Energy Security in Baltic Countries and Finland:

development of electricity systems in Baltic States and Finland taking into account security and reliability aspects

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(The study was performed by the Lithuanian Energy Institute and Aalto university)

REEEM

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691739.

Introduction and methodological approach

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Energy security

- Energy security is a complex and multidimensional concept that has evolved along the years

- It started with the 1970s oil crises and its concerns on the dependency on fossil fuel import and other interdisciplinary issues, such as affordability, social acceptance, and environmental impacts.

- Energy security is defined as "the ability of the energy system to **uninterruptedly supply** energy to consumers **under acceptable prices** and to **resist potential disruptions** arising due to technical, natural, economic, socio-political and geopolitical threats"

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Object of the analysis

Electricity system of Baltic States and Finland and district heating systems (in lower extent)

- *Although positive from a diversification point of view, significant share of intermittent electricity generation (in particular wind) creates additional energy security challenges as it requires the power system to maintain sufficient **balancing capacities** at all time*
- *Substantial amount of electricity imports from third countries to Baltic countries together with possible malfunctions of individual elements of the electricity system is another energy security concern because it requires large **reserve capacities***

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General assumptions and conditions

In order to ensure energy security, measures for it’s assurance have to be foreseen already at the energy development planning stage and put into practice in time.

Energy security in Estonia, Finland, Latvia, and Lithuania is considered in the context of the development of the energy sector operating under market conditions that determine the cost-effectiveness of different individual energy generation sources as well as the attractiveness of energy security measures.

Environmental restrictions associated with climate change mitigation as well as country specific and EU energy policy requirements also are taken into account.

Energy security analysis in the REEEM project was based on mathematical modelling of prospective energy sector operation and development

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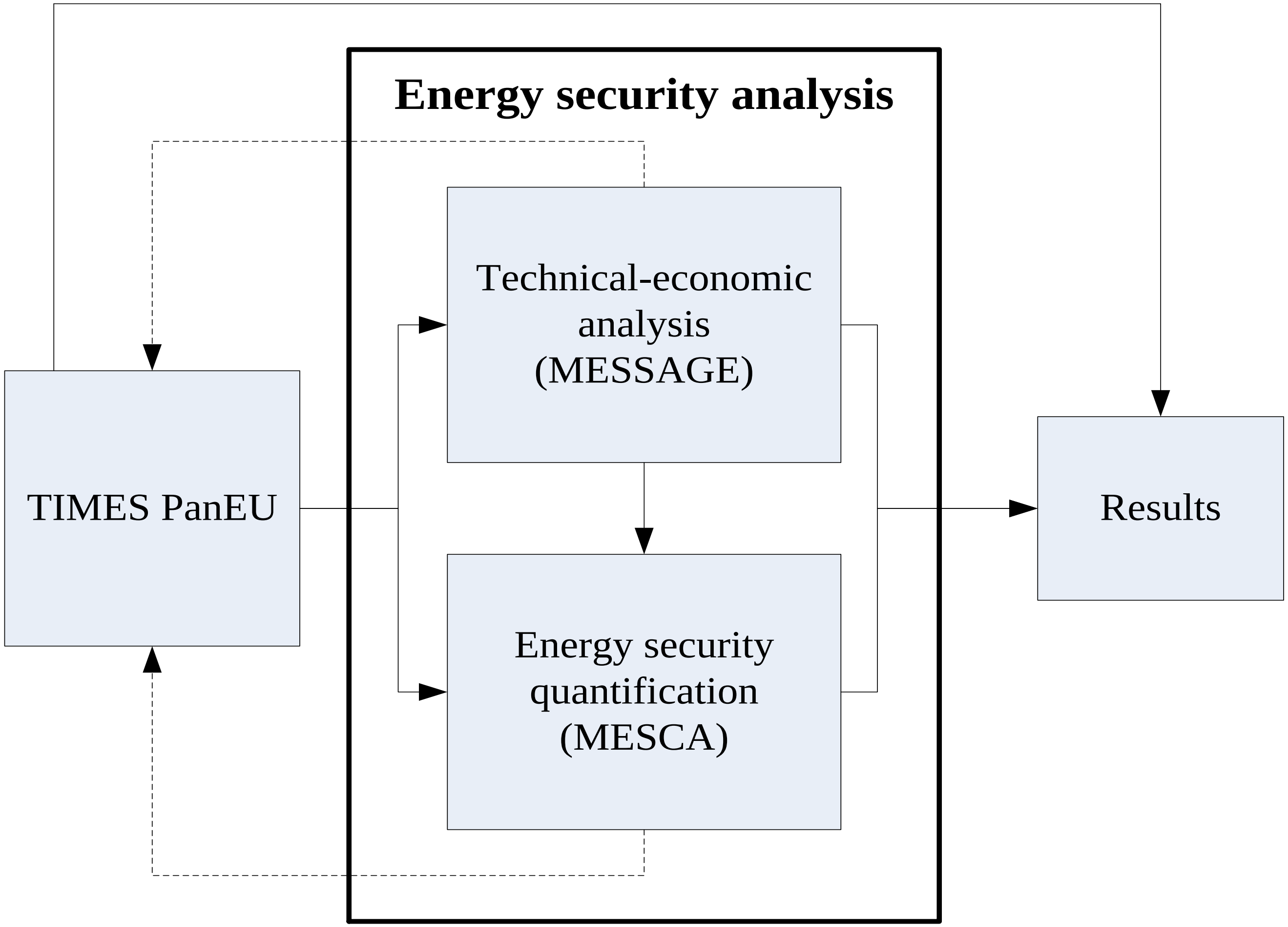
Mathematical models in analysis of energy security



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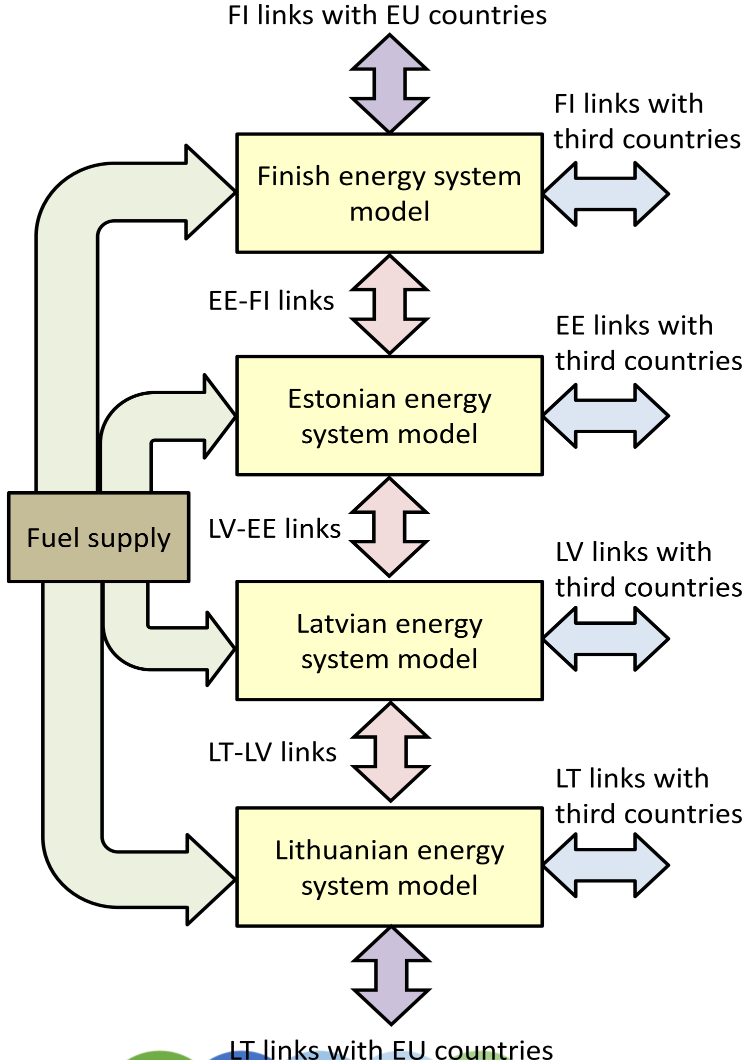
Structure of mathematical model for analysis of energy system operation and development



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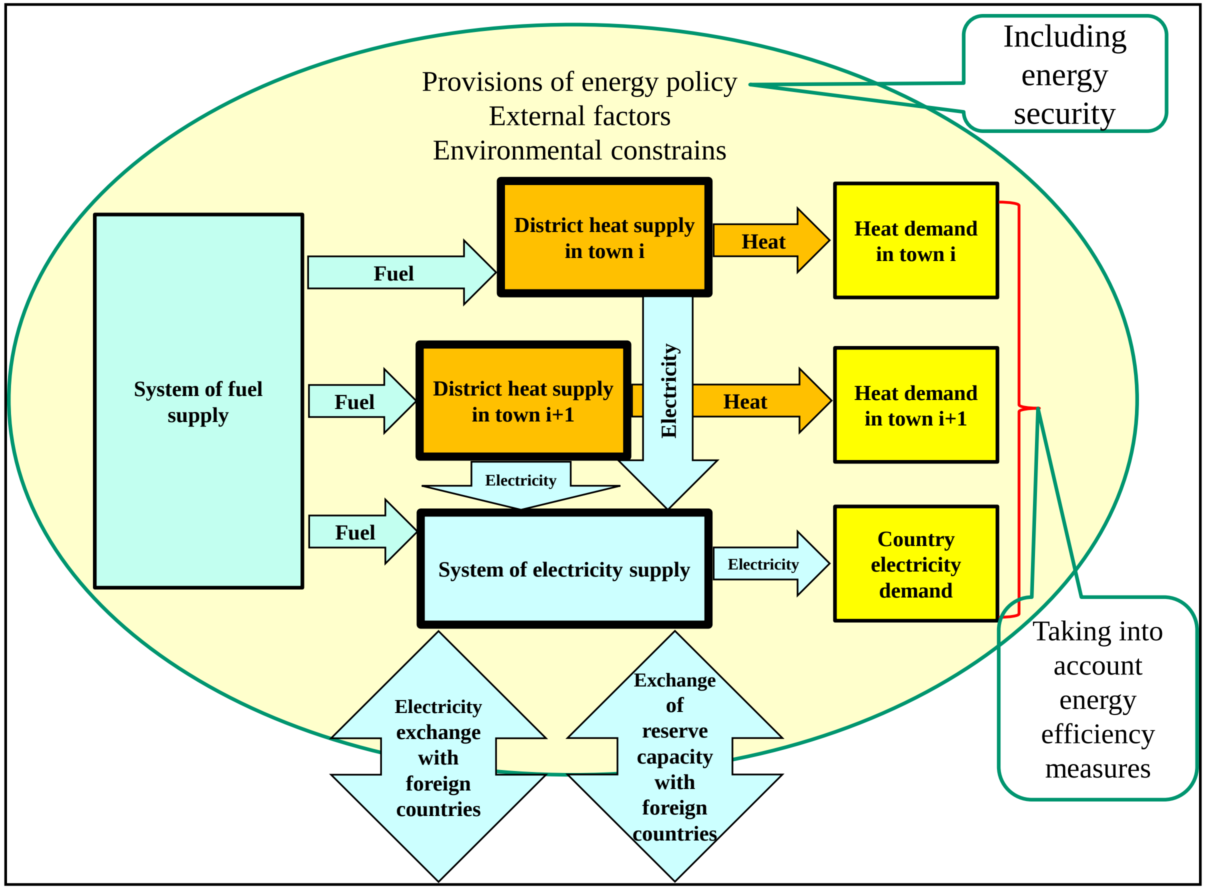
Structure of country energy system model



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Methodological approach
Modelling of wind variability

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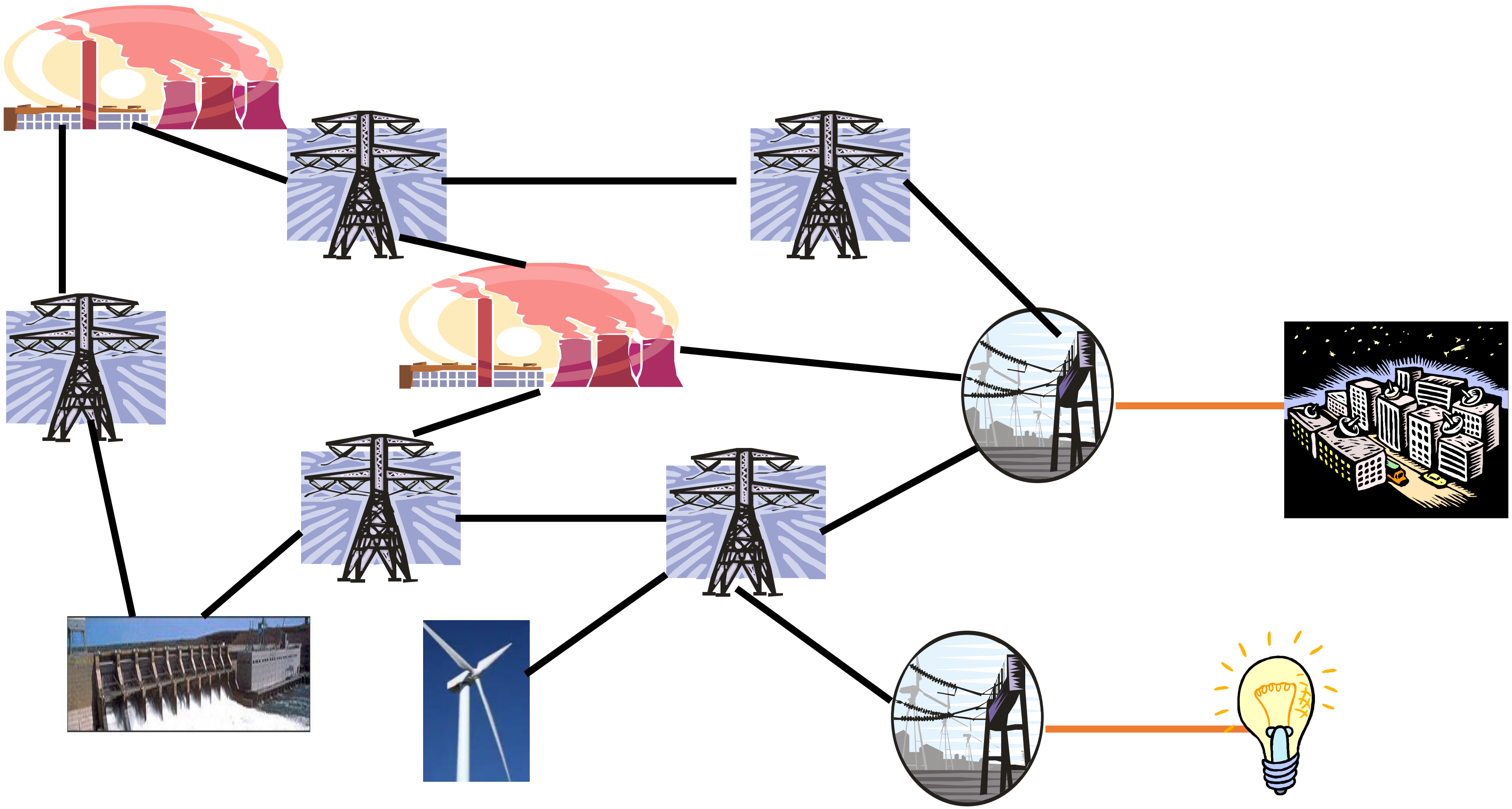
Principal structure of electricity system



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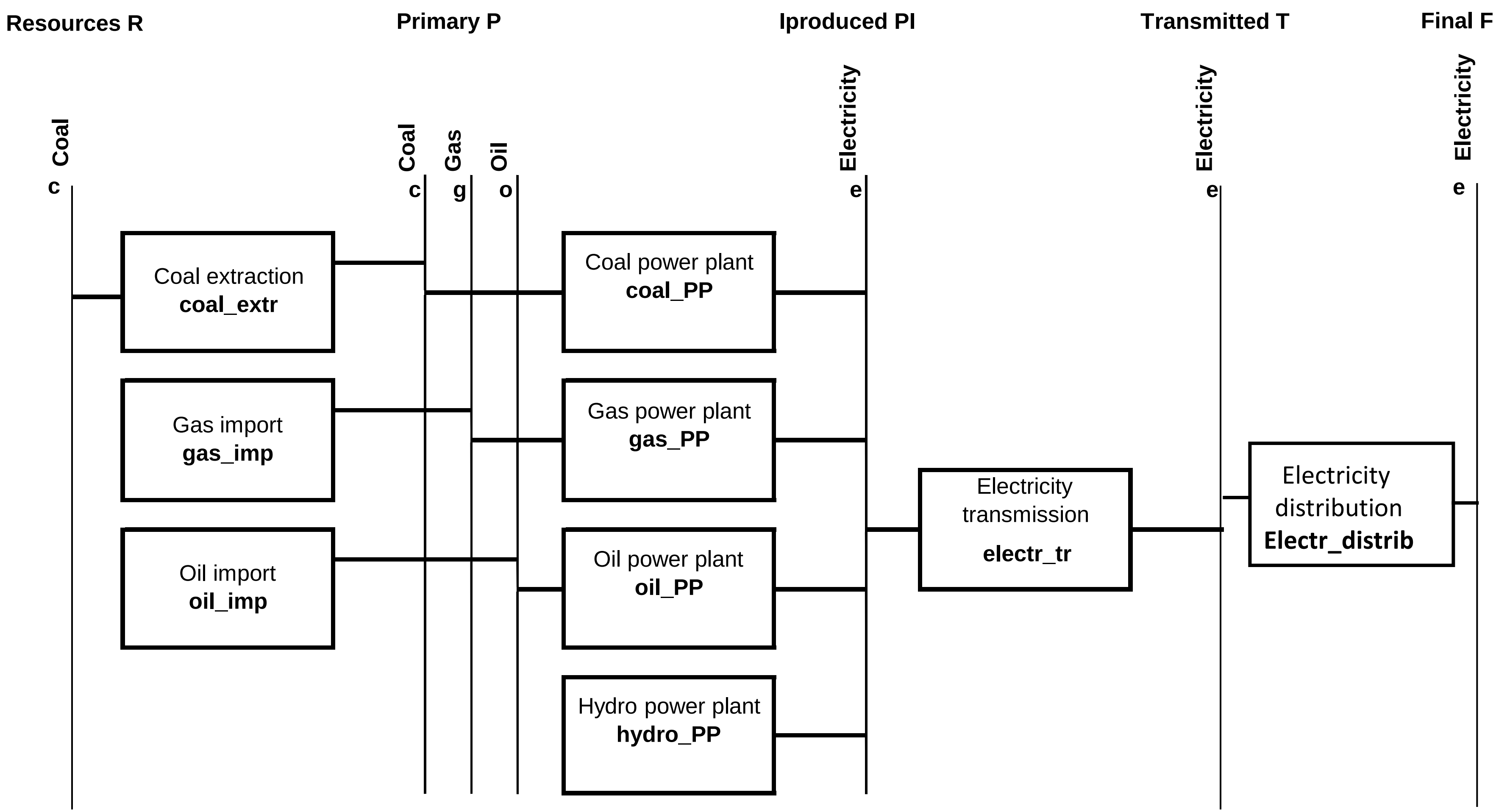
Representation of electricity system in model



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Mathematical formulation of energy system development problem

- **min c' * x**

- **Subject to**
- **A * x => b**

- ***u* <= x <= *l***

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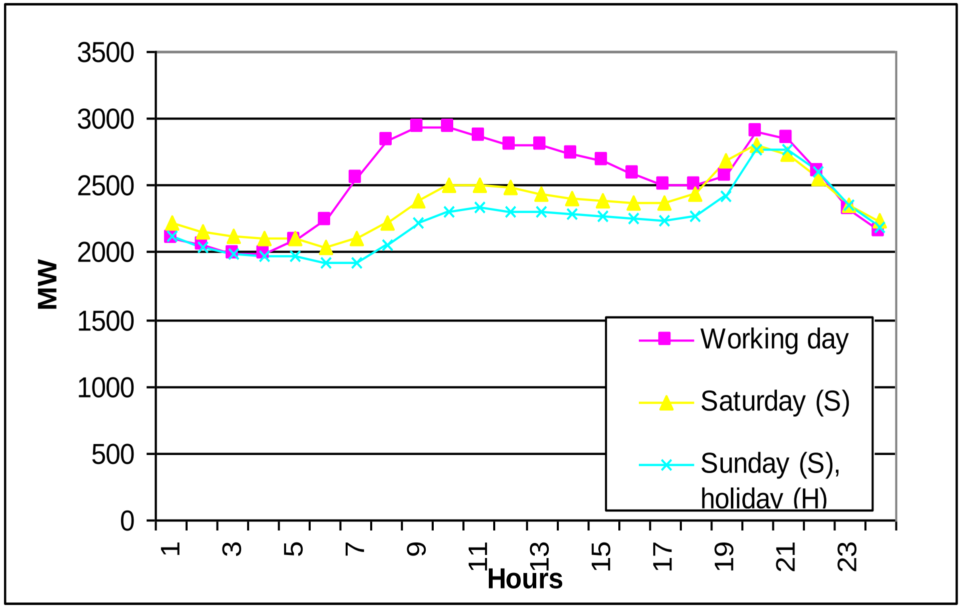
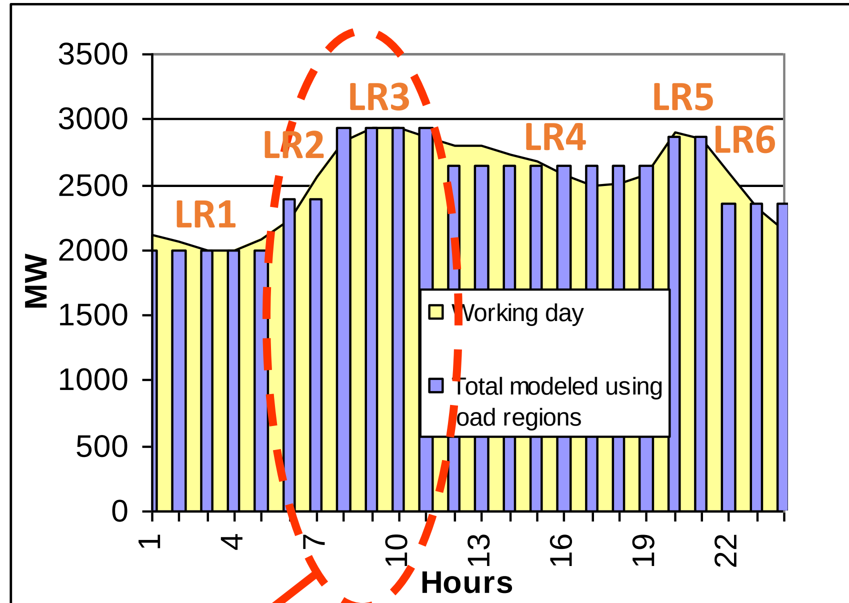
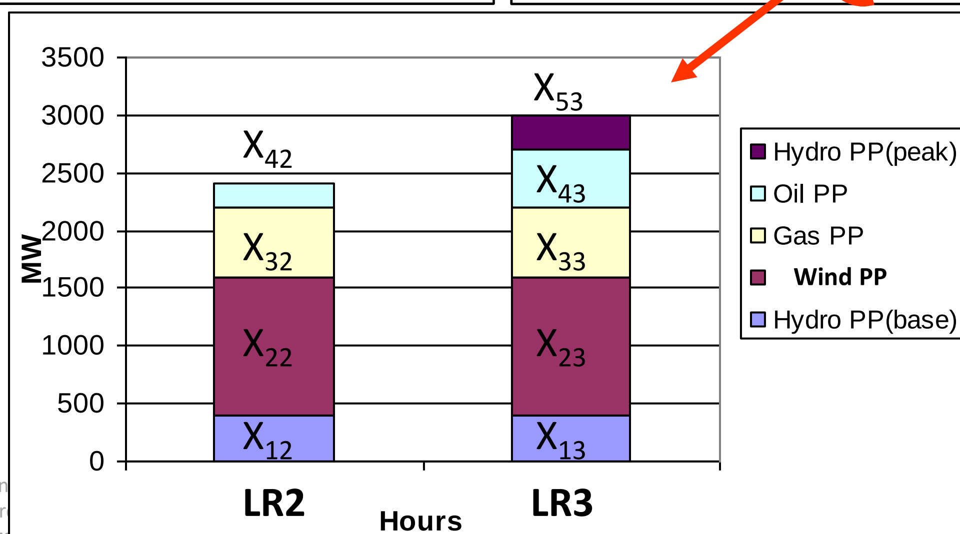
Formulation of energy balance equations

$$\sum \text{production} - \sum \text{consumption} \geq 0$$







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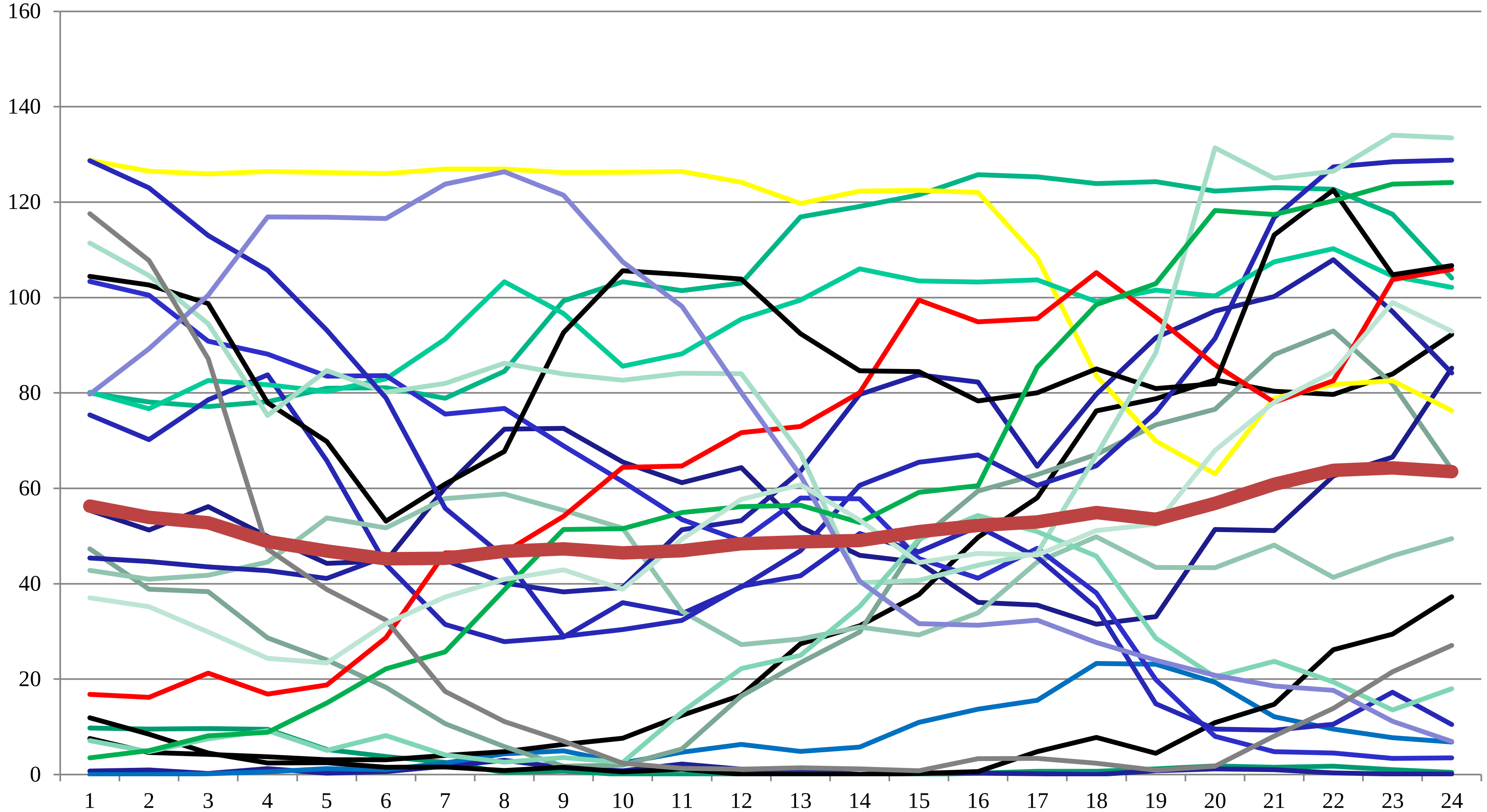
Electricity generation by Wind PP



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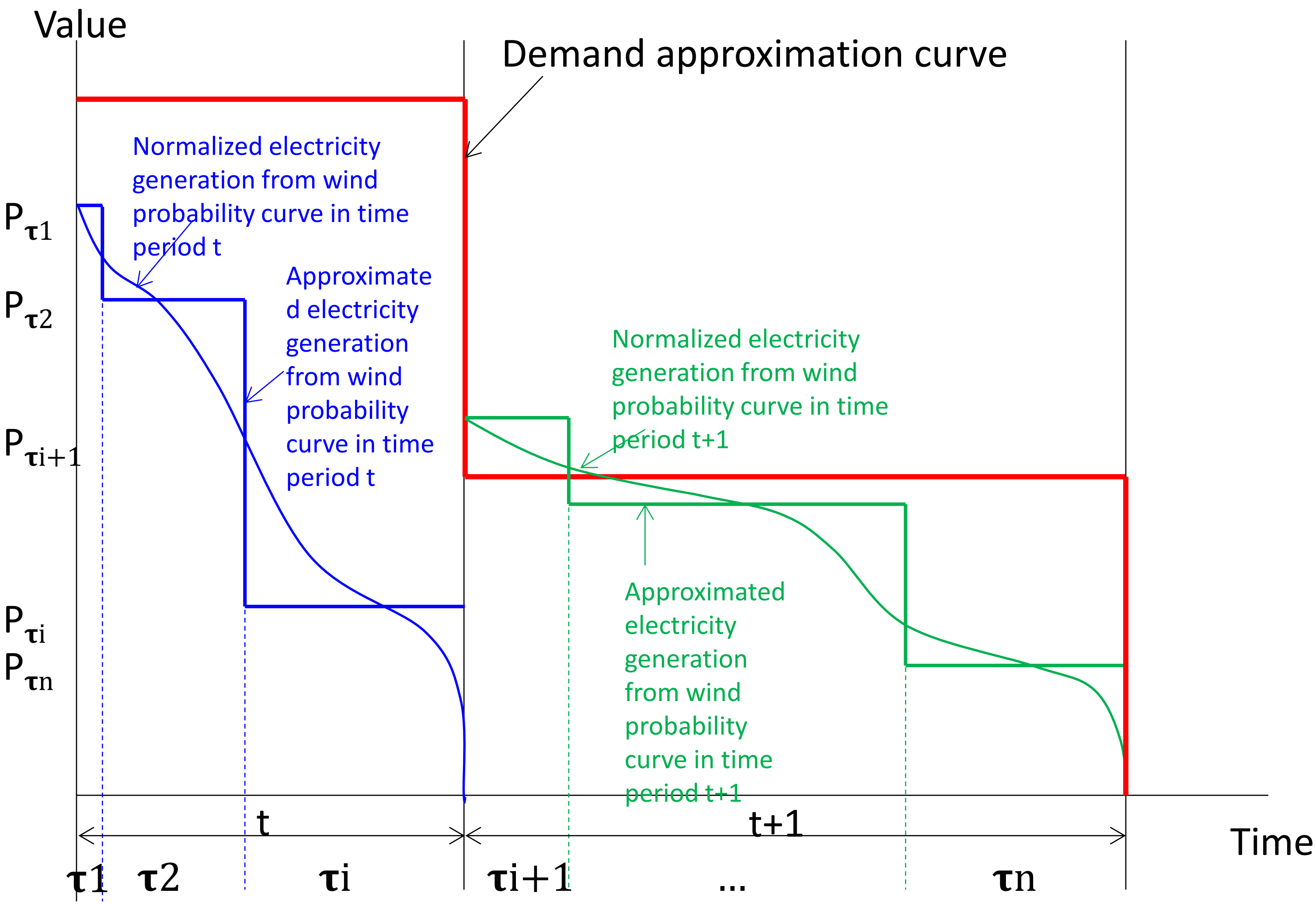
Wind probability curves and their use



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Methodological approach
Modelling of reservation options

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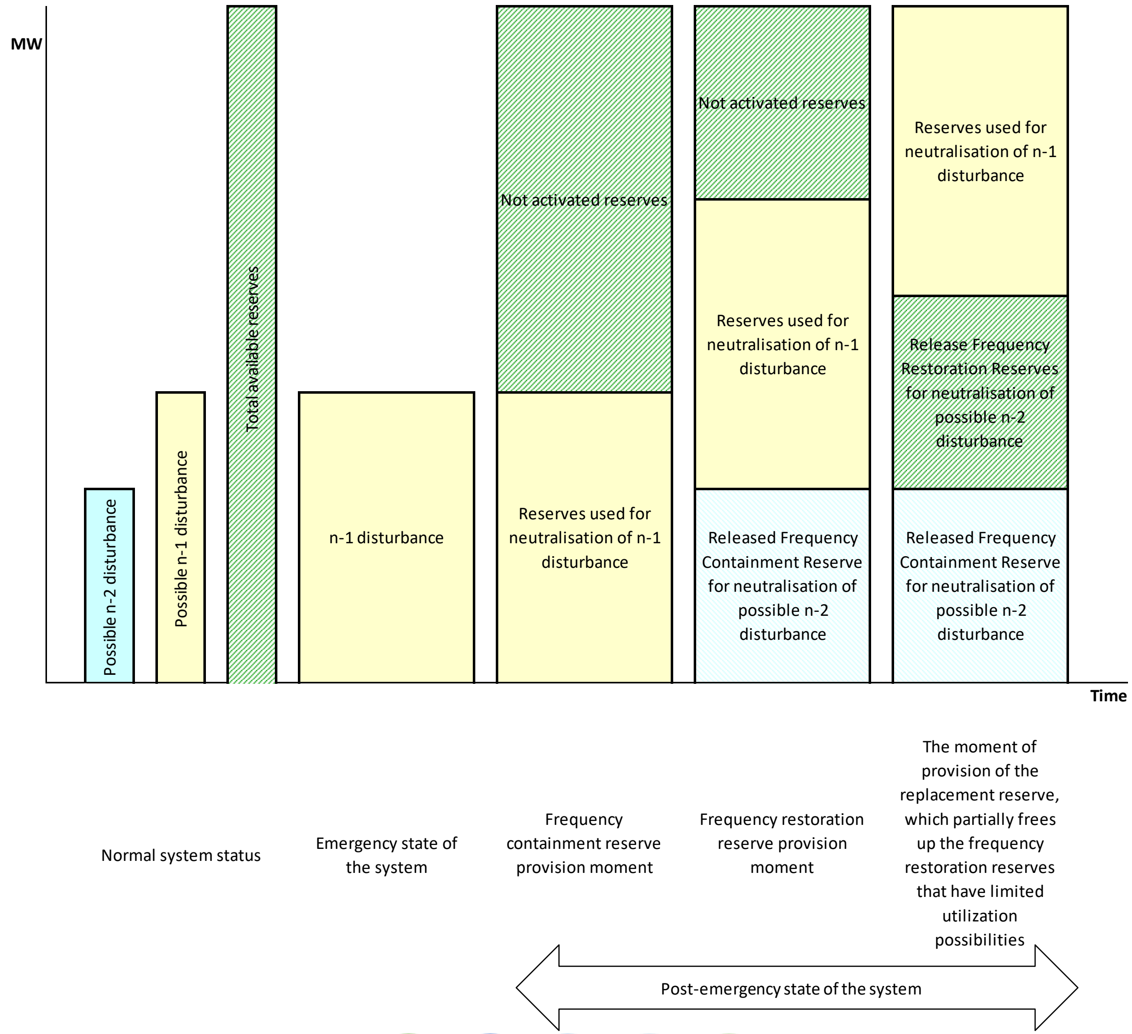
Reserve requirements for reservation of large units in power systems



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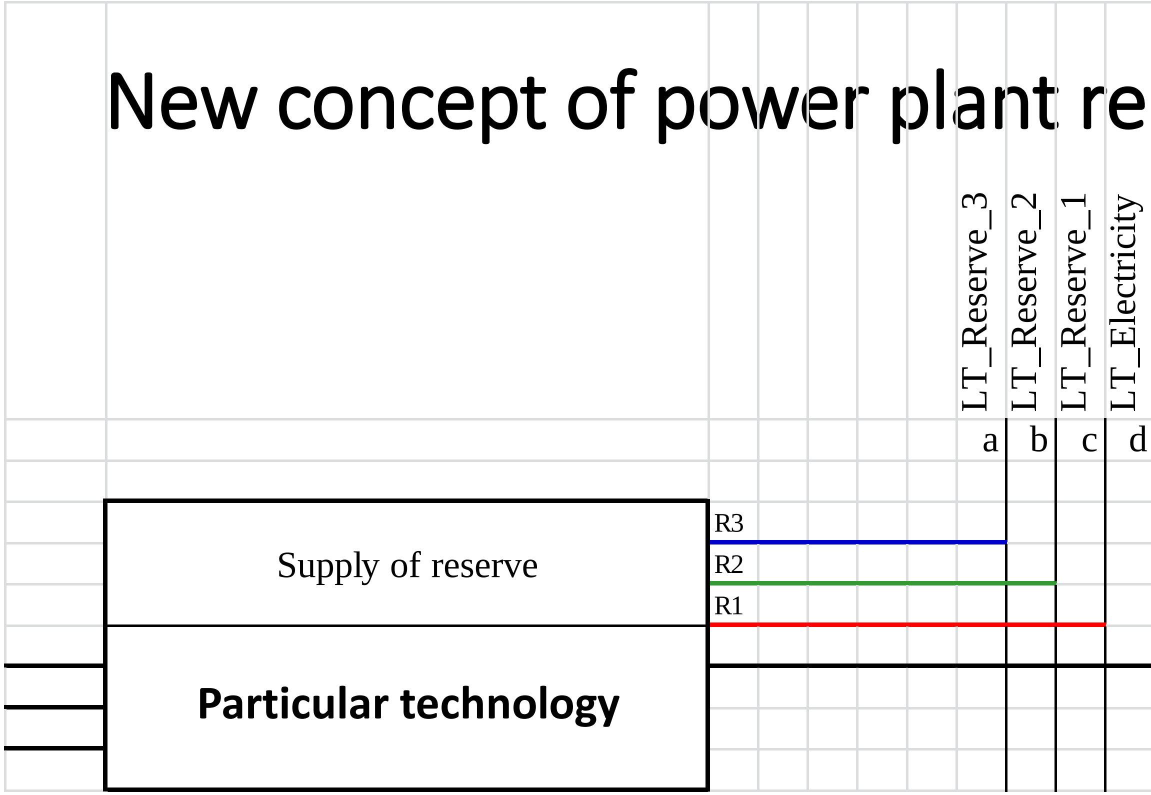
New concept of power plant representation



X_{LR} gives **Utilized capacity**$_{LR}$

Primary reserve: Is plant suitable to provide R1?

$R1_{LR} <= a*X_{LR}$ (If suitable),

$R1_{LR} <= 0$ (If not suitable)

Secondary and tertiary reserve: Is plant suitable for supplying R2?

$R2_{LR} <= 0$ (If not suitable)

Plants based on renewable sources (Wind, Solar)?

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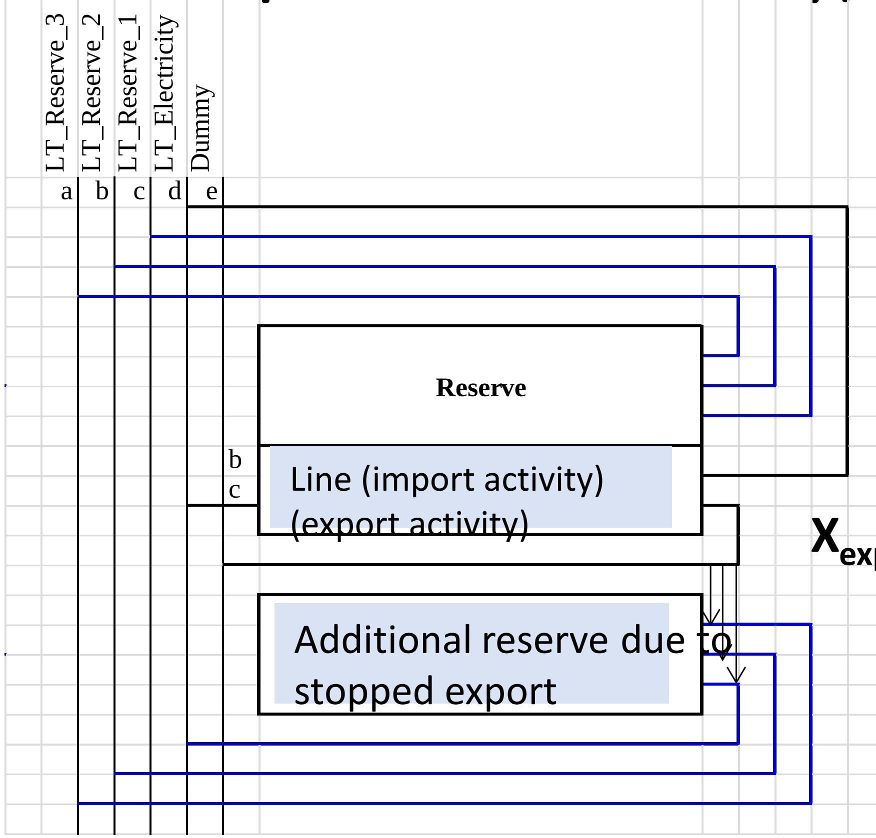
Supply of reserves via line between countries (Import and export of electricity)



$X_{export\ LR}$ gives **Utilized capacity$_{LR}$**

Reserve capacities (R1,R2,R3) in each LR that can be taken from other countries due to stopped electricity export are <= $X_{export\ LR}$

($R1_{LR} <= X_{export\ LR}$, $R2_{LR} <= X_{export\ LR}$, $R3_{LR} <= X_{export\ LR}$)

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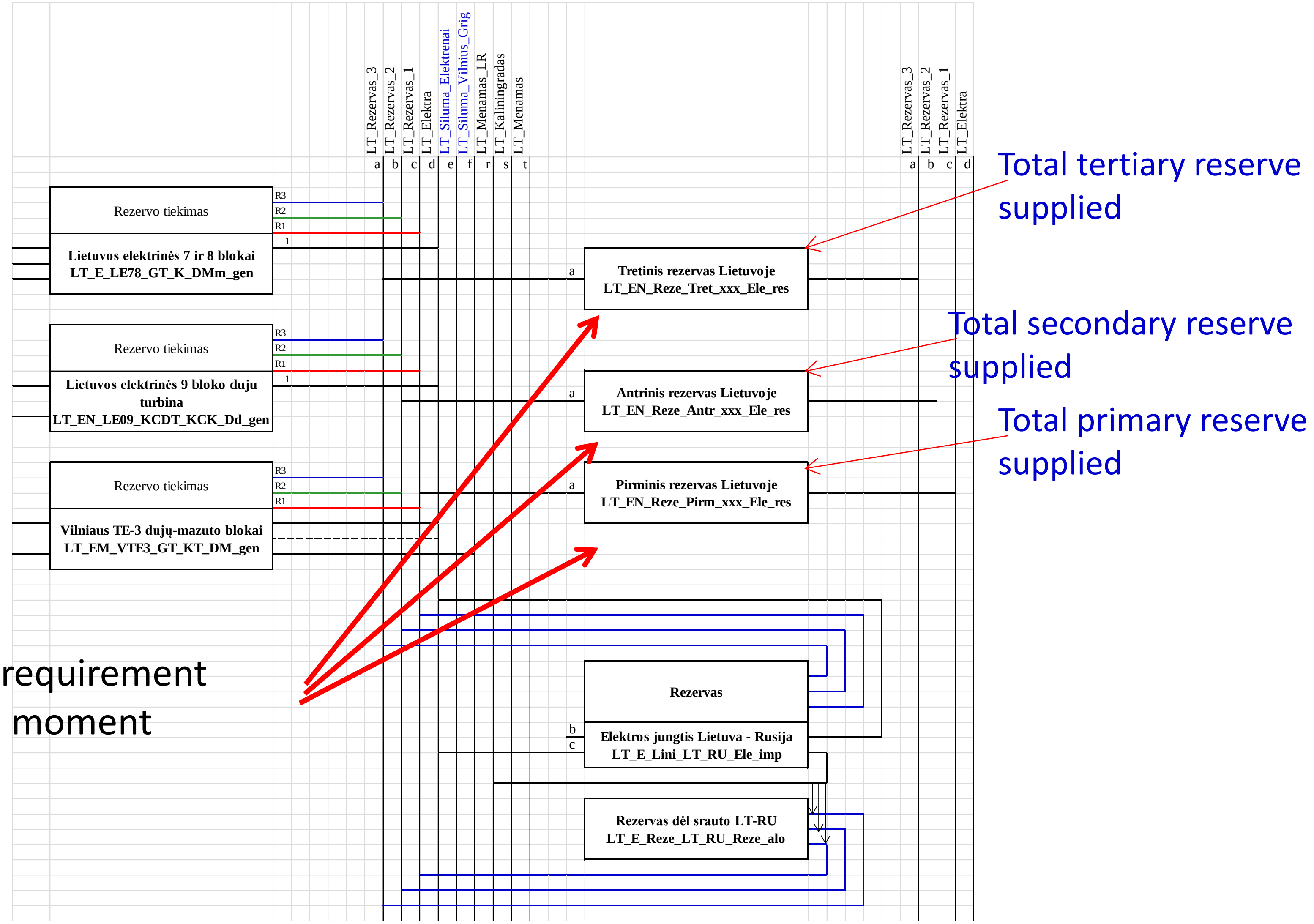
Modelling of reserves



What is it's requirement
in the each moment
(LR)?

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Reserve (R1,R2,R3)requirement in each moment (LR) of time

$R1_{LR}$ => $X_{\text{largest unit LR}}$ + $R1_{\text{largest unit LR}}$
$R2_{LR}$ => $X_{\text{largest unit LR}}$ + $R2_{\text{largest unit LR}}$
$R3_{LR}$ => $X_{\text{largest unit LR}}$ + $R3_{\text{largest unit LR}}$

$R1_{LR}$ => $X_{\text{second largest unit LR}}$ + $R1_{\text{second largest unit LR}}$
$R2_{LR}$ => $X_{\text{second largest unit LR}}$ + $R1_{\text{second largest unit LR}}$
$R3_{LR}$ => $X_{\text{second largest unit LR}}$ + $R1_{\text{second largest unit LR}}$

$R1_{LR}$ => reserve margin * peak demand_{LR}
$R2_{LR}$ => reserve margin * peak demand_{LR}
$R3_{LR}$ => reserve margin * peak demand_{LR}

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Harmonisation of the Baltic energy security study with the research on energy sector development on EU level

(With the results of TIMES PanEU model)

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Main factors defining energy sector development pathways in the TIMES PanEU model

- **Emissions of greenhouse gases (GHG)**
- **Use of renewable energy sources**

*The emission reduction target for the emission trading sector (ETS) was set for the entire European Union. It was assumed that GHG emissions in the ETS should be reduced by **21% in 2020, by 43% in 2030 and by 83% in 2050**. All reduction rates are compared to the 2005 emission level.*

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Emission reduction targets for non ETS

	Targets for 2020	Targets for 2030	Target for 2050
Finland	-16%	-39%	-80%
Estonia	11%	-13%	-60%
Latvia	17%	-6%	-60%
Lithuania	15%	-9%	-60%

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RES targets for the country

	2020	2030	2040	2050
Finland	38%	50%	68%	85%
Estonia	25%	38%	56%	75%
Latvia	40%	49%	62%	75%
Lithuania	23%	36%	56%	75%

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Targets for entire region *(derived from Times PanEU results)*

RES target shares in primary energy consumption for electricity and district heat production

	2015	2020	2025	2030	2035	2040	2045	2050
TIMES PanEU Base scenario	0.326	0.329	0.432	0.594	0.672	0.697	0.742	0.758
TIMES PanEU High RES scenario	0.327	0.329	0.430	0.581	0.672	0.742	0.819	0.852

CO_2 prices, Eur/t

Scenario	2015	2020	2025	2030	2035	2040	2045	2050
TIMES PanEU Base	0	0	1.6	28.9	32.2	27.6	52.8	501.1
TIMES PanEU High RES	0	0	0	25.1	29.7	24.1	30.1	489.1
Additional	0	10	89.8	169.7	249.6	329.4	409.3	489.1

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Scenarios analysed

Scenarios	RES share in primary energy consumption	CO_2 prices
Base	According to TIMES PanEU Base scenario	According to TIMES PanEU Base scenario
High RES	According to TIMES PanEU High RES scenario	According to TIMES PanEU High RES scenario
BaseCO2Lin	According to TIMES PanEU Base scenario	Linear growth from 10 Eur/t in 2020 up to value estimated in TIMES PanEU Base scenario for 2050

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Results of energy system's development analysis

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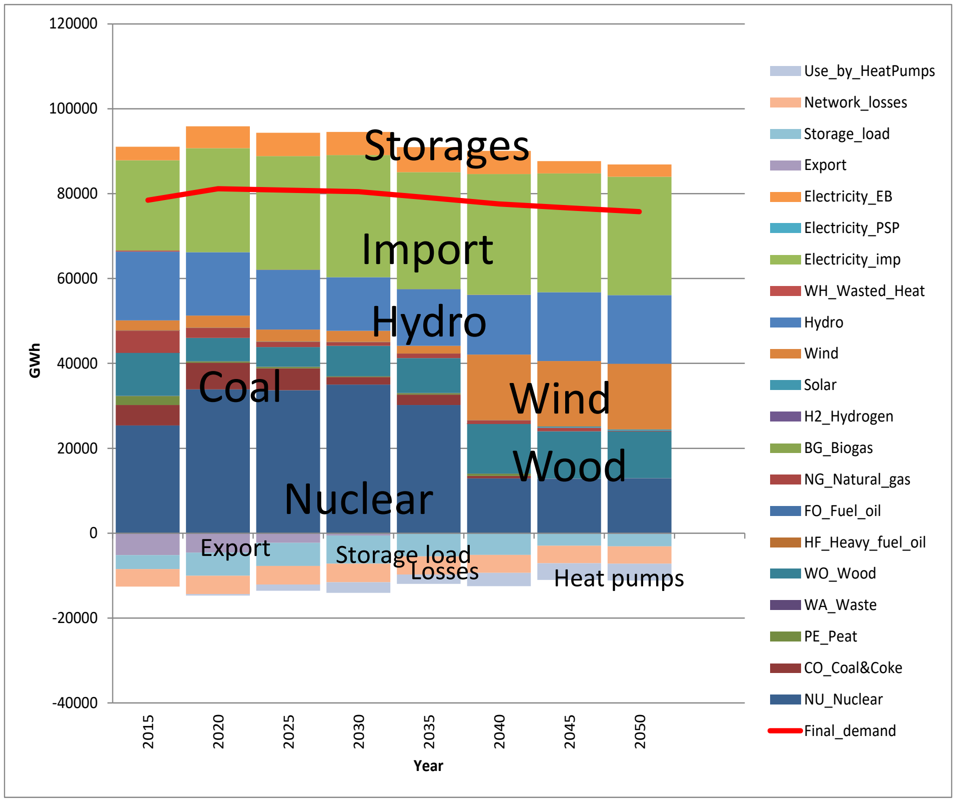
Electricity production in Finland (Base sc.)



Electricity supply in Finland is and will remain sufficiently *diversified both in terms of primary energy sources and supply channels*. **Nuclear fuel, hydro, wind resources, gas and biomass** can be mentioned in case of *primary energy sources* are concerned. *Electricity import is also possible from different countries* (Sweden, Norway, Estonia and Russia), i.e. from different suppliers

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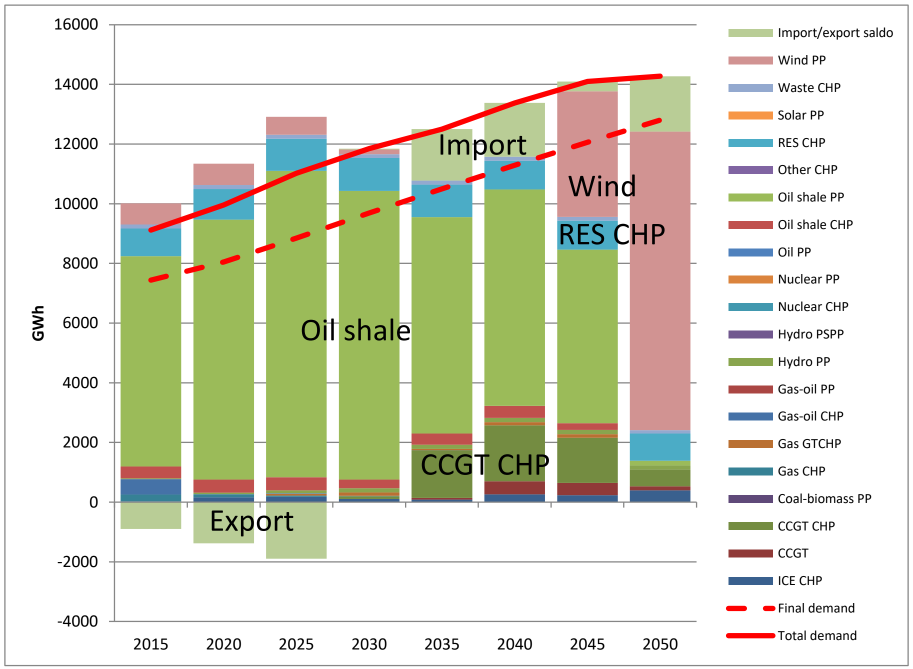
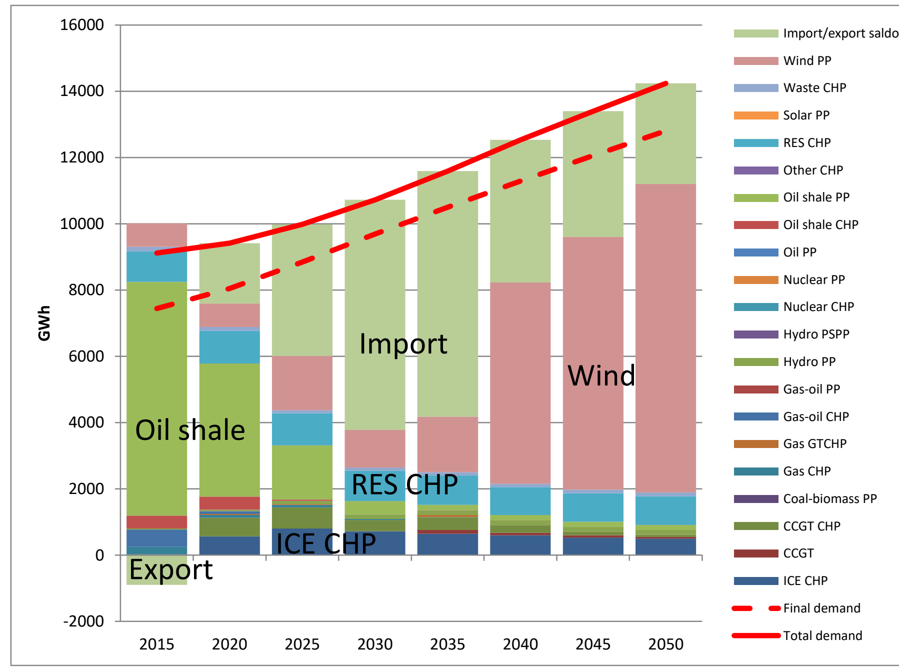
Electricity production in Estonia

Base scenario



BaseCO2Lin scenario



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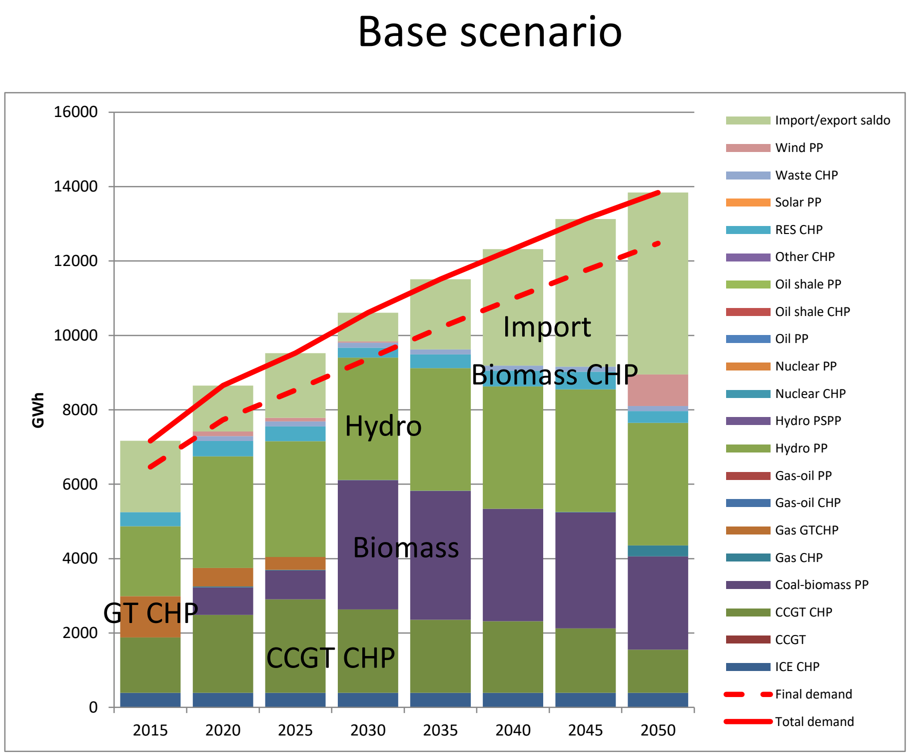
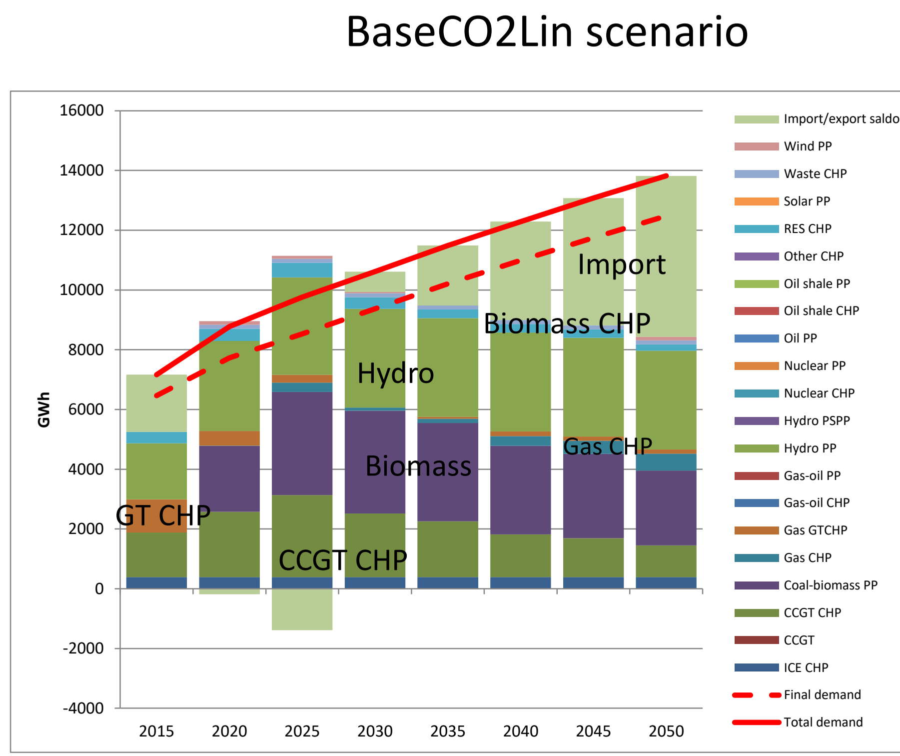
Electricity production in Latvia





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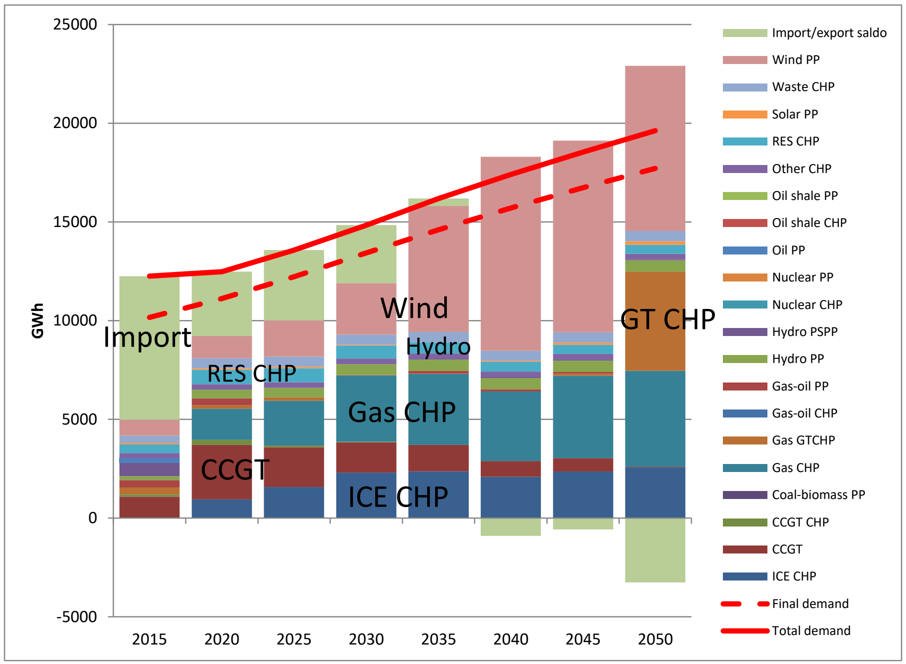
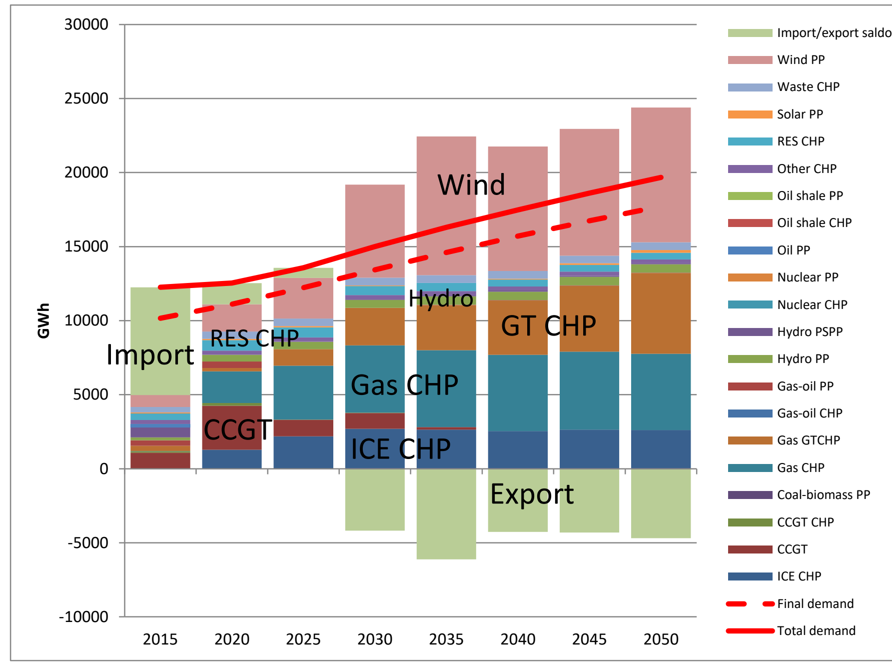
Electricity production in Lithuania

Base scenario



BaseCO2Lin scenario



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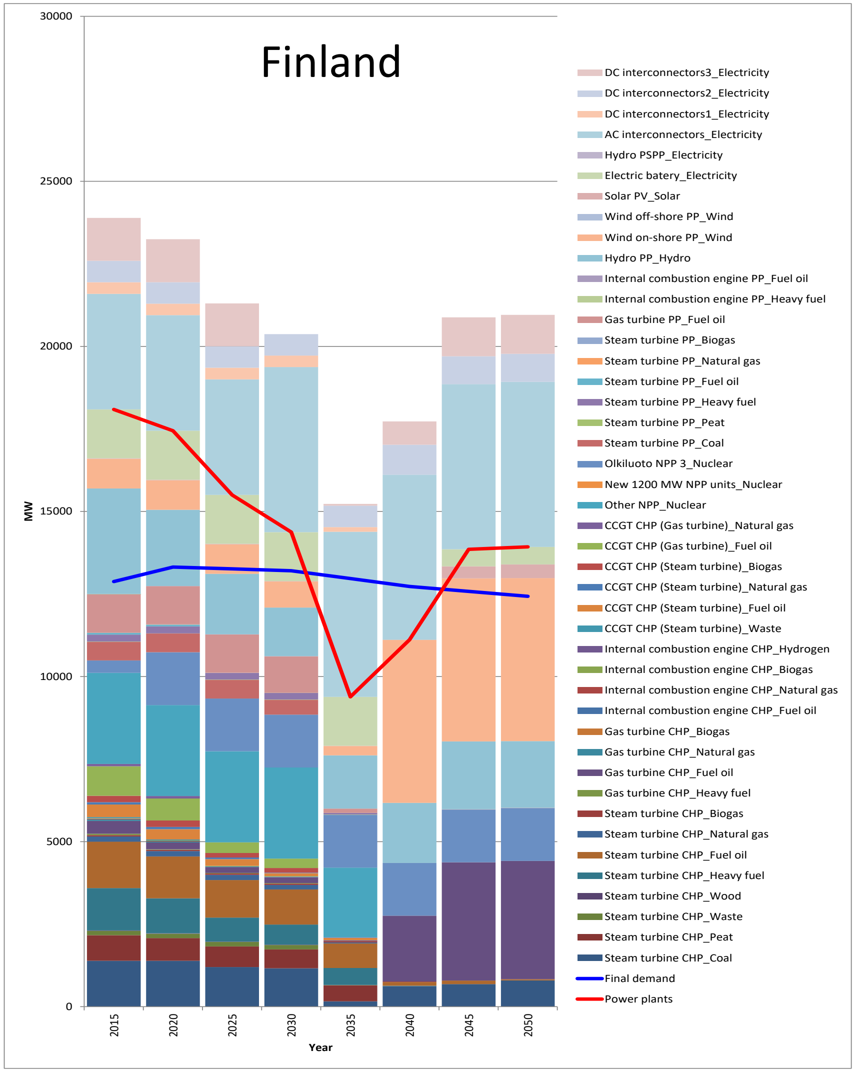
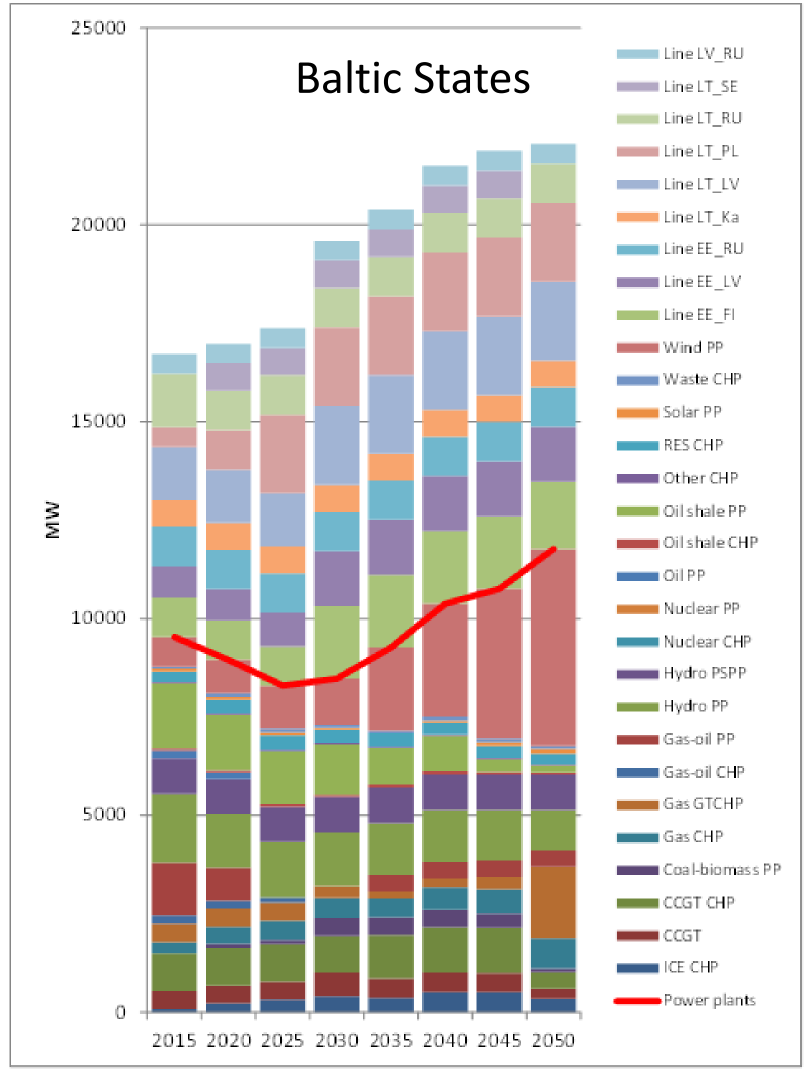
Available capacities





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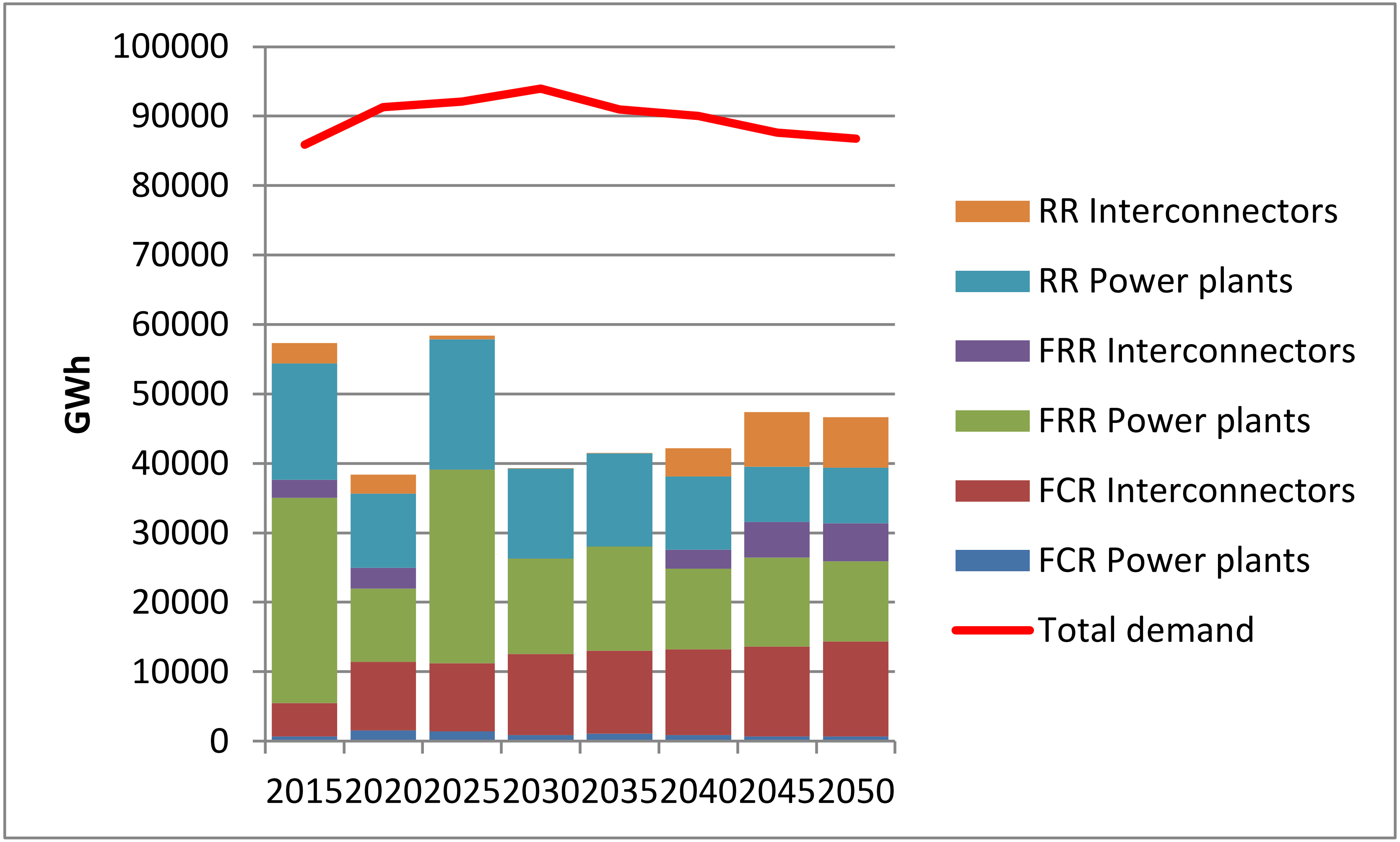
Provision of reserve capacity in Finland



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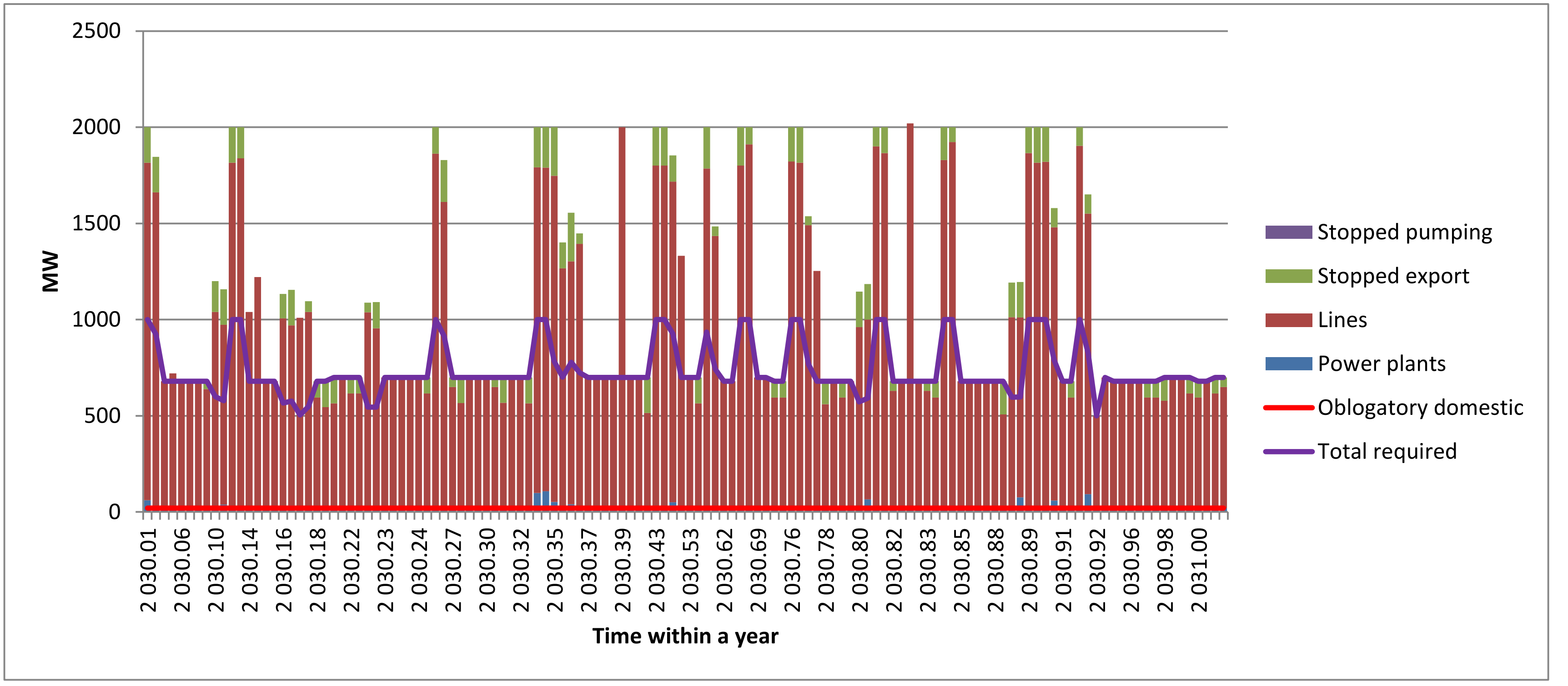
Provission of FCR in Baltic States



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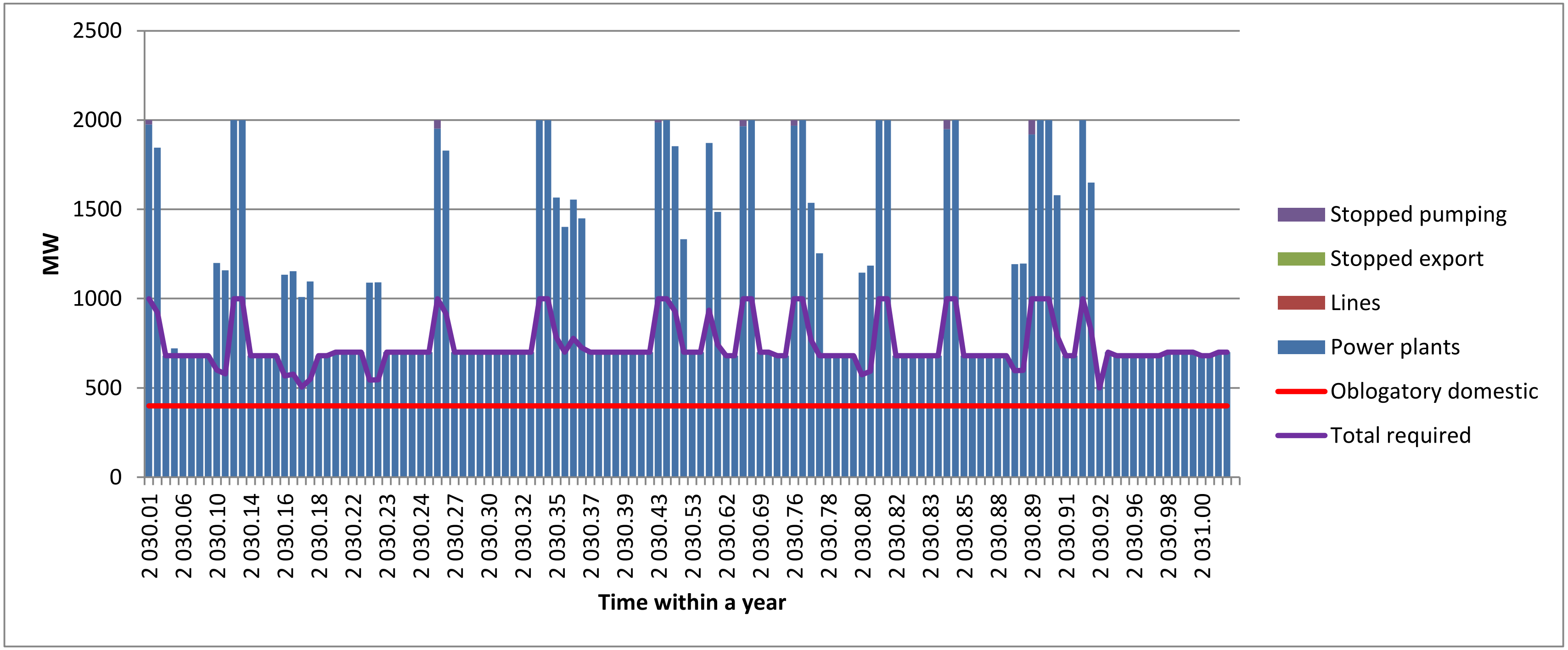
Provission of FRR in Baltic States



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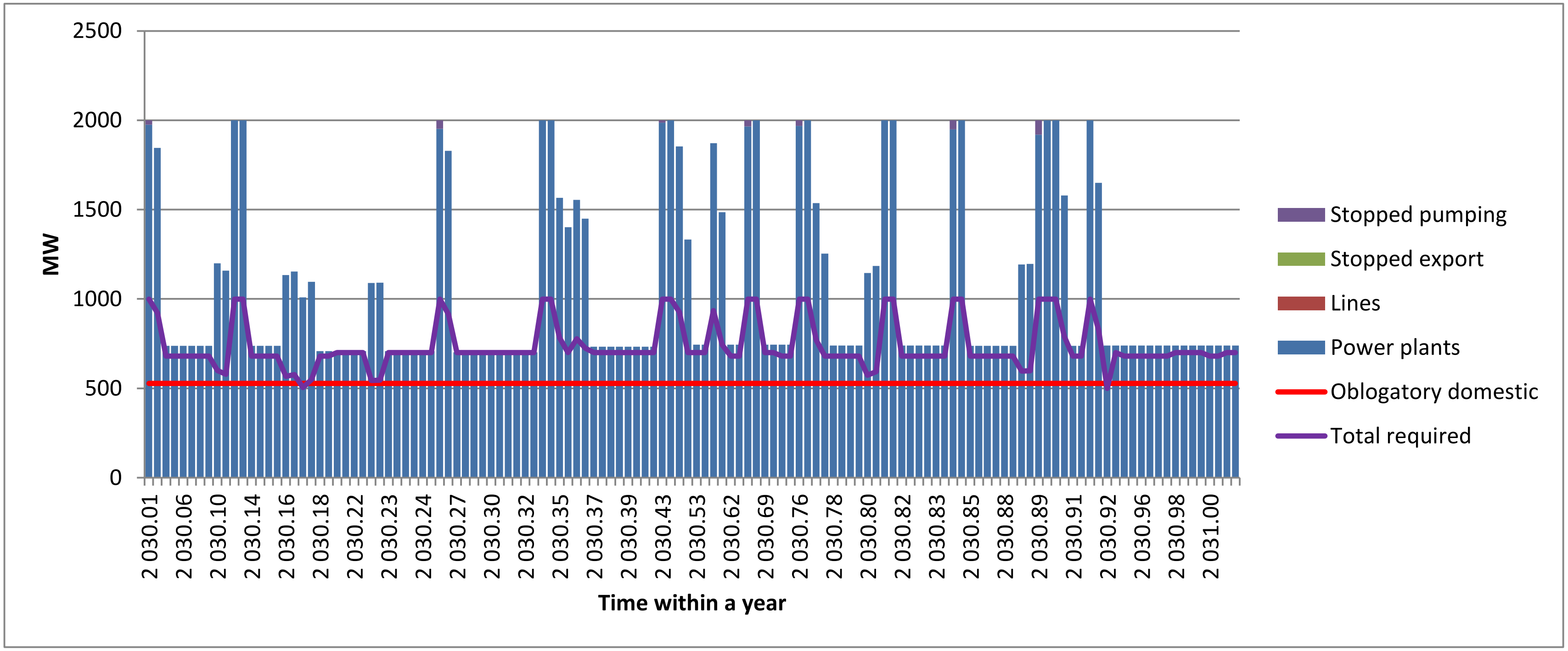
Provission of RR in Baltic States



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Understanding of time slices

Time and wind availability				Corresponding value in time axis
I season (January 1 - February 28)	Working days	1 - 6 hours	Strong wind	2050.008982
			Weak wind	2050.028767
		7 - 11 hours	Strong wind	2050.036335
			Weak wind	2050.052739
		12 - 17 hours	Strong wind	2050.061858
			Weak wind	2050.081506
		18 - 20 hours	Strong wind	2050.086751
			Weak wind	2050.09589
		21 - 24 hours	Strong wind	2050.102849
			Weak wind	2050.115068
	Weekends and hollidays	1 - 8 hours	Strong wind	2050.120828
			Weak wind	2050.130594
		9 - 17 hours	Strong wind	2050.137603
			Weak wind	2050.14806
		18 - 21 hours	Strong wind	2050.150877
			Weak wind	2050.155822
		22 - 24 hours	Strong wind	2050.157819
			Weak wind	2050.161644
II season (March 1 - 31)	Working days	1 - 6 hours	Strong wind	2050.167574
			Weak wind	2050.176713
		7 - 12 hours	Strong wind	2050.182276
			Weak wind	2050.191782
		13 - 22 hours	Strong wind	2050.202176
			Weak wind	2050.216897
		23 - 24 hours	Strong wind	2050.219289
			Weak wind	2050.221919
	Weekends and hollidays	1 - 8 hours	Strong wind	2050.225032
			Weak wind	2050.230139
		9 - 18 hours	Strong wind	2050.234775
			Weak wind	2050.240413
		19 - 21 hours	Strong wind	2050.241317
			Weak wind	2050.243495
		22 - 24 hours	Strong wind	2050.24455
			Weak wind	2050.246577

Time and wind availability				Corresponding value in time axis
III season (April 1 - 30)	Working days	1 - 7 hours	Strong wind	2050.251387
			Weak wind	2050.264157
		8 - 11 hours	Strong wind	2050.266297
			Weak wind	2050.274203
		12 - 22 hours	Strong wind	2050.279954
			Weak wind	2050.301828
		23 - 24 hours	Strong wind	2050.303176
			Weak wind	2050.30685
	Weekends and hollidays	1 - 8 hours	Strong wind	2050.309349
			Weak wind	2050.314156
		9 - 24 hours	Strong wind	2050.318948
			Weak wind	2050.328768
IV season (May 1 - 31)	Working days	1 - 7 hours	Strong wind	2050.334411
			Weak wind	2050.345549
		8 - 11 hours	Strong wind	2050.348101
			Weak wind	2050.355139
		12 - 17 hours	Strong wind	2050.359261
			Weak wind	2050.369522
		18 - 22 hours	Strong wind	2050.372473
			Weak wind	2050.381508
		23 - 24 hours	Strong wind	2050.383019
			Weak wind	2050.386302
	Weekends and hollidays	1 - 8 hours	Strong wind	2050.389895
			Weak wind	2050.395434
		9 - 24 hours	Strong wind	2050.40163
			Weak wind	2050.413699

Time and wind availability				Corresponding value in time axis
V season (June 1 - September 30)	Working days	1 - 7 hours	Strong wind	2050.430265
			Weak wind	2050.484019
		8 - 11 hours	Strong wind	2050.491852
			Weak wind	2050.5242
		12 - 15 hours	Strong wind	2050.534049
			Weak wind	2050.564383
		16 - 20 hours	Strong wind	2050.576334
			Weak wind	2050.614612
		21 - 24 hours	Strong wind	2050.622599
			Weak wind	2050.654795
	Weekends and hollidays	1 - 8 hours	Strong wind	2050.661316
			Weak wind	2050.685845
		9 - 15 hours	Strong wind	2050.691766
			Weak wind	2050.713015
		16 - 24 hours	Strong wind	2050.720413
			Weak wind	2050.747946
VI season (October 1 - 31)	Working days	1 - 7 hours	Strong wind	2050.755362
			Weak wind	2050.765525
		8 - 11 hours	Strong wind	2050.769803
			Weak wind	2050.775571
		12 - 18 hours	Strong wind	2050.783046
			Weak wind	2050.793151
		19 - 21 hours	Strong wind	2050.797122
			Weak wind	2050.800685
		22 - 24 hours	Strong wind	2050.804526
			Weak wind	2050.808219
	Weekends and hollidays	1 - 8 hours	Strong wind	2050.811245
			Weak wind	2050.816438
		9 - 17 hours	Strong wind	2050.81817
			Weak wind	2050.825685
		18 - 21 hours	Strong wind	2050.826549
			Weak wind	2050.829794
		22 - 24 hours	Strong wind	2050.830689
			Weak wind	2050.832877

Time and wind availability				Corresponding value in time axis
VII season (November 1 - 30)	Working days	1 - 7 hours	Strong wind	2050.837364
			Weak wind	2050.849658
		8 - 13 hours	Strong wind	2050.852895
			Weak wind	2050.864042
		14 - 17 hours	Strong wind	2050.866212
			Weak wind	2050.873631
		18 - 20 hours	Strong wind	2050.875665
			Weak wind	2050.880822
		21 - 24 hours	Strong wind	2050.883969
			Weak wind	2050.890411
	Weekends and hollidays	1 - 7 hours	Strong wind	2050.893269
			Weak wind	2050.897603
		8 - 17 hours	Strong wind	2050.901978
			Weak wind	2050.907877
		18 - 21 hours	Strong wind	2050.90955
			Weak wind	2050.911987
		22 - 24 hours	Strong wind	2050.913324
			Weak wind	2050.915069
VIII season (December 1 - 31)	Working days	1 - 6 hours	Strong wind	2050.924198
			Weak wind	2050.930822
		7 - 16 hours	Strong wind	2050.943235
			Weak wind	2050.957078
		17 - 19 hours	Strong wind	2050.96149
			Weak wind	2050.964954
		20 - 24 hours	Strong wind	2050.972177
			Weak wind	2050.978081
	Weekends and hollidays	1 - 7 hours	Strong wind	2050.981667
			Weak wind	2050.984474
		8 - 16 hours	Strong wind	2050.989084
			Weak wind	2050.992693
		17 - 20 hours	Strong wind	2050.995075
			Weak wind	2050.996346
		21 - 24 hours	Strong wind	2050.998633
			Weak wind	2050.999999

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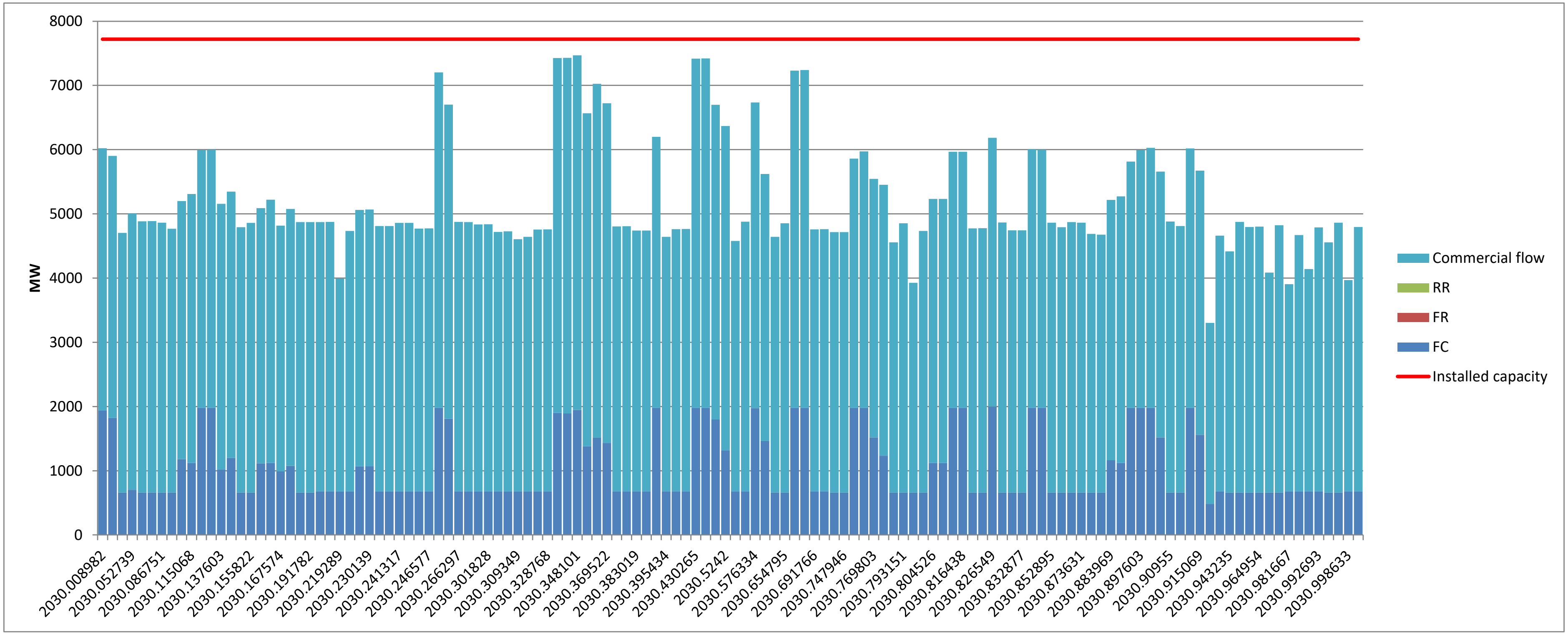
Utilisation of interconnectors in Baltics

Base scenario, 2030



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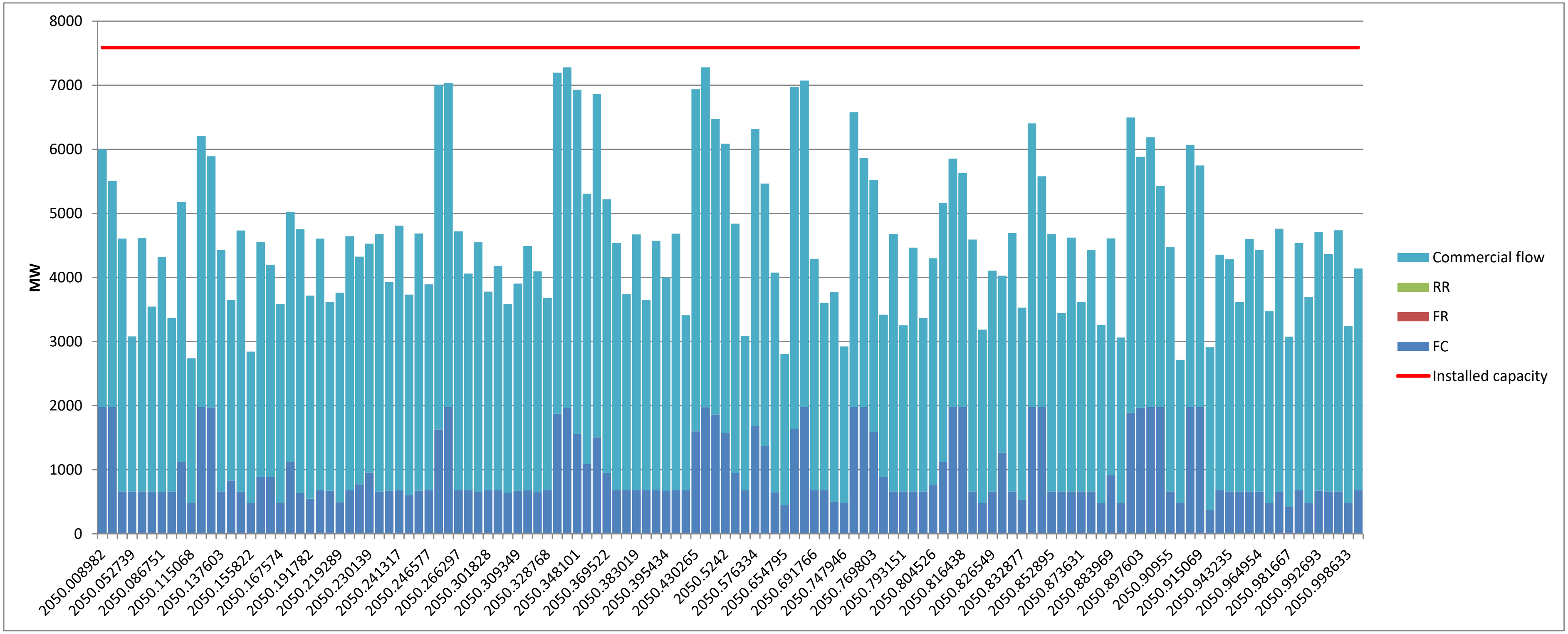
Utilisation of interconnectors in Baltics

Base scenario, 2050



This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691739.

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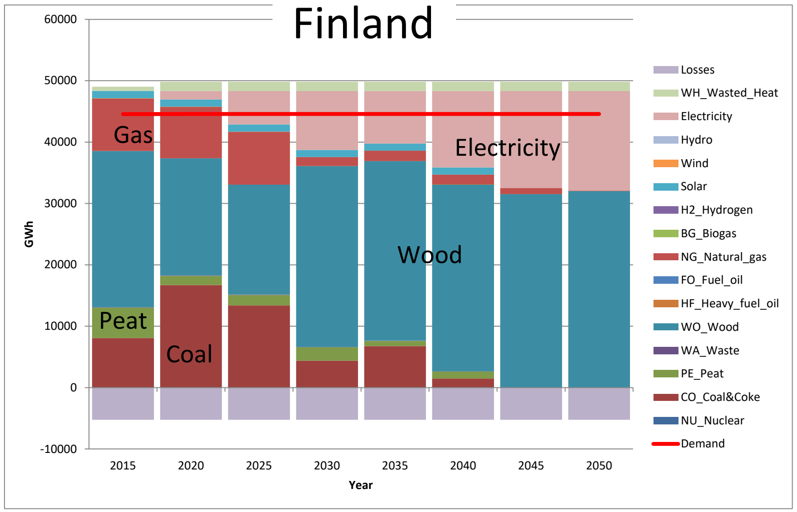
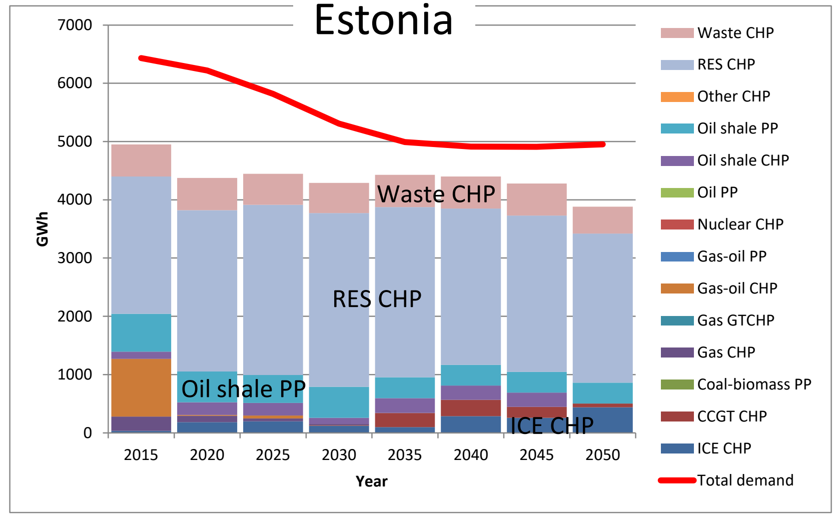
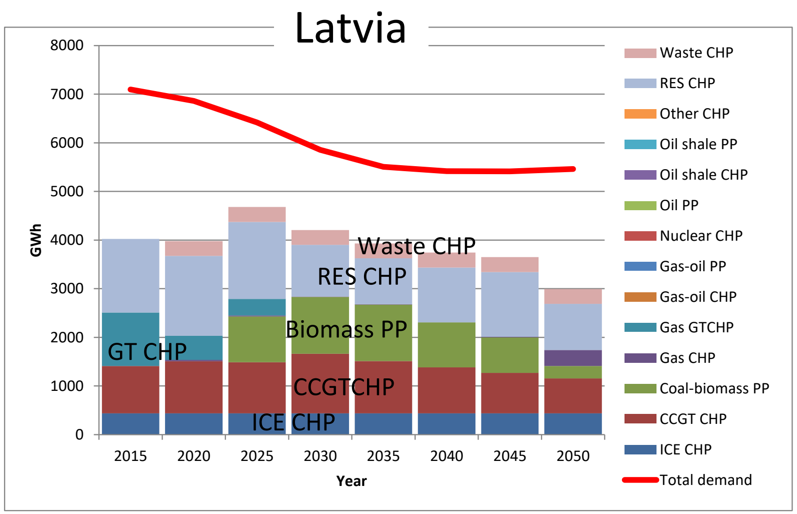
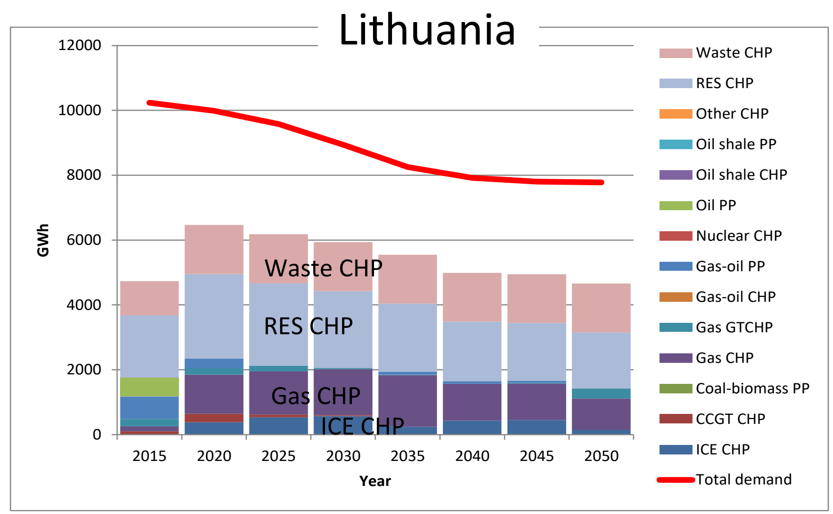
Production of district heat (Base sc.)









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Conclussions

- *Refurbishment of existing hydro power plants, construction of wind power plants, CHPs running on biomass and municipal waste, CHPs running on natural gas and biogas* are the most attractive electricity generation options in the Baltic States and Finland. *Biomass boilers, CHP's and heat pumps* are economically more preferable for heat production. The development of other technologies in the near future is economically less justifiable, due to electricity import driven by the relatively low electricity market prices and environmental limitations

- *Significant share of intermittent electricity generation* (in particular from wind) *imposes energy security challenges* as it requires the power system to maintain sufficient *balancing capacities*

- Balancing power obtained via *interconnectors* from available sources in neighbouring countries, *gas turbine CHPs, gas turbine power plants* and plants with *internal combustion engines* are the most cost effective measures to reduce the generation intermittence problem

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Conclussions

- The Baltic States have powerful electrical connections with neighbouring power systems from which they import large amount of required electricity. The capacity of a separate power line may exceed 30-50% of each country's total power demand. *The possible malfunctions of such a line may cause significant energy security problems if required reserve capacities are not available*

- Study results show that in theory the *power system should not face any serious disruptions*. However, in practice, certain elements that ensure the provision of reservation services ***may not be implemented or their functioning may not correspond to the real threats*** that can appear due to failure of a powerful line, especially in the case where throughput capacity of interconnectors could be reduced due to various reasons. Looking at the current situation, the *biggest problems are related to the provision of frequency containment and replacement reserves*.

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Conclussions

The results of the case study suggest that the *number of interconnectors and their throughput capacities*, used for electricity trade between countries as well as for providing balancing and reservation services, *should be maintained or even extended*

Existing fossil fuel power plants, currently not competitive in the electricity market *can still be a cost-effective option to provide reserve services and ensure energy security*.

*Significant growth of biofuel use and it's dominance , especially in heat production, is not a good phenomenon in terms of energy security. This may have an impact on the competition between fuel types and **lead to fuel price growth**. On the other hand, this **can cause unsustainable processes in forestry** if insufficient attention is paid to reforestation, cultivation and forest care*

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Thank you for your attention

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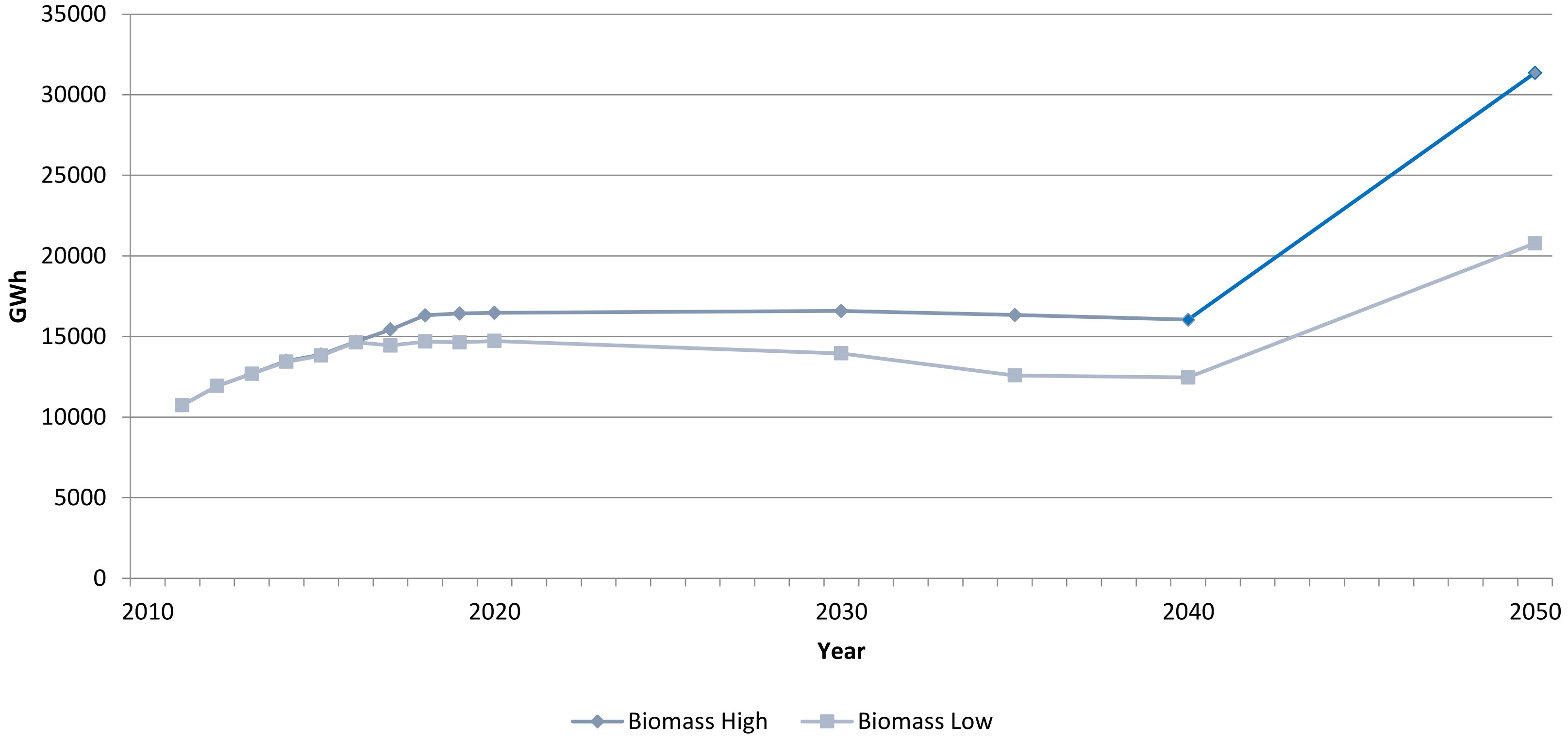
Sustainability of wood supply



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