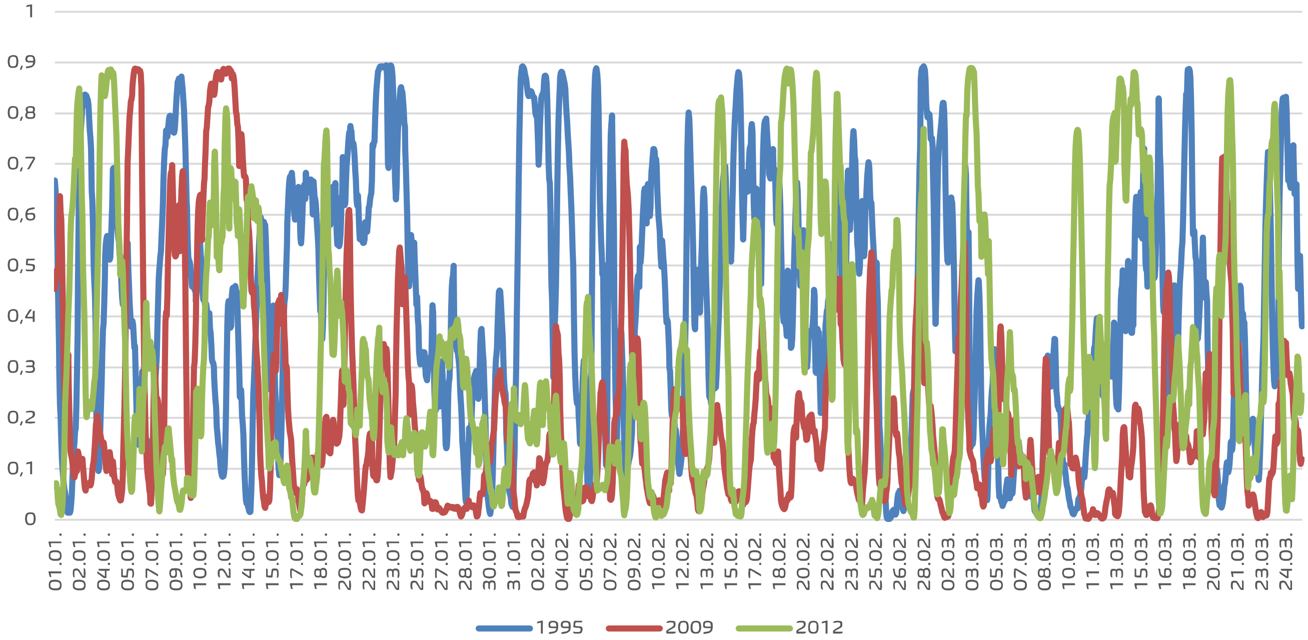


Figure 25: Capacity factor curve for Estonian wind onshore technology

CY 2009

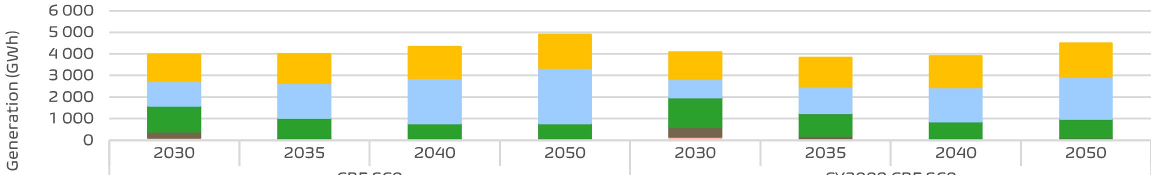
In the Estonian context climate year 2009 is characterized by a lower VRE potential compared to the reference year. In the following the results of the different scenarios in 2009 will be analyzed on an energy system level. The results of each scenario of the climate year 2009 will be compared to the same scenario in reference year conditions.

CBE SC0, RD SC0, RDS SC0

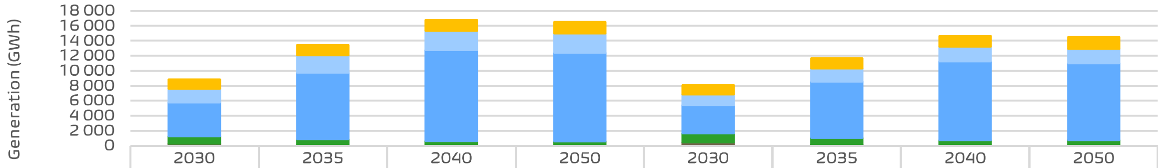
The first scenario analyzed is the SC0, this is the reference scenario and the capacity in Estonia are the same of the reference scenario and the Pathways in the SC0 case.

Electricity generation

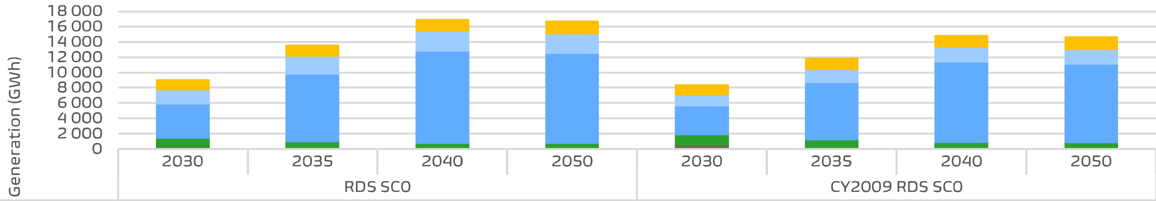
The climatic disparities between 2009 and the 1995 scenario exert a notable influence on Variable Renewable Energy (VRE) generation. In 2009, lower irradiation levels impact solar energy production, while distinct wind patterns affect wind power output. These variations emphasize the significance of considering climate factors in evaluating and forecasting VRE performance, providing valuable insights for stakeholders in the renewable energy sector. More specifically, Figure 26 shows the difference between the electricity generation in CBE SC0, RD SC0 and RDS SC0 with climate year 2009 and the reference climate year. The effect of a lower irradiation and wind speed on the electricity generation is mainly a higher generation from dispatchable sources (natural gas, shale, and biomass) in all three cases. Furthermore, the total electricity generated yearly is lower suggesting higher dependency on imports in the case of CY 2009. In the following the effect on electricity transmission is also examined.



	2030	2035	2040	2050	2030	2035	2040	2050
	CBE SC0				CY2009 CBE SC0			
Solar	1 229	1 336	1 444	1 554	1 228	1 335	1 442	1 552
Onshore wind	1 138	1 616	2 095	2 573	858	1 219	1 580	1 940
Biomass	1 199	946	766	737	1 371	1 059	830	875
Shale	286	87	14	38	456	200	44	116
Gas	116				160	0	0	



	2030	2035	2040	2050	2030	2035	2040	2050
	RD SC0				CY2009 RD SC0			
Solar	1 229	1 336	1 444	1 554	1 228	1 335	1 442	1 552
Onshore wind	1 855	2 334	2 573	2 573	1 399	1 760	1 940	1 940
Offshore wind	4 463	8 873	12 113	11 780	3 773	7 493	10 515	10 264
Biomass	1 020	813	609	576	1 203	927	702	670
Shale	171	46	7	16	329	131	34	53
Gas	84		0		128			



	2030	2035	2040	2050	2030	2035	2040	2050
	RDS SC0				CY2009 RDS SC0			
Solar	1 229	1 336	1 444	1 554	1 228	1 335	1 442	1 552
Onshore wind	1 855	2 334	2 573	2 573	1 399	1 760	1 940	1 940
Offshore wind	4 463	8 875	12 111	11 801	3 772	7 490	10 522	10 265
Biomass	1 128	926	756	744	1 343	1 059	856	824
Shale	208	65	12	20	403	185	47	55
Gas	105				158			

Figure 26: Electricity generation of CBE RD and RDS scenario 0 for reference climate year and 2009.

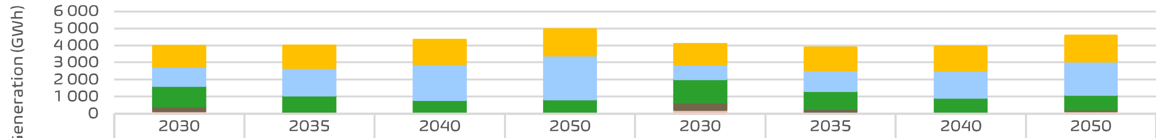
[redacted]

CBE SC1, RD SC1, RDS SC1

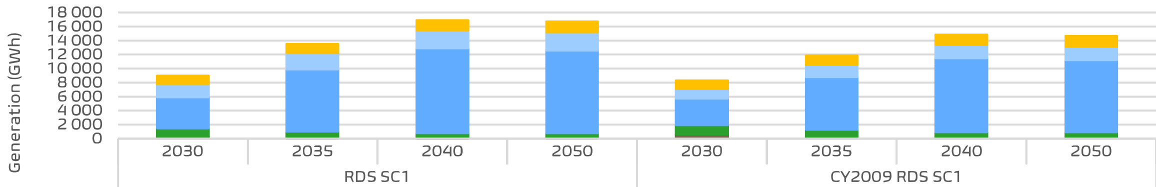
The scenarios CBE SC1, RD SC1 and RDS SC1 are in the following analyzed, these scenarios differ from the pathways for the presence of the additional dispatchable capacity, namely the open cycle gas turbine.

Electricity generation

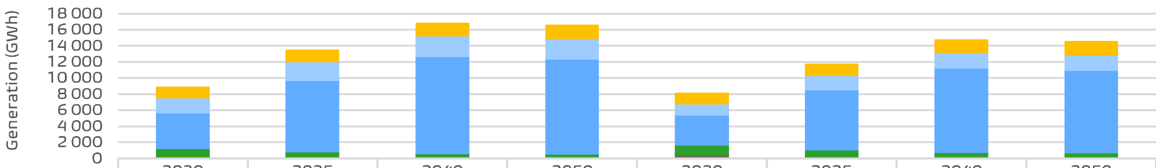
Figure 27 shows the difference between the electricity generation in CBE SC1, RD SC1 and RDS SC1 with climate year 2009 and the reference climate year. The effect of a lower irradiation and wind speed on the electricity generation is mainly a higher generation from dispatchable sources, more specifically it is possible to see how the gas turbine is generating more in the case of climate year 2009 in all three scenarios.



	CBE SC1				CY2009 CBE SC1			
	2030	2035	2040	2050	2030	2035	2040	2050
Solar	1 229	1 336	1 444	1 554	1 228	1 335	1 442	1 552
Onshore wind	1 138	1 616	2 095	2 573	858	1 219	1 580	1 940
Biomass	1 198	943	765	732	1 367	1 056	830	855
Shale	276	84	14	33	439	191	44	101
Gas	136	29	11	60	206	78	46	138



	RDS SC1				CY2009 RDS SC1			
	2030	2035	2040	2050	2030	2035	2040	2050
Solar	1 229	1 336	1 444	1 554	1 228	1 335	1 442	1 552
Onshore wind	1 855	2 334	2 573	2 573	1 399	1 760	1 940	1 940
Offshore wind	4 463	8 875	12 101	11 799	3 772	7 488	10 523	10 271
Biomass	1 132	925	754	739	1 340	1 055	852	815
Shale	211	65	10	17	395	167	43	46
Gas	105	8	3	17	188	53	36	40



	RD SC1				CY2009 RD SC1			
	2030	2035	2040	2050	2030	2035	2040	2050
Solar	1 229	1 336	1 444	1 554	1 228	1 335	1 442	1 552
Onshore wind	1 855	2 334	2 573	2 573	1 399	1 760	1 940	1 940
Offshore wind	4 462	8 873	12 109	11 780	3 773	7 492	10 525	10 262
Biomass	1 019	812	609	570	1 203	930	702	653
Shale	166	45	7	12	317	125	33	38
Gas	93	14	4	15	165	55	39	40

Figure 27: Electricity generation of CBE RD and RDS SC1 for reference climate year and 2009.

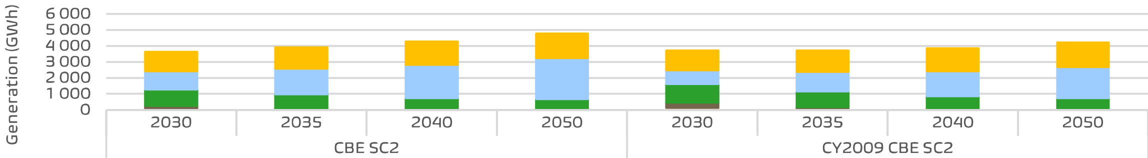
[redacted]

CBE SC2, RD SC2, RDS SC2

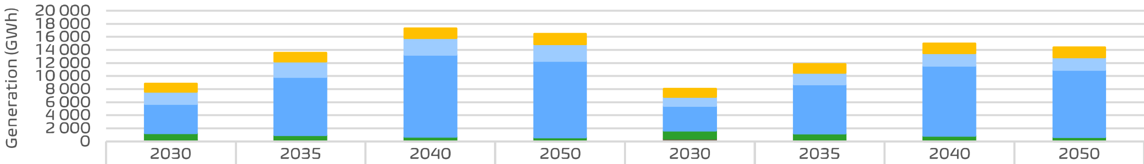
The scenarios CBE SC2, RD SC2 and RDS SC2 scenarios differ from the pathways for the presence of the additional interconnection capacity between Estonia and Finland.

Electricity generation

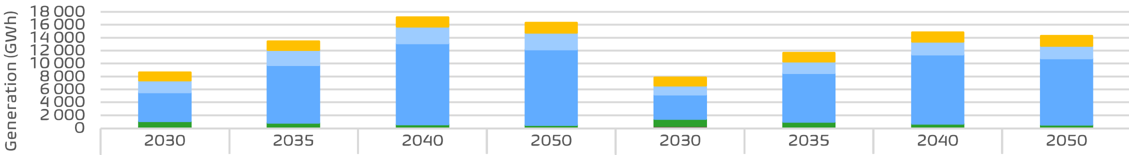
Figure 26**Figure 28** shows the difference between the electricity generation in CBE, RD and RDS SC2 in climate year 2009 and the reference climate year. As mentioned in the previous cases the main difference lies in the generation of dispatchable sources biomass shale and gas in 2030.



	CBE SC2				CY2009 CBE SC2			
	2030	2035	2040	2050	2030	2035	2040	2050
Solar	1 229	1 336	1 444	1 554	1 228	1 335	1 442	1 552
Onshore wind	1 138	1 616	2 095	2 573	858	1 219	1 580	1 940
Biomass	1 021	902	724	639	1 185	1 004	799	694
Shale	167	67	8	17	316	162	39	36
Gas	87	0			128		0	



	RDS SC2				CY2009 RDS SC2			
	2030	2035	2040	2050	2030	2035	2040	2050
Solar	1 229	1 336	1 444	1 554	1 228	1 335	1 442	1 552
Onshore wind	1 855	2 334	2 573	2 573	1 399	1 760	1 940	1 940
Offshore wind	4 463	8 914	12 528	11 698	3 772	7 527	10 709	10 253
Biomass	1 048	906	720	630	1 222	1 034	828	669
Shale	159	56	7		310	174	45	0
Gas	71				130			



	RD SC2				CY2009 RD SC2			
	2030	2035	2040	2050	2030	2035	2040	2050
Solar	1 229	1 336	1 444	1 554	1 228	1 335	1 442	1 552
Onshore wind	1 855	2 334	2 573	2 573	1 399	1 760	1 940	1 940
Offshore wind	4 463	8 914	12 527	11 683	3 772	7 527	10 710	10 246
Biomass	924	796	595	521	1 089	903	682	561
Shale	114	39	4	0	245	116	32	1
Gas	53				101			

Figure 28: Electricity generation of CBE RD and RDS SC2 for climate year 2009.

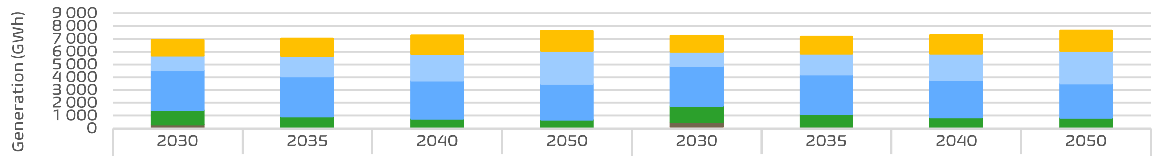
[redacted]

CBE SC4, RD SC4, RDS SC4

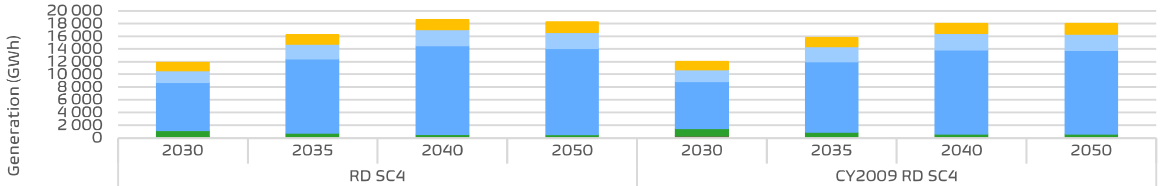
The scenarios CBE, RD and RDS SC4 differ from the pathways for the presence of an offshore wind park of 700 MW in meshed connection with Estonia.

Electricity generation

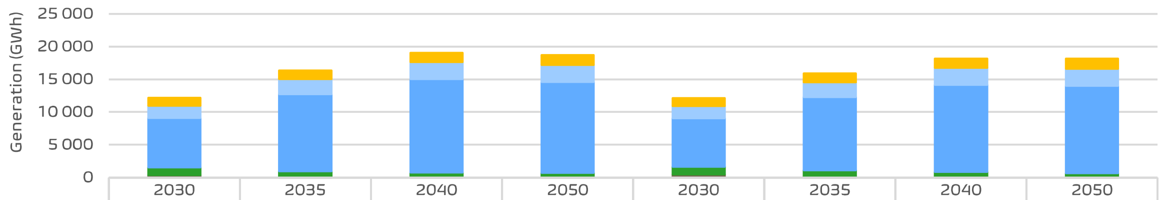
Figure 29 shows the difference between the electricity generation in CBE, RD and RDS SC4 with climate year 2009 and the reference climate year.



	CBE SC4				CY2009 CBE SC4			
	2030	2035	2040	2050	2030	2035	2040	2050
Solar	1 229	1 336	1 444	1 554	1 228	1 335	1 442	1 552
Onshore wind	1 138	1 616	2 095	2 573	1 138	1 616	2 095	2 573
Offshore wind	3 127	3 126	2 977	2 803	3 110	3 093	2 901	2 683
Biomass	1 113	891	738	666	1 267	984	808	756
Shale	221	50	8	19	366	144	39	71
Gas	95		0		126	0		



	RD SC4				CY2009 RD SC4			
	2030	2035	2040	2050	2030	2035	2040	2050
Solar	1 229	1 336	1 444	1 554	1 228	1 335	1 442	1 552
Onshore wind	1 855	2 334	2 573	2 573	1 855	2 334	2 573	2 573
Offshore wind	7 571	11 701	13 953	13 541	7 407	11 115	13 243	13 171
Biomass	983	768	584	538	1 140	855	648	612
Shale	143	25	5	6	278	88	20	34
Gas	68				96	0		



	RDS SC4				CY2009 RDS SC4			
	2030	2035	2040	2050	2030	2035	2040	2050
Solar	1 229	1 336	1 444	1 554	1 228	1 335	1 442	1 552
Onshore wind	1 855	2 334	2 573	2 573	1 855	2 334	2 573	2 573
Offshore wind	7 571	11 763	14 294	13 905	7 418	11 154	13 357	13 385
Biomass	1 160	902	762	691	1 186	971	810	652
Shale	237	52	2	11	293	117	22	1
Gas	108				136			

Figure 29: Electricity generation of CBE RD and RDS for climate year 2009.

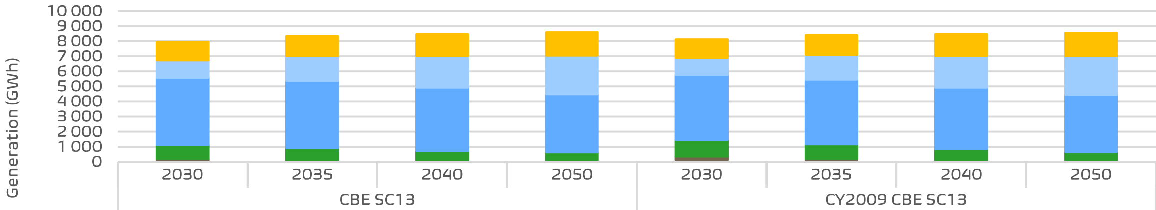
[redacted]

CBE SC13, RD SC13, RDS SC13

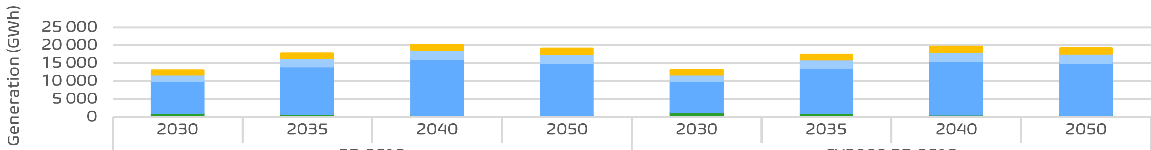
The scenarios CBE, RD and RDS SC13 scenarios differ from the pathways for the presence of the additional capacity of a gas turbine, the addition of 700MW capacity interconnector between Estonia and Finland and for 1000 MW wind park radially connected to Estonia.

Electricity generation

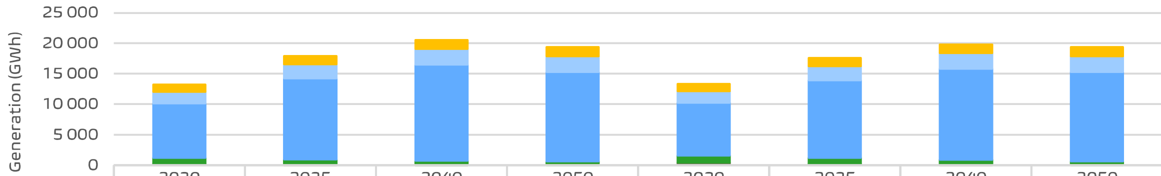
Figure 30 shows the difference between the electricity generation in the three scenarios in climate year 2009 and in the reference climate year.



	2030	2035	2040	2050	2030	2035	2040	2050
	CBE SC13				CY2009 CBE SC13			
Solar	1 229	1 336	1 444	1 554	1 228	1 335	1 442	1 552
Onshore wind	1 138	1 616	2 095	2 573	1 138	1 616	2 095	2 573
Offshore wind	4 464	4 465	4 201	3 843	4 310	4 303	4 077	3 791
Biomass	940	852	703	606	1 093	960	771	637
Shale	111	43	6	6	232	129	32	6
Gas	63	14	5	10	124	65	45	



	2030	2035	2040	2050	2030	2035	2040	2050
	RD SC13				CY2009 RD SC13			
Solar	1 229	1 336	1 444	1 554	1 228	1 335	1 442	1 552
Onshore wind	1 855	2 334	2 573	2 573	1 855	2 334	2 573	2 573
Offshore wind	8 908	13 237	15 484	14 410	8 660	12 671	14 858	14 470
Biomass	875	763	576	508	1 025	860	649	542
Shale	84	32	4	0	194	87	22	0
Gas	48	8	4		96	47	26	



	2030	2035	2040	2050	2030	2035	2040	2050
	RDS SC13				CY2009 RDS SC13			
Solar	1 229	1 336	1 444	1 554	1 228	1 335	1 442	1 552
Onshore wind	1 855	2 334	2 573	2 573	1 855	2 334	2 573	2 573
Offshore wind	8 908	13 246	15 748	14 634	8 658	12 668	14 889	14 608
Biomass	1 019	890	725	606	1 178	1 017	826	630
Shale	141	54	5		274	150	37	
Gas	63	8	4		124	53	19	

Figure 30: Electricity generation of CBE RD and RDS for climate year 2009.

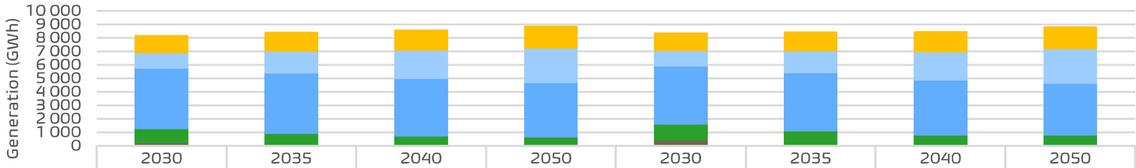
[redacted]

CBE SC14, RD SC14, RDS SC14

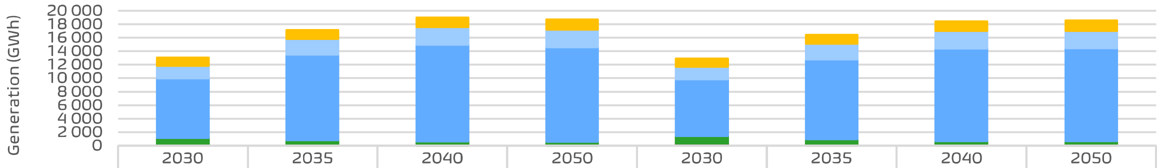
The scenarios CBE SC14, RD SC14 and RDS SC14 scenarios differ from the pathways for the presence of the additional 1000 MW wind park radially connected to Estonia.

Electricity generation

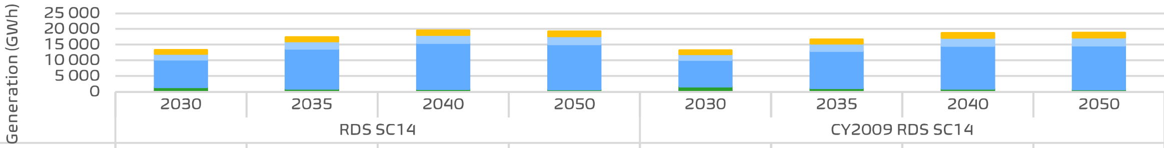
Figure 31 shows the difference between the electricity generation in CBE, RD and RDS SC14 with climate year 2009 and the reference climate year.



	CBE SC14 2030	CBE SC14 2035	CBE SC14 2040	CBE SC14 2050	CY2009 CBE SC14 2030	CY2009 CBE SC14 2035	CY2009 CBE SC14 2040	CY2009 CBE SC14 2050
Solar	1 229	1 336	1 444	1 554	1 228	1 335	1 442	1 552
Onshore wind	1 138	1 616	2 095	2 573	1 138	1 616	2 095	2 573
Offshore wind	4 464	4 463	4 265	4 011	4 310	4 299	4 062	3 836
Biomass	1 042	895	738	668	1 199	989	796	756
Shale	179	63	11	24	321	152	35	69
Gas	89				120			



	RD SC14 2030	RD SC14 2035	RD SC14 2040	RD SC14 2050	CY2009 RD SC14 2030	CY2009 RD SC14 2035	CY2009 RD SC14 2040	CY2009 RD SC14 2050
Solar	1 229	1 336	1 444	1 554	1 228	1 335	1 442	1 552
Onshore wind	1 855	2 334	2 573	2 573	1 855	2 334	2 573	2 573
Offshore wind	8 849	12 671	14 379	14 030	8 426	11 828	13 729	13 766
Biomass	938	767	593	557	1 073	854	651	624
Shale	124	36	7	12	239	96	24	35
Gas	60		0		93			



	RDS SC14 2030	RDS SC14 2035	RDS SC14 2040	RDS SC14 2050	CY2009 RDS SC14 2030	CY2009 RDS SC14 2035	CY2009 RDS SC14 2040	CY2009 RDS SC14 2050
Solar	1 229	1 336	1 444	1 554	1 228	1 335	1 442	1 552
Onshore wind	1 855	2 334	2 573	2 573	1 855	2 334	2 573	2 573
Offshore wind	8 850	12 766	14 737	14 411	8 432	11 821	13 743	13 941
Biomass	1 103	909	771	691	1 221	1 019	852	721
Shale	196	54	7	14	314	151	37	33
Gas	94				130			

Figure 31: Electricity generation of CBE RD and RDS for climate year 2009.

[redacted]

CY 2012

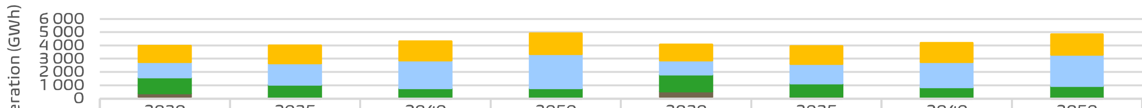
The effect of climate year 2012, once again characterized by a lower wind and solar potential compared to the reference year, however the solar potential in the other Baltic Countries appear to be higher compared to reference year. In the following the results of the different scenarios in 2012 will be analyzed on an energy system level.

CBE SCO, RD SCO, RDS SCO

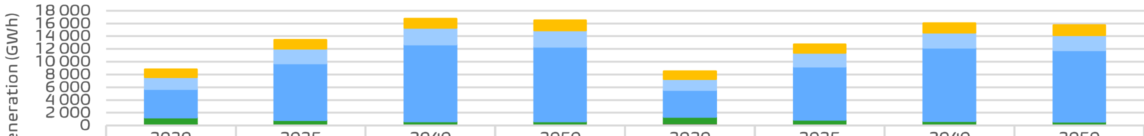
The first scenario analyzed is the SCO, this is the reference scenario and the capacity in Estonia are the same of the reference scenario and the Pathways in the SCO case.

Electricity generation

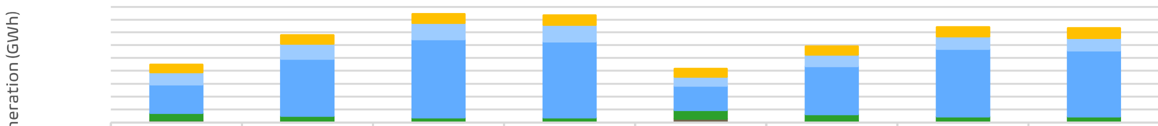
Figure 32 shows the difference between the electricity generation. Comparing the output of the climate year 2012 with the one of 2009 it is possible to see how the generation from wind and solar is higher, however this is still lower compared to the reference climate year. The effect on the generation is comparable to what found for the climate year 2009, namely higher generation from dispatchable sources (biomass, shale, and gas turbines).



	CBE SCO				CY2012 CBE SCO			
	2030	2035	2040	2050	2030	2035	2040	2050
Solar	1 229	1 336	1 444	1 554	1 220	1 326	1 433	1 542
Onshore wind	1 138	1 616	2 095	2 573	1 039	1 475	1 912	2 348
Biomass	1 199	946	766	737	1 287	987	805	835
Shale	286	87	14	38	401	147	34	114
Gas	116				132			



	RD SCO				CY2012 RD SCO			
	2030	2035	2040	2050	2030	2035	2040	2050
Solar	1 229	1 336	1 444	1 554	1 220	1 326	1 433	1 542
Onshore wind	1 855	2 334	2 573	2 573	1 694	2 130	2 348	2 348
Offshore wind	4 463	8 873	12 113	11 780	4 188	8 326	11 569	11 225
Biomass	1 020	813	609	576	1 056	844	637	578
Shale	171	46	7	16	243	92	18	9
Gas	84		0		94			



	RDS SCO				CY2012 RDS SCO			
	2030	2035	2040	2050	2030	2035	2040	2050
Solar	1 229	1 336	1 444	1 554	1 228	1 335	1 442	1 552
Onshore wind	1 855	2 334	2 573	2 573	1 399	1 760	1 940	1 940
Offshore wind	4 463	8 875	12 111	11 801	3 772	7 490	10 522	10 265
Biomass	1 128	926	756	744	1 343	1 059	856	824
Shale	208	65	12	20	403	185	47	55
Gas	105				158			

Figure 32: Electricity generation of CBE RD and RDS for climate year 2012.

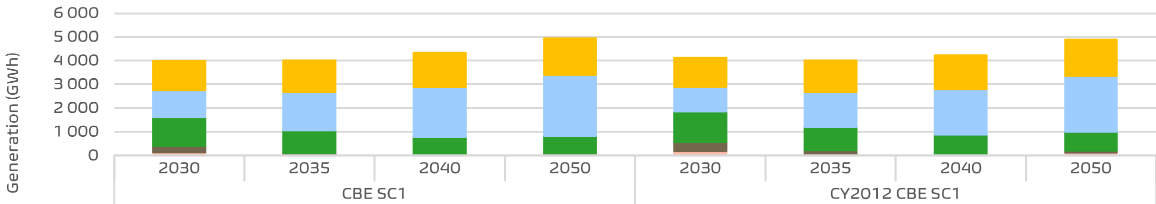
[redacted]

CBE SC1, RD SC1, RDS SC1

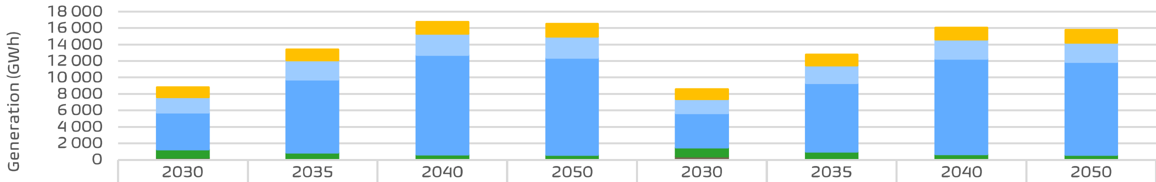
The scenarios CBE SC1, RD SC1 and RDS SC1 are in the following analyzed, these scenarios differ from the pathways for the presence of the additional dispatchable capacity, namely the open cycle gas turbine.

Electricity generation

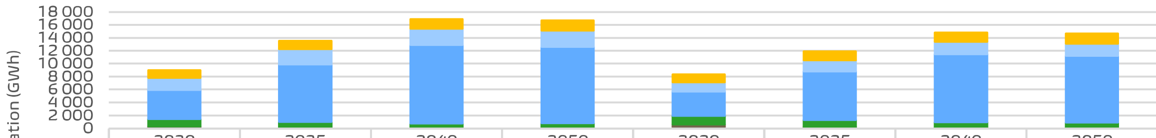
Figure 33 shows the difference between the electricity generation in CBE SC1, RD SC1 and RDS SC1 with climate year 2012 and the reference climate year.



	CBE SC1				CY2012 CBE SC1			
	2030	2035	2040	2050	2030	2035	2040	2050
Solar	1 229	1 336	1 444	1 554	1 220	1 326	1 433	1 542
Onshore wind	1 138	1 616	2 095	2 573	1 039	1 475	1 912	2 348
Biomass	1 198	943	765	732	1 282	988	804	800
Shale	276	84	14	33	390	146	33	84
Gas	136	29	11	60	183	72	40	121



	RD SC1				CY2012 RD SC1			
	2030	2035	2040	2050	2030	2035	2040	2050
Solar	1 229	1 336	1 444	1 554	1 220	1 326	1 433	1 542
Onshore wind	1 855	2 334	2 573	2 573	1 694	2 130	2 348	2 348
Offshore wind	4 462	8 873	12 109	11 780	4 188	8 327	11 596	11 285
Biomass	1 019	812	609	570	1 084	857	641	581
Shale	166	45	7	12	259	94	19	8
Gas	93	14	4	15	143	51	25	2



	RDS SC1				CY2012 RDS SC1			
	2030	2035	2040	2050	2030	2035	2040	2050
Solar	1 229	1 336	1 444	1 554	1 228	1 335	1 442	1 552
Onshore wind	1 855	2 334	2 573	2 573	1 399	1 760	1 940	1 940
Offshore wind	4 463	8 875	12 101	11 799	3 772	7 488	10 523	10 271
Biomass	1 132	925	754	739	1 340	1 055	852	815
Shale	211	65	10	17	395	167	43	46
Gas	105	8	3	17	188	53	36	40

Figure 33: Electricity generation of CBE RD and RDS for climate year 2012.

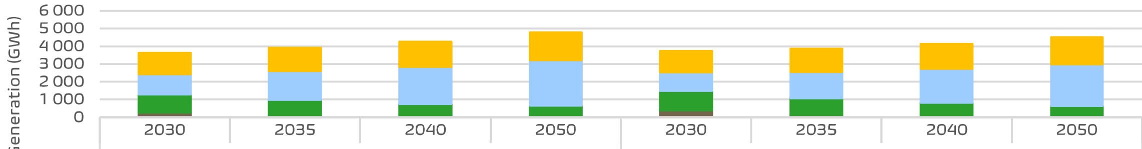
[redacted]

CBE SC2, RD SC2, RDS SC2

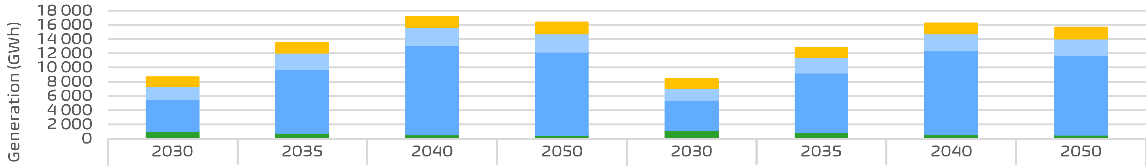
The scenarios CBE SC2, RD SC2 and RDS SC2 scenarios differ from the pathways for the presence of the additional interconnection capacity between Estonia and Finland.

Electricity generation

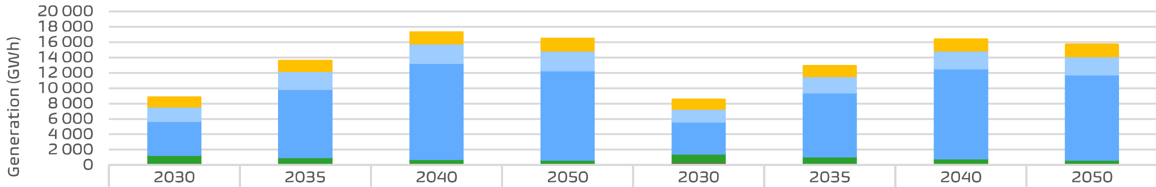
Figure 34 shows the difference between the electricity generation in CBE RDS SC2 with climate year 2012 and the reference climate year.



	CBE SC2 2030	CBE SC2 2035	CBE SC2 2040	CBE SC2 2050	CY2012 CBE SC2 2030	CY2012 CBE SC2 2035	CY2012 CBE SC2 2040	CY2012 CBE SC2 2050
Solar	1 229	1 336	1 444	1 554	1 220	1 326	1 433	1 542
Onshore wind	1 138	1 616	2 095	2 573	1 039	1 475	1 912	2 348
Biomass	1 021	902	724	639	1 100	939	768	623
Shale	167	67	8	17	276	126	32	
Gas	87	0			104		0	



	RD SC2 2030	RD SC2 2035	RD SC2 2040	RD SC2 2050	CY2012 RD SC2 2030	CY2012 RD SC2 2035	CY2012 RD SC2 2040	CY2012 RD SC2 2050
Solar	1 229	1 336	1 444	1 554	1 220	1 326	1 433	1 542
Onshore wind	1 855	2 334	2 573	2 573	1 694	2 130	2 348	2 348
Offshore wind	4 463	8 914	12 527	11 683	4 188	8 354	11 751	11 164
Biomass	924	796	595	521	978	856	645	547
Shale	114	39	4	0	199	98	21	4
Gas	53				75	0		



	RDS SC2 2030	RDS SC2 2035	RDS SC2 2040	RDS SC2 2050	CY2012 RDS SC2 2030	CY2012 RDS SC2 2035	CY2012 RDS SC2 2040	CY2012 RDS SC2 2050
Solar	1 229	1 336	1 444	1 554	1 220	1 326	1 433	1 542
Onshore wind	1 855	2 334	2 573	2 573	1 694	2 130	2 348	2 348
Offshore wind	4 463	8 914	12 528	11 698	4 188	8 354	11 758	11 154
Biomass	1 048	906	720	630	1 092	946	767	626
Shale	159	56	7		254	125	36	
Gas	71				93			

Figure 34: Electricity generation of CBE RD and RDS for climate year 2012.

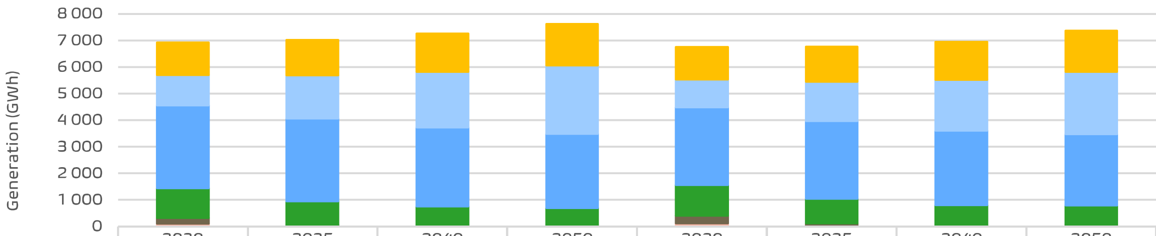
[redacted]

CBE SC4, RD SC4, RDS SC4

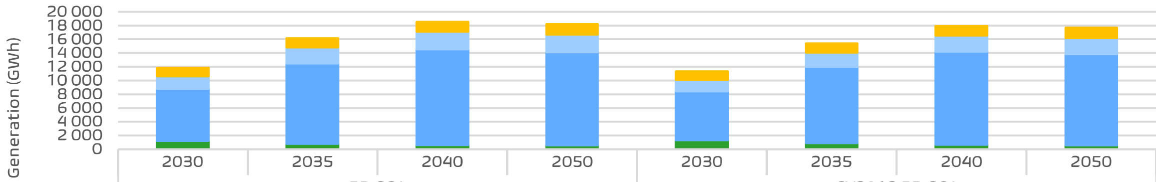
The scenarios CBE, RD and RDS SC4 differ from the pathways for the presence of an offshore wind park of 700 MW in meshed connection with Estonia.

Electricity generation

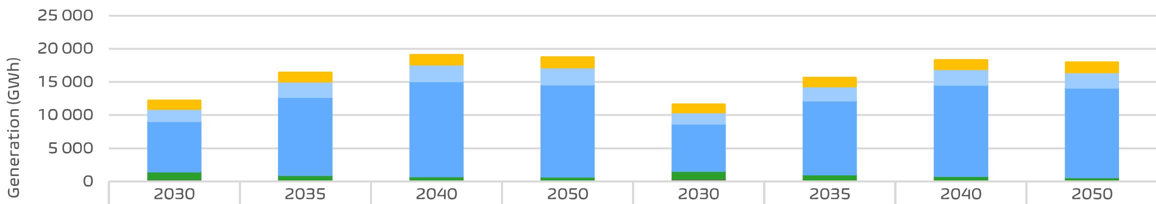
Figure 35 shows the difference between the electricity generation in CBE, RD and RDS SC4.



	CBE SC4				CY2012 CBE SC4			
	2030	2035	2040	2050	2030	2035	2040	2050
Solar	1 229	1 336	1 444	1 554	1 220	1 326	1 433	1 542
Onshore wind	1 138	1 616	2 095	2 573	1 039	1 475	1 912	2 348
Offshore wind	3 127	3 126	2 977	2 803	2 933	2 928	2 813	2 683
Biomass	1 113	891	738	666	1 153	934	770	729
Shale	221	50	8	19	296	109	25	59
Gas	95		0		109			



	RD SC4				CY2012 RD SC4			
	2030	2035	2040	2050	2030	2035	2040	2050
Solar	1 229	1 336	1 444	1 554	1 220	1 326	1 433	1 542
Onshore wind	1 855	2 334	2 573	2 573	1 694	2 130	2 348	2 348
Offshore wind	7 571	11 701	13 953	13 541	7 099	11 065	13 542	13 253
Biomass	983	768	584	538	1 028	812	622	555
Shale	143	25	5	6	212	64	14	5
Gas	68				78			



	RDS SC4				CY2012 RDS SC4			
	2030	2035	2040	2050	2030	2035	2040	2050
Solar	1 229	1 336	1 444	1 554	1 220	1 326	1 433	1 542
Onshore wind	1 855	2 334	2 573	2 573	1 694	2 130	2 348	2 348
Offshore wind	7 571	11 763	14 294	13 905	7 098	11 116	13 746	13 471
Biomass	1 160	902	762	691	1 191	962	783	622
Shale	237	52	2	11	285	99	20	
Gas	108				116	0	0	

Figure 35: Electricity generation of CBE RD and RDS for climate year 2012.

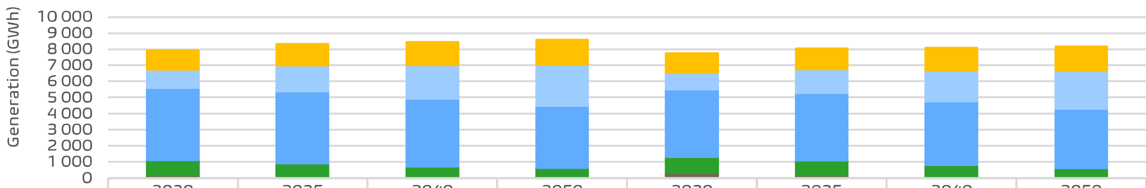
[redacted]

CBE SC13, RD SC13, RDS SC13

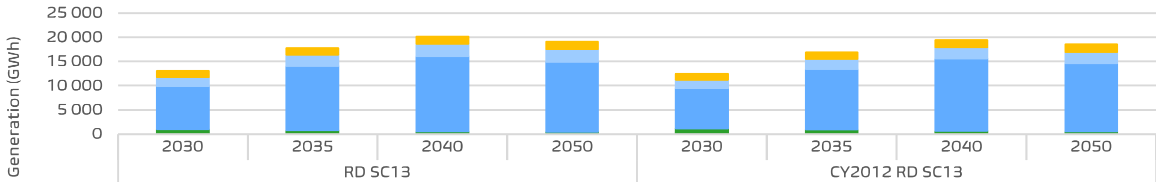
The scenarios CBE, RD and RDS SC13 scenarios differ from the pathways for the presence of the additional capacity of a gas turbine, the addition of 700MW capacity interconnector between Estonia and Finland and for 1000 MW wind park radially connected to Estonia.

Electricity generation

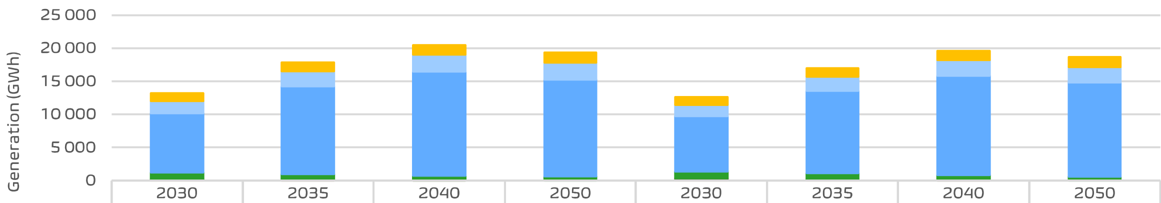
Figure 26 shows the difference between the electricity generation in CBE, RD and RDS SC13 with climate year 2012 and the reference climate year.



	CBE SC13 2030	CBE SC13 2035	CBE SC13 2040	CBE SC13 2050	CY2012 CBE SC13 2030	CY2012 CBE SC13 2035	CY2012 CBE SC13 2040	CY2012 CBE SC13 2050
Solar	1 229	1 336	1 444	1 554	1 220	1 326	1 433	1 542
Onshore wind	1 138	1 616	2 095	2 573	1 039	1 475	1 912	2 348
Offshore wind	4 464	4 465	4 201	3 843	4 190	4 179	3 934	3 680
Biomass	940	852	703	606	991	907	747	607
Shale	111	43	6	6	195	109	28	
Gas	63	14	5	10	117	64	39	



	RD SC13 2030	RD SC13 2035	RD SC13 2040	RD SC13 2050	CY2012 RD SC13 2030	CY2012 RD SC13 2035	CY2012 RD SC13 2040	CY2012 RD SC13 2050
Solar	1 229	1 336	1 444	1 554	1 220	1 326	1 433	1 542
Onshore wind	1 855	2 334	2 573	2 573	1 694	2 130	2 348	2 348
Offshore wind	8 908	13 237	15 484	14 410	8 340	12 442	14 928	14 063
Biomass	875	763	576	508	922	824	622	526
Shale	84	32	4	0	152	84	17	
Gas	48	8	4		95	46	25	



	RDS SC13 2030	RDS SC13 2035	RDS SC13 2040	RDS SC13 2050	CY2012 RDS SC13 2030	CY2012 RDS SC13 2035	CY2012 RDS SC13 2040	CY2012 RDS SC13 2050
Solar	1 229	1 336	1 444	1 554	1 220	1 326	1 433	1 542
Onshore wind	1 855	2 334	2 573	2 573	1 694	2 130	2 348	2 348
Offshore wind	8 908	13 246	15 748	14 634	8 339	12 442	15 047	14 215
Biomass	1 019	890	725	606	1 039	932	758	592
Shale	141	54	5		202	113	35	
Gas	63	8	4		116	54	21	

Figure 36:Electricity generation of CBE RD and RDS for climate year 2012.

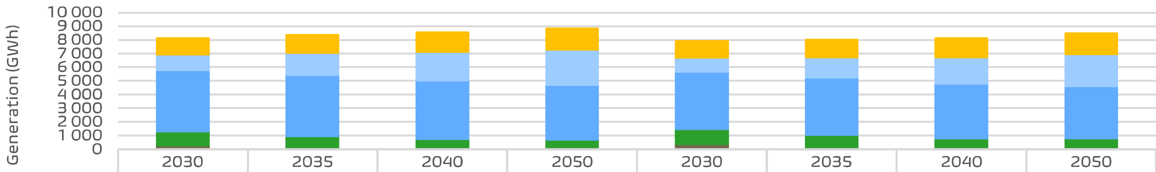
[redacted]

CBE SC14, RD SC14, RDS SC14

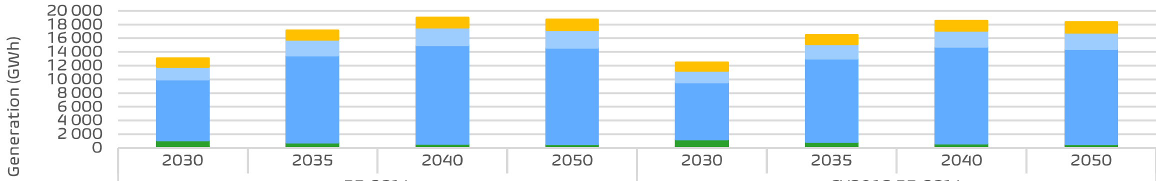
The scenarios CBE SC0, RD SC0 and RDS SC0 scenarios differ from the pathways for the presence of the additional interconnection capacity between Estonia and Finland.

Electricity generation

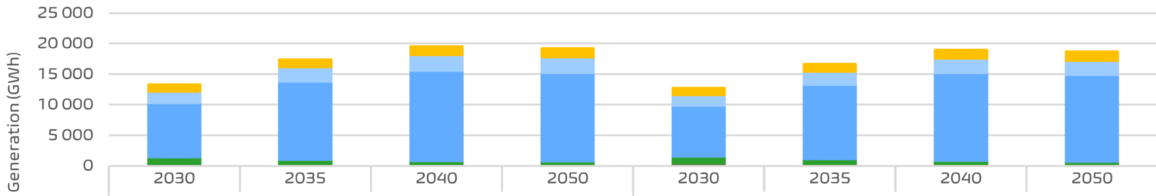
Figure 37Figure 26 shows the difference between the electricity generation in CBE RD and RDS SC14.



	CBE SC14 2030	CBE SC14 2035	CBE SC14 2040	CBE SC14 2050	CY2012 CBE SC14 2030	CY2012 CBE SC14 2035	CY2012 CBE SC14 2040	CY2012 CBE SC14 2050
Solar	1 229	1 336	1 444	1 554	1 220	1 326	1 433	1 542
Onshore wind	1 138	1 616	2 095	2 573	1 039	1 475	1 912	2 348
Offshore wind	4 464	4 463	4 265	4 011	4 190	4 176	3 993	3 825
Biomass	1 042	895	738	668	1 094	928	769	721
Shale	179	63	11	24	270	118	30	56
Gas	89				104		0	



	RD SC14 2030	RD SC14 2035	RD SC14 2040	RD SC14 2050	CY2012 RD SC14 2030	CY2012 RD SC14 2035	CY2012 RD SC14 2040	CY2012 RD SC14 2050
Solar	1 229	1 336	1 444	1 554	1 220	1 326	1 433	1 542
Onshore wind	1 855	2 334	2 573	2 573	1 694	2 130	2 348	2 348
Offshore wind	8 849	12 671	14 379	14 030	8 315	12 114	14 123	13 874
Biomass	938	767	593	557	982	811	620	569
Shale	124	36	7	12	199	82	16	7
Gas	60		0		74			



	RDS SC14 2030	RDS SC14 2035	RDS SC14 2040	RDS SC14 2050	CY2012 RDS SC14 2030	CY2012 RDS SC14 2035	CY2012 RDS SC14 2040	CY2012 RDS SC14 2050
Solar	1 229	1 336	1 444	1 554	1 220	1 326	1 433	1 542
Onshore wind	1 855	2 334	2 573	2 573	1 694	2 130	2 348	2 348
Offshore wind	8 850	12 766	14 737	14 411	8 313	12 132	14 319	14 157
Biomass	1 103	909	771	691	1 135	956	799	639
Shale	196	54	7	14	268	115	33	5
Gas	94				102			

Figure 37: Electricity generation of CBE RD and RDS for climate year 2012.

[redacted]

Appendix

Table 8: Generation capacity in 2030 on a Country level (MW)

	Coal	Gas	Shale	Other	Nuclear	Biomass	Biogas	Waste	Hydro	Offshore wind	Onshore wind	Solar
Austria	0	4.250	0	106	0	586	0	0	8.795	0	10.271	17.369
Belgium	0	9.708	0	158	0	904	0	0	148	5.345	4.910	15.567
Czech	2.907	3.760	0	0	4.055	676	0	0	471	0	5.748	9.289
Den-mark	0	2.163	0	197	0	2.251	56	199	0	15.254	5.526	6.224
Estonia	0	300	660	0	0	104	4	32	0	0	476	1.160
Finland	0	2.146	0	0	4.394	2.182	19	516	3.237	1.512	12.369	1.498
France	0	10.331	0	1.255	61.696	2.411	0	0	23.446	15.222	42.210	76.711
Ger-many	9.031	34.210	0	3.898	0	2.331	3.532	1.684	6.029	36.868	79.793	67.298
Great Britain	0	24.044	0	71	7.658	4.310	1.229	806	2.095	42.553	22.968	27.762
Italy	0	46.817	0	0	0	4.714	0	0	15.916	9.000	23.799	70.711
Latvia	0	1.061	0	0	0	91	55	13	1.592	711	413	396
Lithua-nia	0	538	0	187	0	128	39	45	128	2.120	2.000	1.250
Luxem-bourg	0	100	0	0	0	96	0	0	1.352	0	320	328
Nether-lands	0	14.101	0	0	486	3.900	0	0	38	19.000	8.878	47.181
Norway	0	265	0	0	0	0	0	180	33.361	2.643	9.457	333
Poland	8.844	12.057	0	220	0	1.751	0	1.137	794	8.794	11.723	8.813
Sweden	0	146	0	190	6.835	4.366	0	389	16.447	1.496	20.010	3.781
Switzer-land	0	600	0	0	2.930	400	0	0	4.210	0	255	5.487

Table 9: Generation capacity in 2035 on a Country level (MW)

	Coal	Gas	Shale	Other	Nuclear	Biomass	Biogas	Waste	Hydro	Offshore wind	Onshore wind	Solar
Austria	0	2.604	0	106	0	586	0	0	8.991	0	14.692	28.515
Belgium	0	9.598	0	158	0	904	0	0	150	5.630	6.378	19.738
Czech	1.453	4.572	0	0	4.625	752	0	0	471	0	7.589	12.062
Denmark	0	1.820	0	164	0	1.900	54	161	0	21.174	5.901	7.218
Estonia	0	250	466	0	0	125	2	23	0	0		1.260
Finland	0	1.484	0	0	4.394	2.551	19	516	3.237	3.260	16.241	3.243
France	0	9.435	0	1.053	61.939	2.499	0	0	23.446	31.684	53.088	118.029
Germany	4.515	35.257	0	3.898	0	2.875	3.532	1.685	6.029	48.573	96.157	100.174
Great Britain	0	25.053	0	71	10.998	5.994	1.229	806	2.193	55.303	27.457	37.250
Italy	0	46.659	0	0	0	4.795	0	0	16.466	10.750	25.345	105.947
Latvia	0	1.061	0	0	0	161	55	14	1.592	1032	413	396
Lithuania	0	538	0	187	0	161	0	51	128	2.120	2.000	1.250
Luxembourg	0	100	0	0	0	109	0	0	1.352	0	335	395
Netherlands	0	18.824	0	0	243	2.250	0	0	38	34.500	11.349	55.590
Norway	0	265	0	0	0	0	0	184	33.291	3.006	11.009	333
Poland	4.428	16.011	0	220	2.200	526	0	1.193	794	11.974	14.678	12.856
Sweden	0	146	0	190	6.283	4.366	0	389	16.447	3.506	20.750	4.100
Switzerland	0	580	0	0	2.060	450	0	0	4.210	0	378	5.869

Table 10: Generation capacity in 2040 on a Country level (MW)

	Coal	Gas	Shale	Other	Nuclear	Biomass	Biogas	Waste	Hydro	Offshore wind	Onshore wind	Solar
Austria	0	957	0	106	0	586	0	0	9.187	0	19.114	39.661
Belgium	0	9.487	0	158	0	904	0	0	151	5.915	7.847	23.910
Czech	0	5.384	0	0	5.195	828	0	0	471	0	9.431	14.835
Den-mark	0	1.442	0	164	0	1.537	54	132	0	27.094	6.277	8.213
Estonia	0	250	274	0	0	124	2	23	0	0	876	1.360
Finland	0	823	0	0	3.504	2.920	19	516	3.237	5.007	26.936	3.243
France	0	8.540	0	0	62.181	2.586	0	0	23.446	48.145	63.967	159.347
Ger-many	0	36.301	0	3.898	0	3.419	3.532	1.685	6.029	60.278	112.521	133.049
Great Britain	0	26.061	0	71	14.338	7.679	1.229	806	2.291	68.052	31.947	46.739
Italy	0	46.501	0	0	0	4.875	0	0	17.016	12.500	26.890	141.184
Latvia	0	1.061	0	0	0	231	55	14	1.592	1.352	413	413
Lithua-nia	0	538	0	187	0	161	0	51	128	2.120	2.944	1.250
Luxem-bourg	0	100	0	0	0	121	0	0	1.352	0	350	462
Nether-lands	0	23.546	0	0	0	321	0	0	38	50.000	13.821	63.999
Norway	0	265	0	0	0	0	0	186	33.221	3.368	12.562	333
Poland	70	19.906	0	220	4.400	0	0	550	794	15.153	17.632	16.900
Sweden	0	146	0	190	5.731	4.366	0	389	16.447	5.518	21.491	4.416
Switzer-land	0	560	0	0	1.190	500	0	0	4.210	0	500	6.250

Table 11: Generation capacity in 2050 on a Country level (MW)

	Coal	Gas	Shale	Other	Nuclear	Biomass	Biogas	Waste	Hydro	Offshore wind	Onshore wind	Solar
Austria	0	957	0	0	0	586	0	0	9.187	0	22.171	50.681
Belgium	0	8.638	0	0	0	904	0	0	151	6.675	9.068	28.689
Czech	0	4.461	0	0	3.278	828	0	0	471	0	12.410	19.744
Den-mark	0	816	0	0	0	677	54	70	0	36.621	7.418	12.451
Estonia	0	250	274	0	0	131	0	19	0	0	1.076	1.460
Finland	0	121	0	0	3.504	2.844	19	516	3.237	5.508	38.380	4.545
France	0	5.508	0	0	51.606	2.586	0	0	23.446	66.199	85.568	196.972
Ger-many	0	41.391	0	1.377	0	3.419	3.532	1.685	6.029	70.337	131.083	154.695
Great Britain	0	28.075	0	0	16.008	8.485	1.229	0	2.291	89.983	44.842	62.472
Italy	0	48.310	0	0	0	4.875	0	0	17.016	15.000	29.979	175.720
Latvia	0	65	0	0	0	231	55	14	1.592	1.852	445	445
Lithua-nia	0	167	0	187	0	185	0	27	128	2.260	3.440	1.250
Luxem-bourg	0	100	0	0	0	121	0	0	1.352	0	385	509
Nether-lands	0	34.862	0	0	0	600	0	0	38	74.000	17.400	81.593
Norway	0	824	0	0	0	0	0	189	33.221	4.335	12.562	333
Poland	0	17.033	0	220	9.900	0	0	550	794	20.904	21.080	20.639
Sweden	0	1.094	0	0	3.567	4.366	0	389	16.447	8.582	24.796	8.002
Switzer-land	0	400	0	0	0	1.000	0	0	4.210	0	500	7.013