Turun yliopisto
University of Turku

Tampere University

Technological University of Habana José Antonio Echeverría

cujae

Future of baseload production
The changing structure imposed by an increase of variable wind and solar production

Jyrki Luukkanen, Yrjö Majanne,

Anaely Saunders & Burkhard Auffermann

23rd REFORM Group Meeting, Salzburg – October 13 – 19, 2019:
Geopolitics of the Energy Transformation and Energy Democracy

CONTENTS OF THE PRESENTATION

- Load duration curve for analysing power plant operation
- Residual load duration curve
- Ramping rate
- German case
- German scenarios
- Finland case
- Finland scenarios
- Conclusions

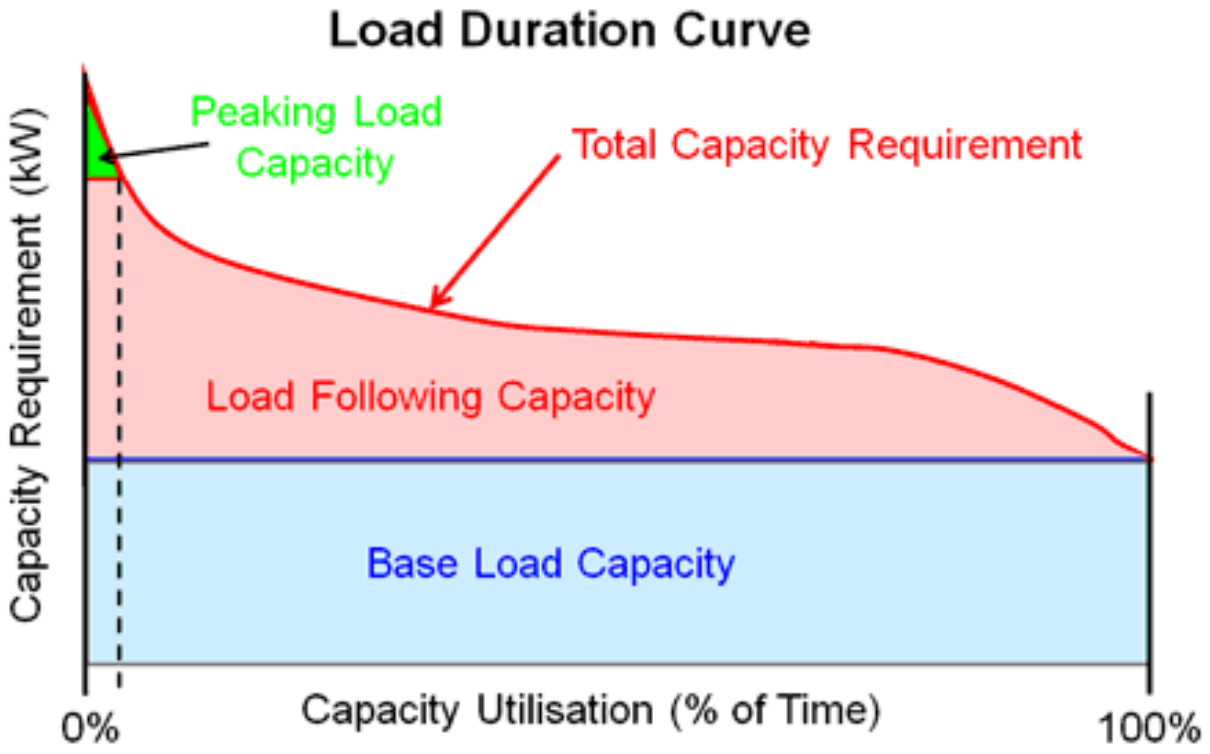
GERMAN ELECTRICITY PRODUCTION AND CONSUMPTION

- **Data source SMARD.de**
- **Production and consumption data for 8.8.2018-7.8.2019**
- **15 min interval.**
- **Different production forms (Realisierte Erzeugung):**
- Biomasse[MWh]
- Wasserkraft[MWh]
- Wind Offshore[MWh]
- Wind Onshore[MWh]
- Photovoltaik[MWh]
- Sonstige Erneuerbare[MWh]
- Kernenergie[MWh]
- Braunkohle[MWh]
- Steinkohle[MWh]
- Erdgas[MWh]
- Pumpspeicher[MWh]
- Sonstige Konventionelle[MWh]
- **Consumption (Realisierter Stromverbrauch)** [MWh]

Turun yliopisto
University of Turku

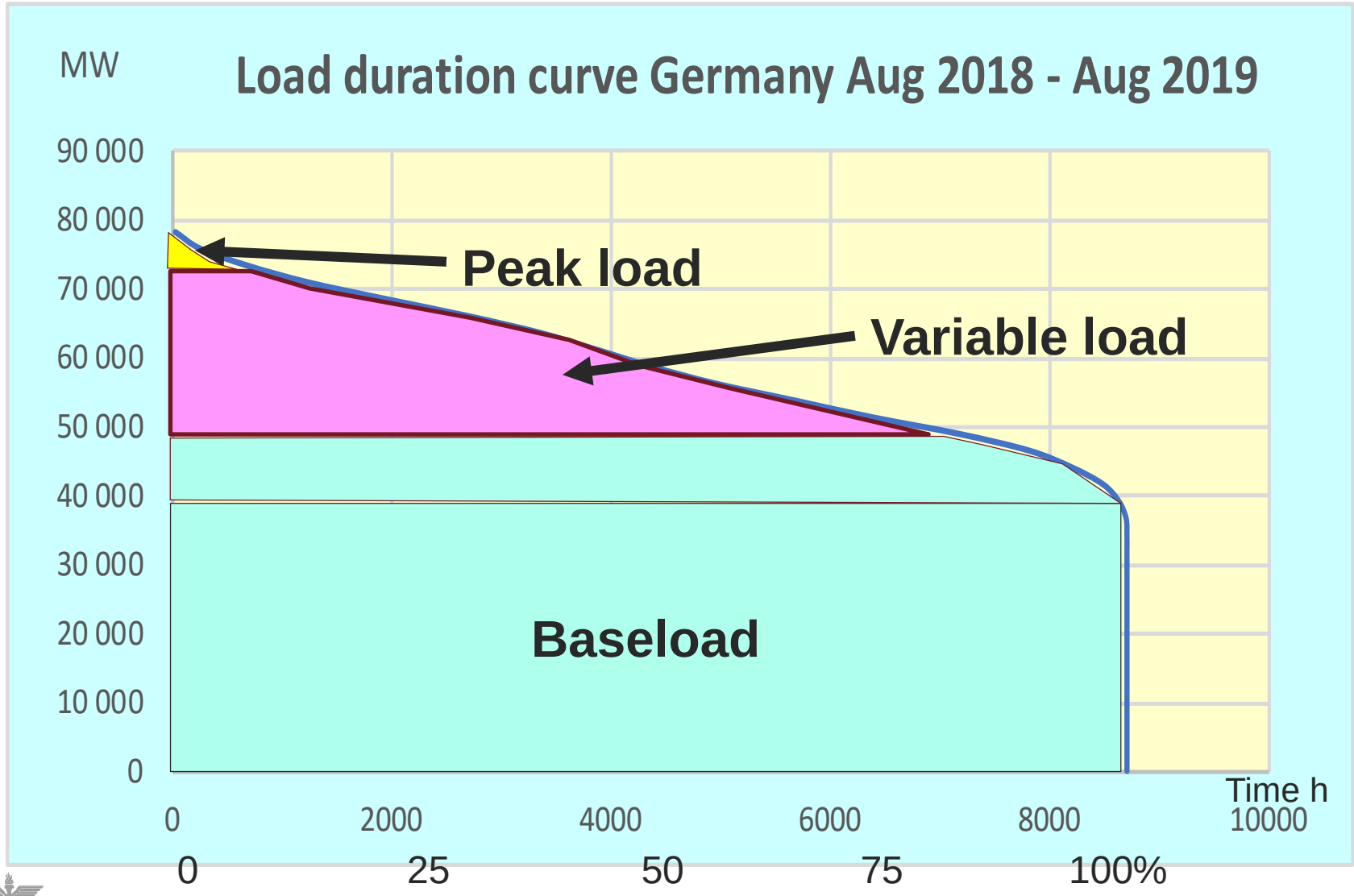
LOAD DURATION CURVE (LDC)

- Can be used for analysing the need for different types of production capacity
- LDC is an arrangement of all load levels (MWh/h) in a descending order of magnitude (for 8760 hours of year)
- The area under the LDC represents the energy demanded by the system (consumed)



LDC can be used in economic dispatching, system planning and reliability evaluation

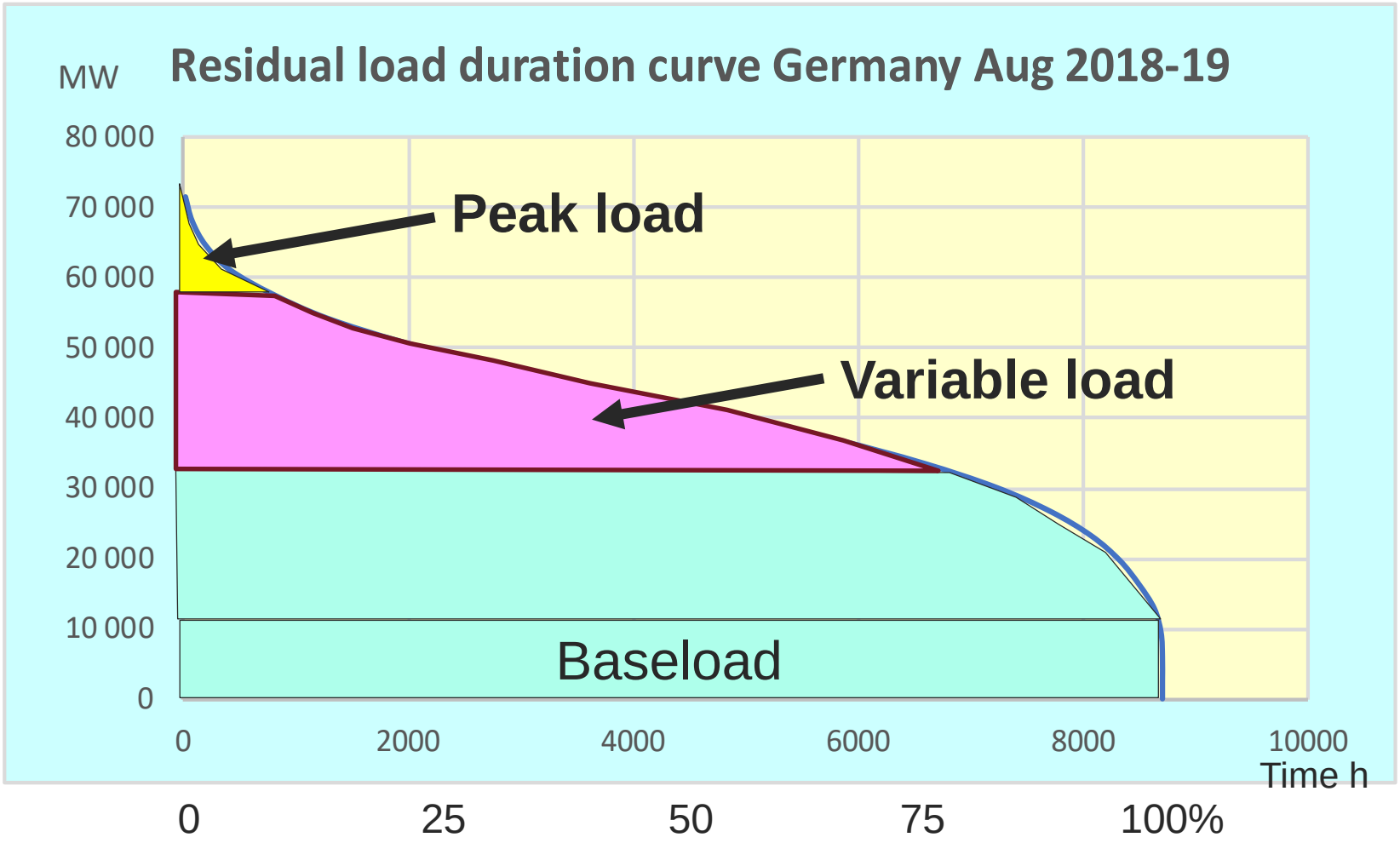
LOAD DURATION CURVE, GERMANY



RESIDUAL LOAD

- **Residual load is important for the point of view of the control of the supply demand balance**
- **Residual load = Load – wind production – solar PV production**
- **Residual load has to be covered with controllable production forms (fossil fuel, nuclear, hydro power, biomass)**
- **Variations in residual load caused by variable production (wind, solar) and variable consumption can cause large ramping rate requirements for prodution**
- **-> Analysis of residual load important**

RESIDUAL LOAD DURATION CURVE

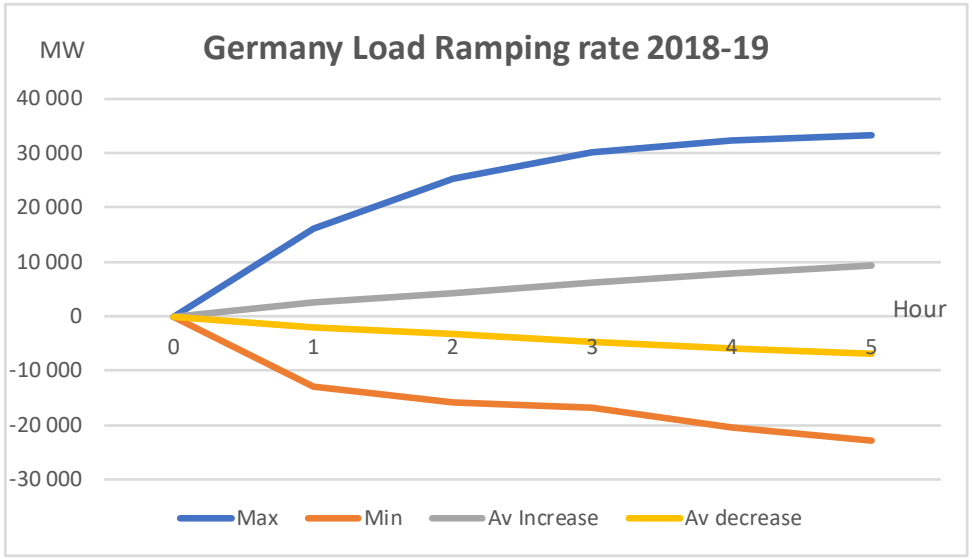


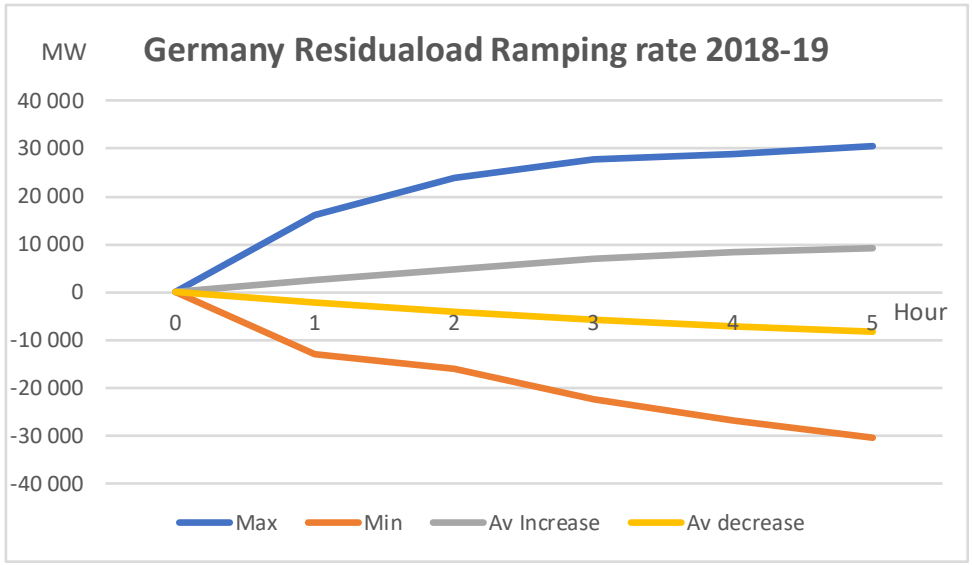
Turun yliopisto
University of Turku

RAMPING RATE

Ramping rate envelope shows how fast the power production has to change in order to follow the load or residual load

Ramping rate indicates what type of power plants are reuired for balancing supply/demand





Control characteristics of some power plant types

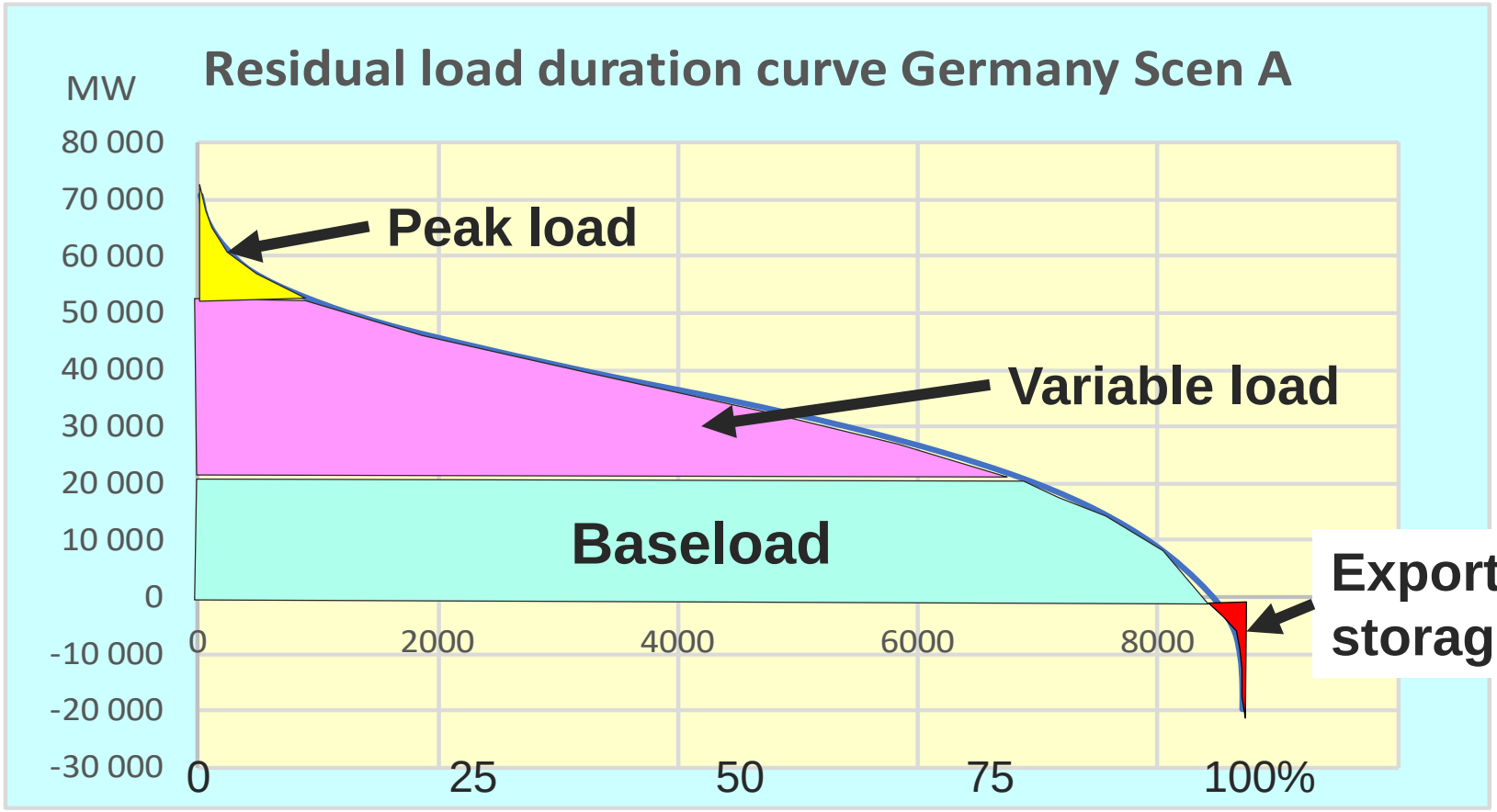
	CONDENSING THERMAL POWER			GAS TURBINE POWER PLANTS		HYDRO POWER
	PULVERIZED COAL FIRED	OIL/GAS FIRED	NUCLEAR	Aircraft "JET"	INDUSTRIAL	
Max. Power change rate in < 30 sec. Normal Special	2 % P_N 5 % P_N	2 % P_N 5 % P_N	(2)* % P_N (10) *% P_N	60 % P_N 70 % P_N	40 % P_N 50 % P_N	30 % P_N 30 % P_N
Max. Power change rate in < 100 sec. Normal Special	4 % P_N 12 % P_N	7 % P_N 20 % P_N	(15) *% P_N	100 % P_N 100 % P_N	70 % P_N 100 % P_N	90 % P_N 90 % P_N
Operation range	40 – 100% P_N	40 – 100% P_N	(60 – 100)* % P_N	0 – 100% P_N	0 – 100% P_N	20 – 100% P_N
Min. Time required for reconnecting to the network, hot start	0,5 – 1 h	0,4 – 1 h	(3 – 6)* h	200 – 400 s	300 – 450 s	150 – 300 s
Cold start	2 – 5 h	2 – 5 h	18 – 40 h	150 – 250 s	300 – 900 s	200 – 300 s
Technical limits for control performance	Thermal stresses, Dynamical properties of the boilers		Thermal stresses,	Stresses in combustion chamber and turbine rotor		Mech. stress in rotor
Economical limits for control performance	Degradation of efficiency in part load operation					

* Technically possible but not allowed by the authorities

SCEN A RESIDUAL LOAD DURATION CURVE

Scenario A: Solar PV 1.5 x 2019 (max hour 45 000 MW), Wind 1.5 x 2019 (max hour 70 000 MW), No change in load

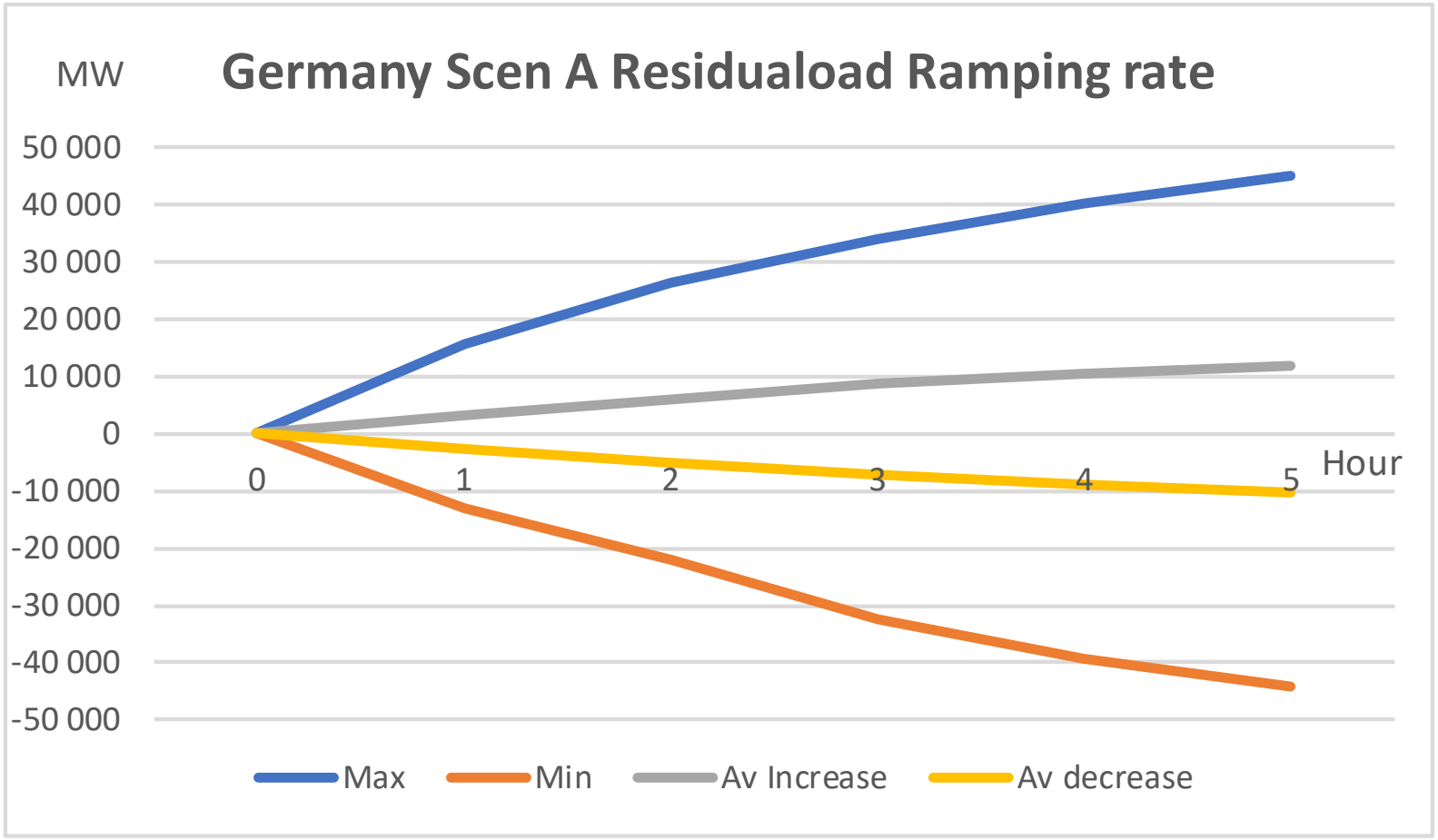
Hourly profile of wind and solar production and consumption is same as 2019



Turun yliopisto
University of Turku

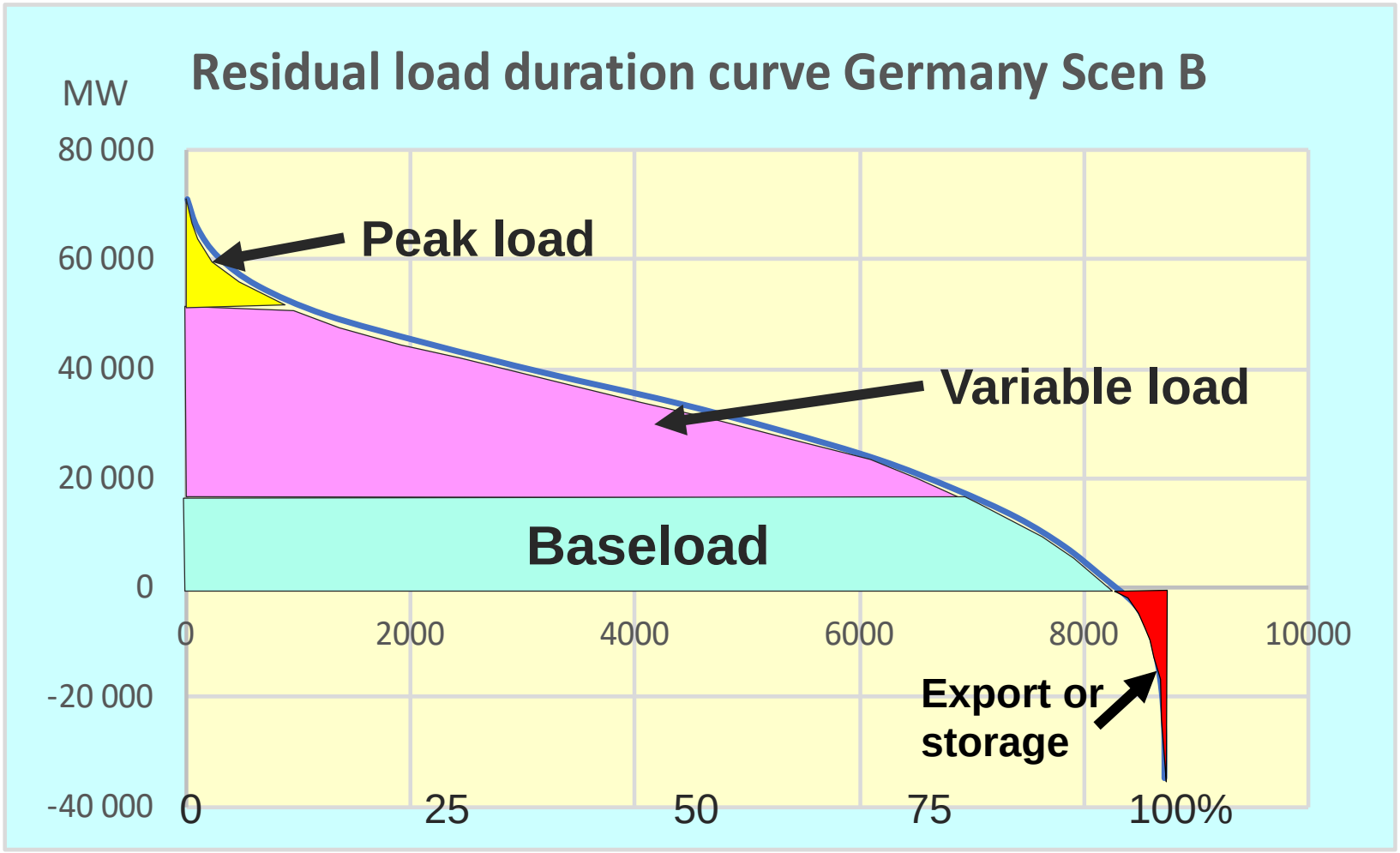
RAMPING RATE

- **Scenario A: Solar PV 1.5 x 2019 (max 45 000MW),**
- **Wind 1.5 x 2019 (70 000 MW), No change in load**



SCEN B RESIDUAL LOAD DURATION CURVE

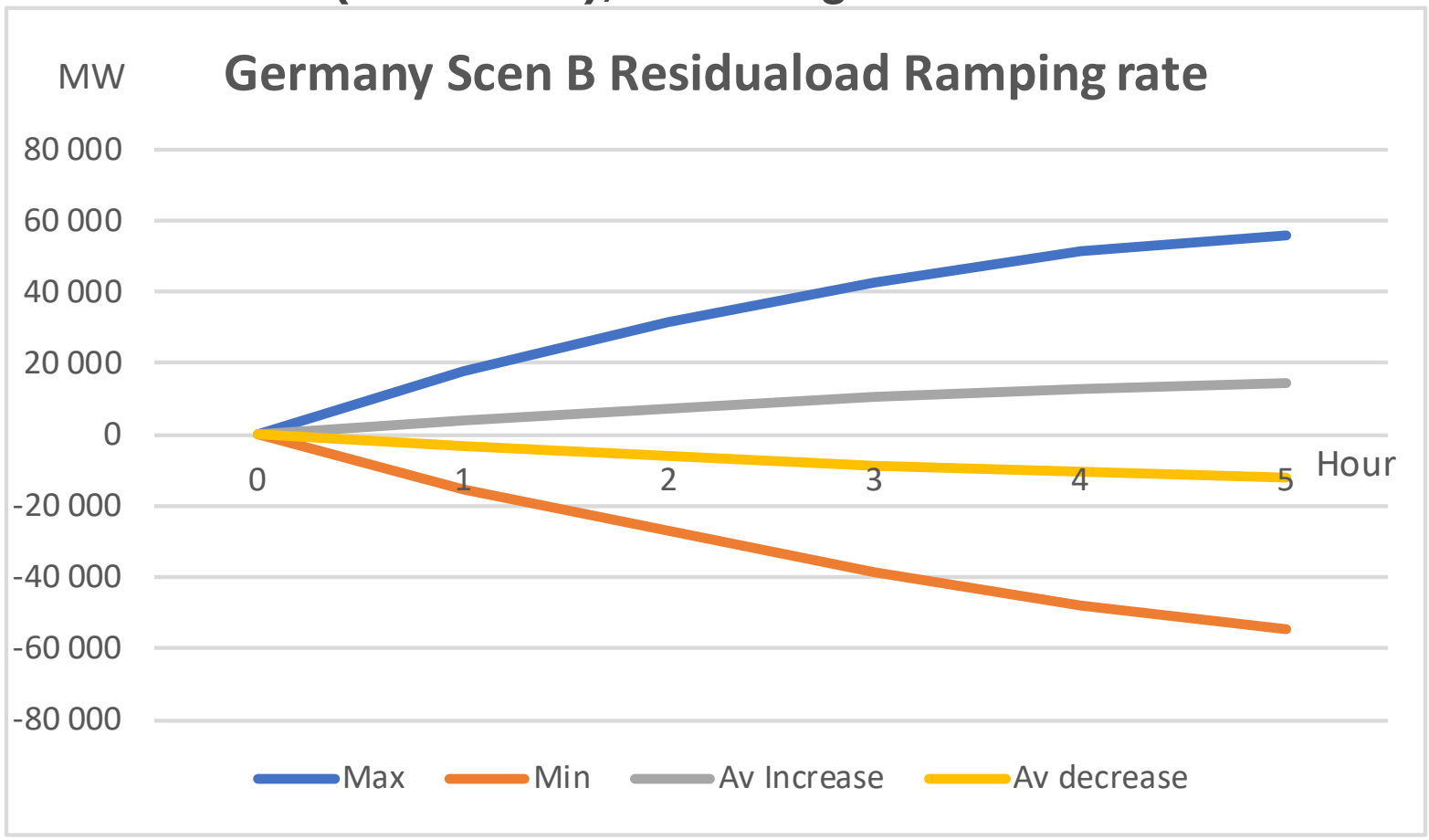
- **Scenario B: Solar PV 2 x 2019 (max hour 60 000MW), Wind 1.5 x 2019 (max hour 70 000 MW), No change in load**



Turun yliopisto
University of Turku

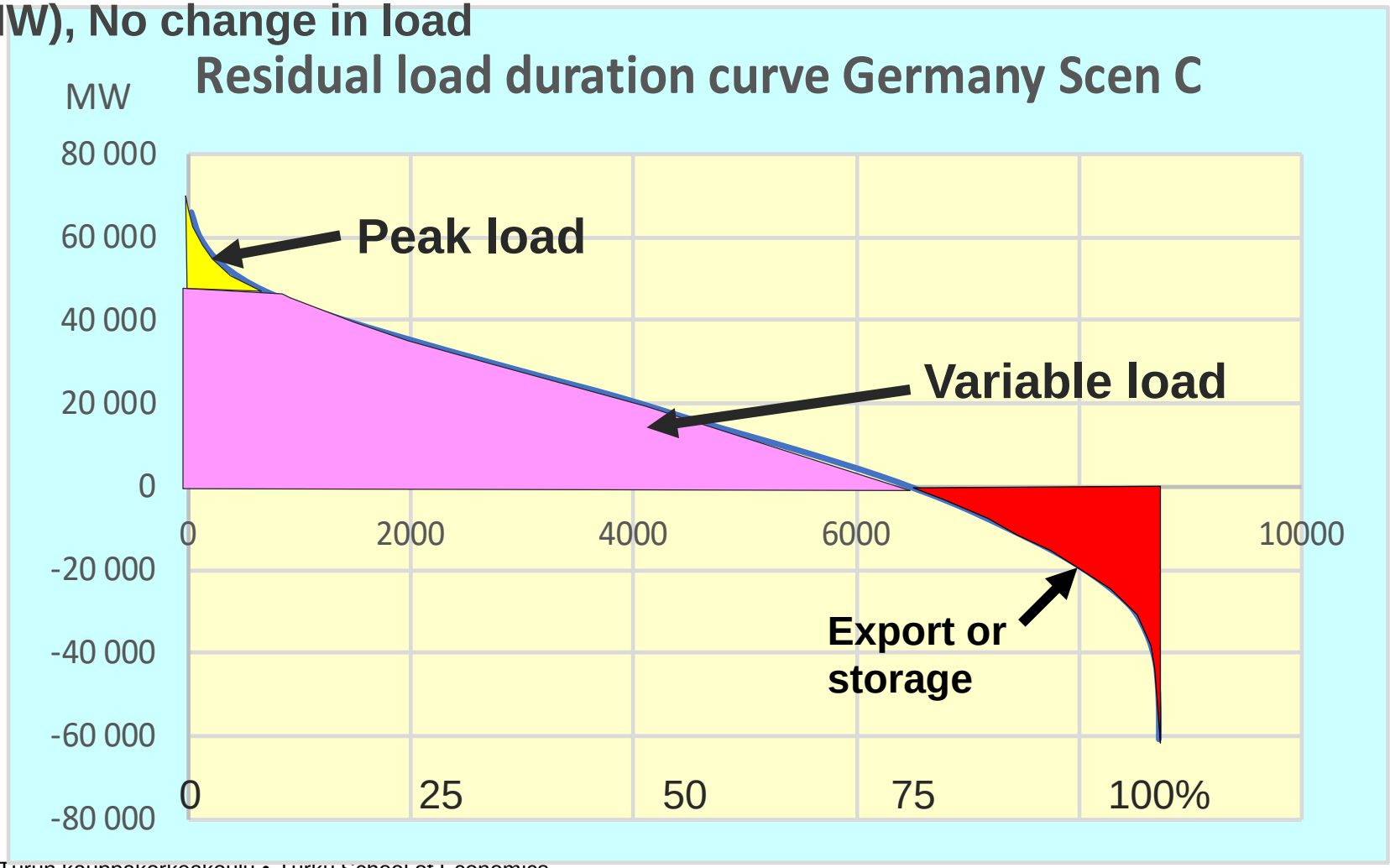
RAMPING RATE

- **Scenario B: Solar PV 2 x 2019 (60 000MW),**
- **Wind 1.5 x 2019 (70 000MW), No change in load**



SCEN C RESIDUAL LOAD DURATION CURVE

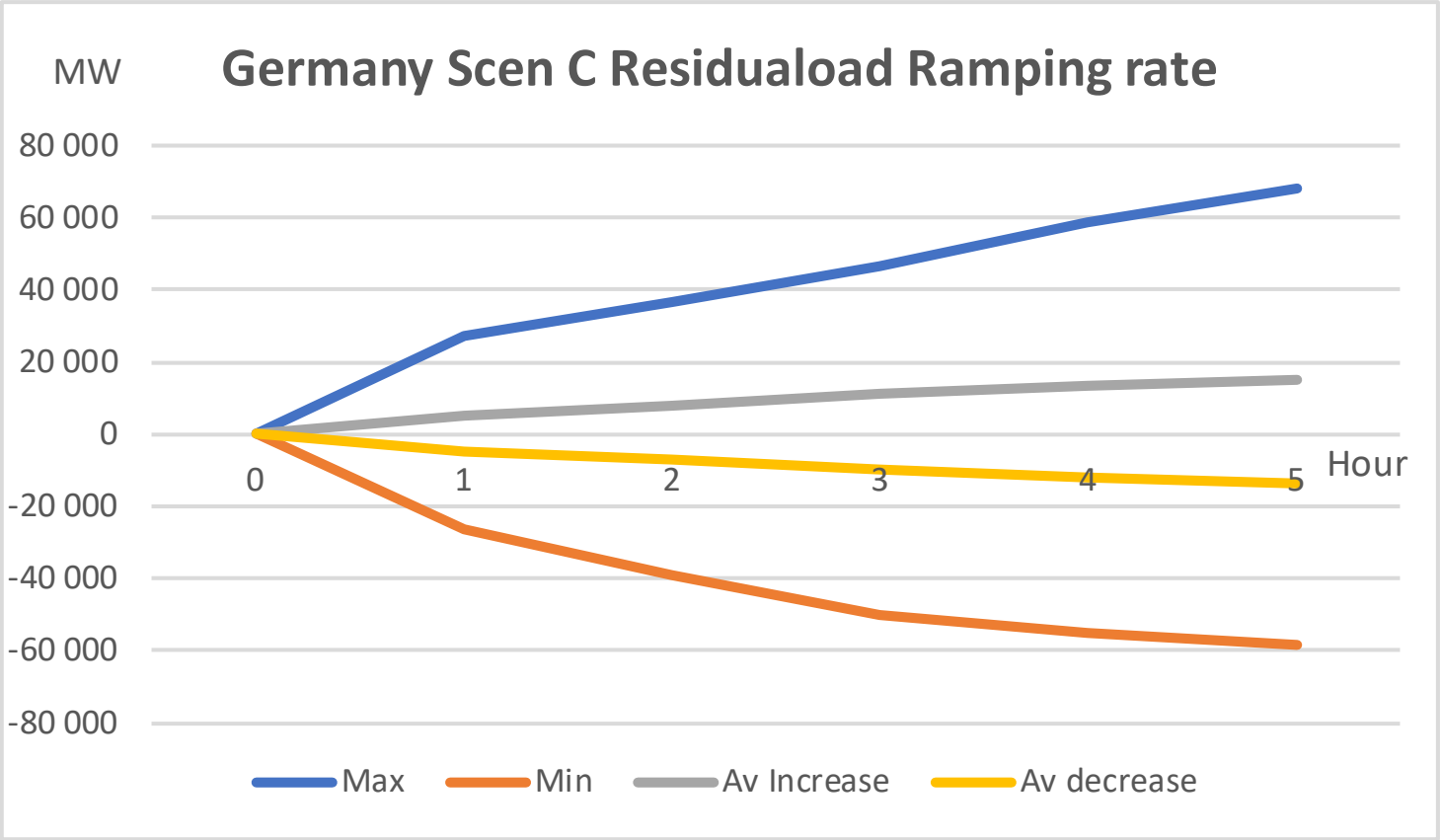
- **Scenario C: Solar PV 2 x 2019 (max hour 60 000MW), Wind Offsh 8 x 2019 (max hour 50 000 MW), Wind Onsh 1.5 x 2019 (max hour 60 000 MW), No change in load**



Turun yliopisto
University of Turku

RAMPING RATE

- **Scenario C: Solar PV 2 x 2019 (60 000MW),**
- **Wind Offsh 8 x 2019 (50 000MW), Wind Onsh 1.5 x 2019 (60 000MW), No change in load**



ELECTRICITY CONSUMPTION MODEL FOR FINLAND

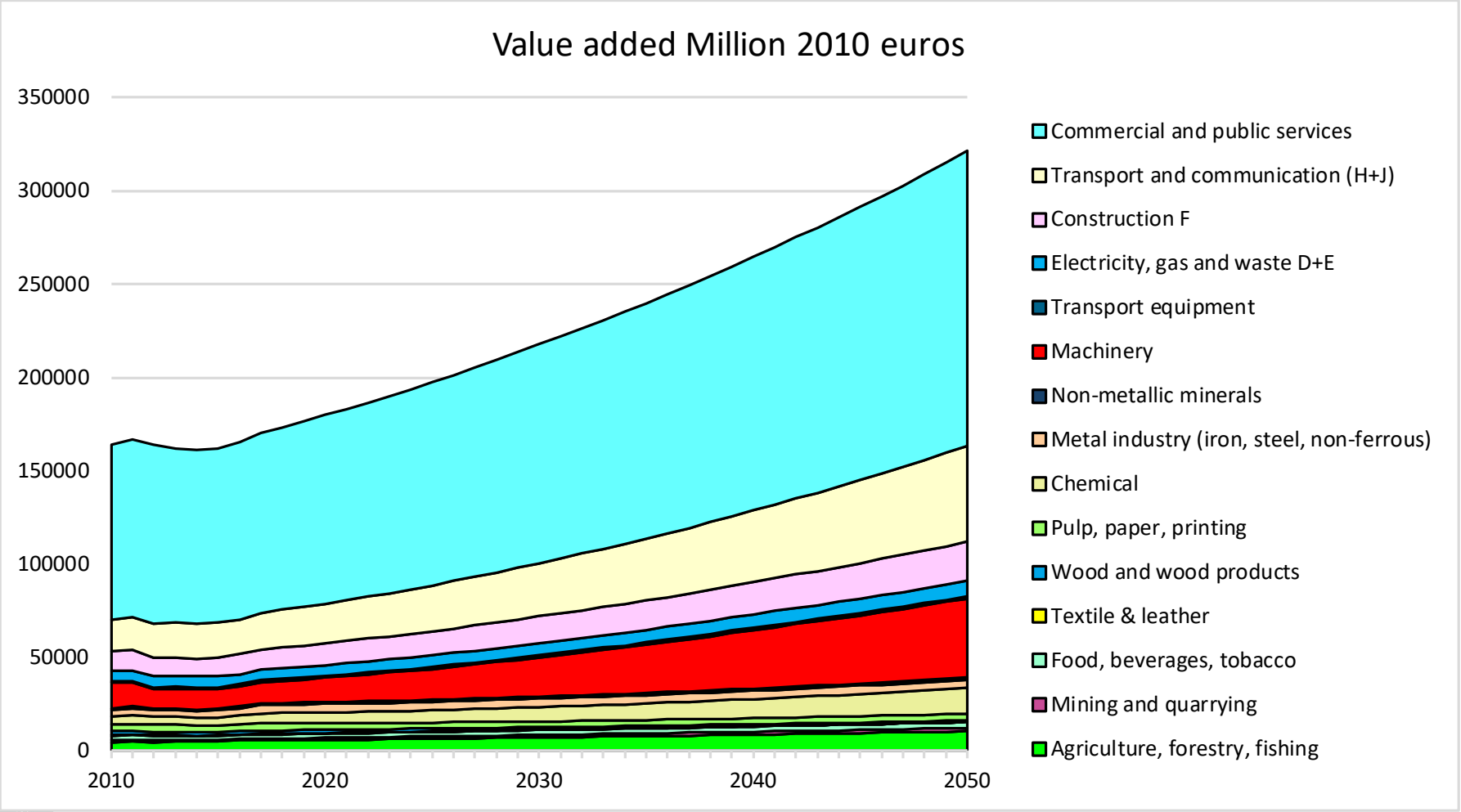
- LINDA model Long-range Integrated Development analysis
- Accounting framework type of model
- Electricity demand depends on sectoral economic value added and electricity intensity
- Annual growth rates and changes in intensity
- Monthly consumption based on productin volumes
- Hourly consumption based on hourly load curves for weekdays and weekends and different months

Turun yliopisto
University of Turku

ELECTRICITY CONSUMPTION MODEL FOR FINLAND

Electricity consumption model aspects:

- **Sectoral economic growth**



Turun yliopisto
University of Turku

ELECTRICITY CONSUMPTION MODEL FOR FINLAND

Consumption model aspects:

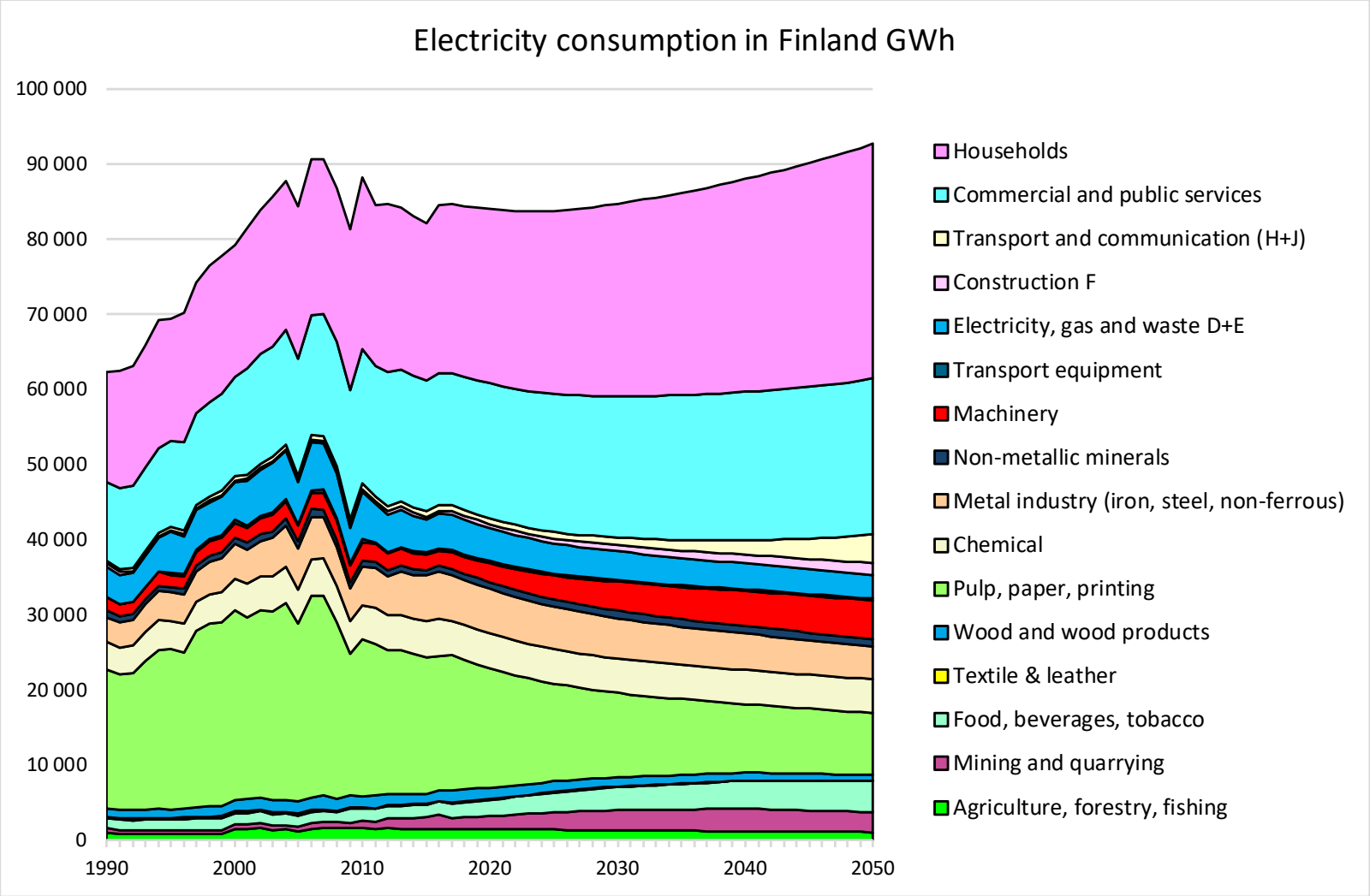
- **Sectoral economic development is given as input**

Electricity intensity change ktoe/Mill euros					Fill in future annual % growth figures in yellow cells			
	1980-1990	1990-2000	2000-2010	2010-2017	2018-2025	2025-2030	2030-2040	2040-2050
Agriculture, forestry, fishing		4 %	0 %	-4 %	-3 %	-3 %	-3 %	-3 %
Mining and quarrying		-1 %	-2 %	5 %	2 %	1 %	0 %	-2 %
Food, beverages, tobacco		0 %	-2 %	5 %	3 %	2 %	1 %	0 %
Textile & leather		3 %	-4 %	0 %	0 %	0 %	0 %	0 %
Wood and wood products		0 %	4 %	1 %	1 %	0 %	0 %	-1 %
Pulp, paper, printing		0 %	0 %	-3 %	-2 %	-2 %	-2 %	-2 %
Chemical		-2 %	-1 %	-3 %	-3 %	-3 %	-3 %	-3 %
Metal industry (iron, steel, non-ferrous)		-1 %	1 %	-1 %	-1 %	-1 %	-1 %	-1 %
Non-metallic minerals		0 %	-1 %	2 %	1 %	0 %	-1 %	-1 %
Machinery (incl. e.g. Eletronics)		-6 %	-2 %	1 %	0 %	-1 %	-2 %	-2 %
Transport equipment		#DIV/0!	6 %	-6 %	-3 %	-3 %	-2 %	-2 %
Electricity, gas and waste D+E		0 %	1 %	-4 %	-3 %	-2 %	-2 %	-2 %
Construction F		-5 %	4 %	3 %	3 %	2 %	2 %	1 %
Transport and communication (H+J)		-1 %	2 %	-2 %	-2 %	2 %	3 %	4 %
Commercial and public services		1 %	2 %	-1 %	-1 %	-1 %	-1 %	-1 %
Households (electricity use)		2 %	3 %	0 %	1 %	1 %	1 %	1 %

Turun yliopisto
University of Turku

ELECTRICITY CONSUMPTION MODEL FOR FINLAND

Sectoral electricity consumption



Turun yliopisto
University of Turku

ELECTRICITY CONSUMPTION MODEL FOR FINLAND

Electricity consumption profile is given for different hours for different weekdays and different months

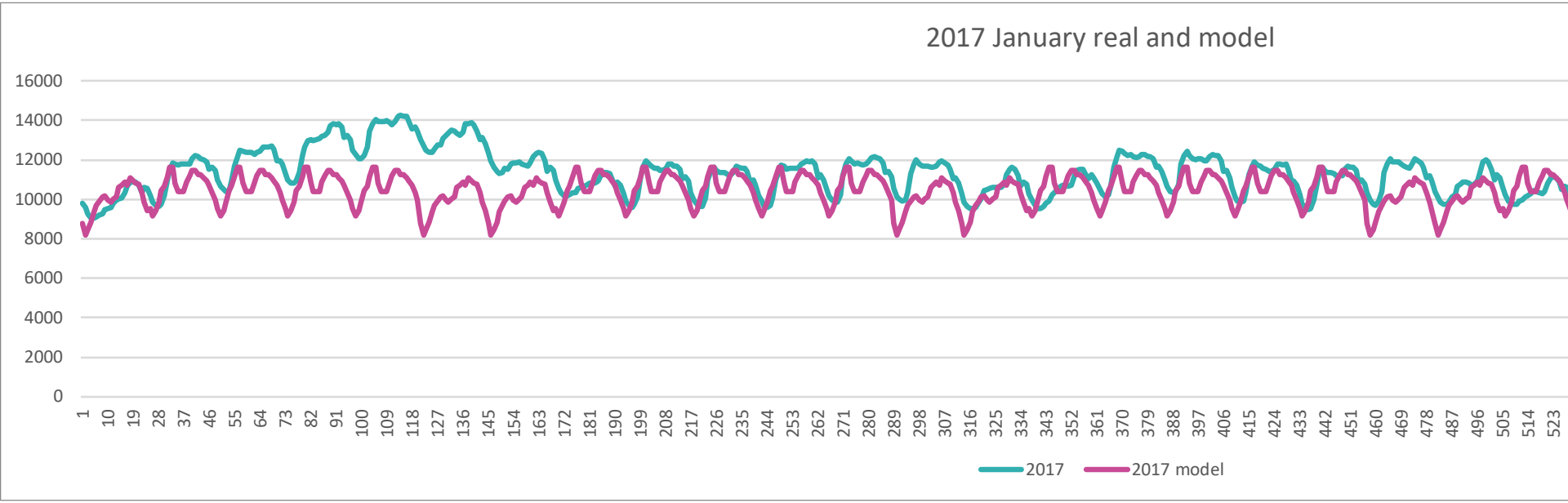
Weekdays	Commercial&Public services				Percentage of max monthly load							
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	80 %	82 %	85 %	85 %	85 %	85 %	85 %	85 %	80 %	80 %	80 %	80 %
2	75 %	75 %	85 %	85 %	85 %	85 %	85 %	85 %	75 %	75 %	75 %	75 %
3	75 %	75 %	85 %	85 %	85 %	85 %	85 %	85 %	75 %	75 %	75 %	75 %
4	75 %	75 %	85 %	85 %	85 %	85 %	85 %	85 %	75 %	75 %	75 %	75 %
5	80 %	80 %	85 %	85 %	85 %	85 %	85 %	85 %	80 %	80 %	80 %	80 %
6	80 %	80 %	85 %	85 %	85 %	85 %	85 %	85 %	80 %	80 %	80 %	80 %
7	85 %	85 %	85 %	85 %	85 %	85 %	85 %	85 %	85 %	85 %	85 %	85 %
8	90 %	90 %	87 %	87 %	87 %	87 %	87 %	87 %	90 %	90 %	90 %	90 %
9	90 %	90 %	87 %	87 %	87 %	87 %	87 %	87 %	90 %	90 %	90 %	90 %
10	80 %	80 %	87 %	87 %	87 %	87 %	87 %	87 %	85 %	85 %	80 %	80 %
11	75 %	75 %	90 %	90 %	90 %	90 %	90 %	90 %	90 %	90 %	75 %	75 %
12	75 %	75 %	90 %	90 %	90 %	90 %	90 %	90 %	90 %	90 %	75 %	75 %
13	75 %	75 %	90 %	90 %	90 %	90 %	90 %	90 %	90 %	90 %	75 %	75 %
14	80 %	80 %	90 %	90 %	90 %	90 %	90 %	90 %	90 %	90 %	80 %	80 %
15	85 %	85 %	95 %	95 %	95 %	95 %	95 %	95 %	95 %	95 %	85 %	85 %
16	90 %	90 %	95 %	95 %	95 %	95 %	95 %	95 %	95 %	95 %	90 %	90 %
17	95 %	95 %	95 %	95 %	95 %	95 %	95 %	95 %	95 %	95 %	95 %	95 %
18	95 %	95 %	95 %	95 %	95 %	95 %	95 %	95 %	95 %	95 %	95 %	95 %
19	100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %
20	100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %
21	98 %	98 %	98 %	98 %	98 %	98 %	98 %	98 %	98 %	98 %	98 %	98 %
22	95 %	95 %	95 %	95 %	95 %	95 %	95 %	95 %	95 %	95 %	95 %	95 %
23	90 %	90 %	90 %	90 %	90 %	90 %	90 %	90 %	90 %	90 %	90 %	90 %
24	85 %	85 %	85 %	85 %	85 %	85 %	85 %	85 %	85 %	85 %	85 %	85 %

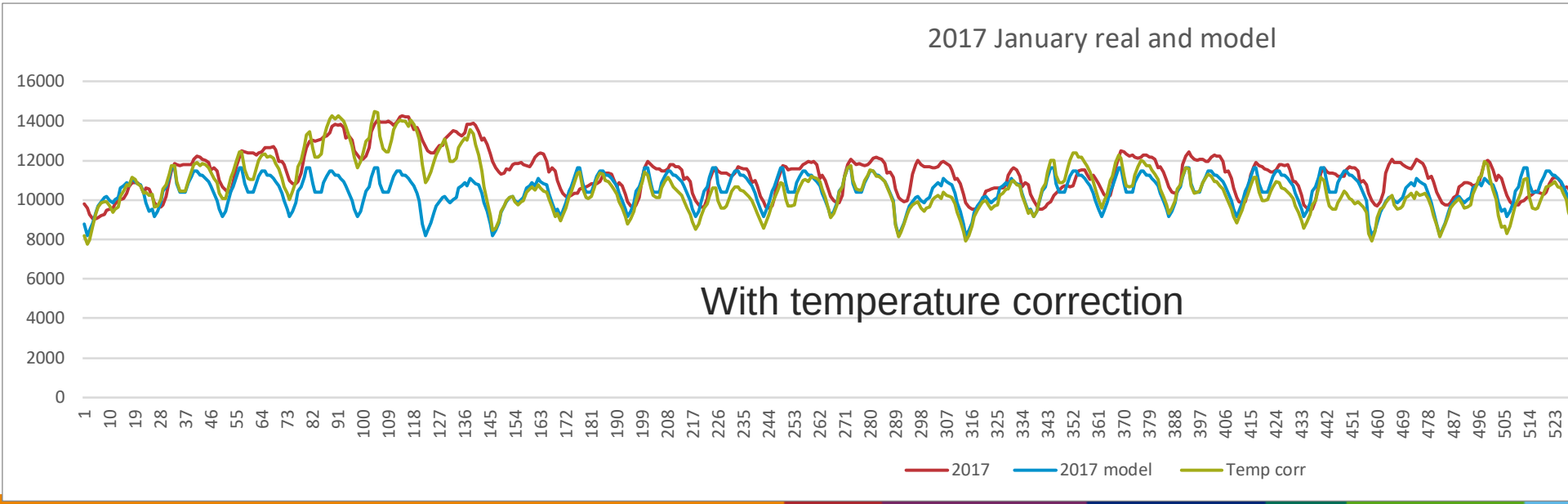
SCENARIOS

- **Scenaros are constructed for:**
  - **Different economic growth types (strong industrial development, commercial sector development, fast growth, no growth)**
  - **Different electricity intensity development**
  - **Transport sector development (amount of electric cars)**
  - **Heat pump development in heating the buldings**

Turun yliopisto
University of Turku

MODEL VERIFICATION



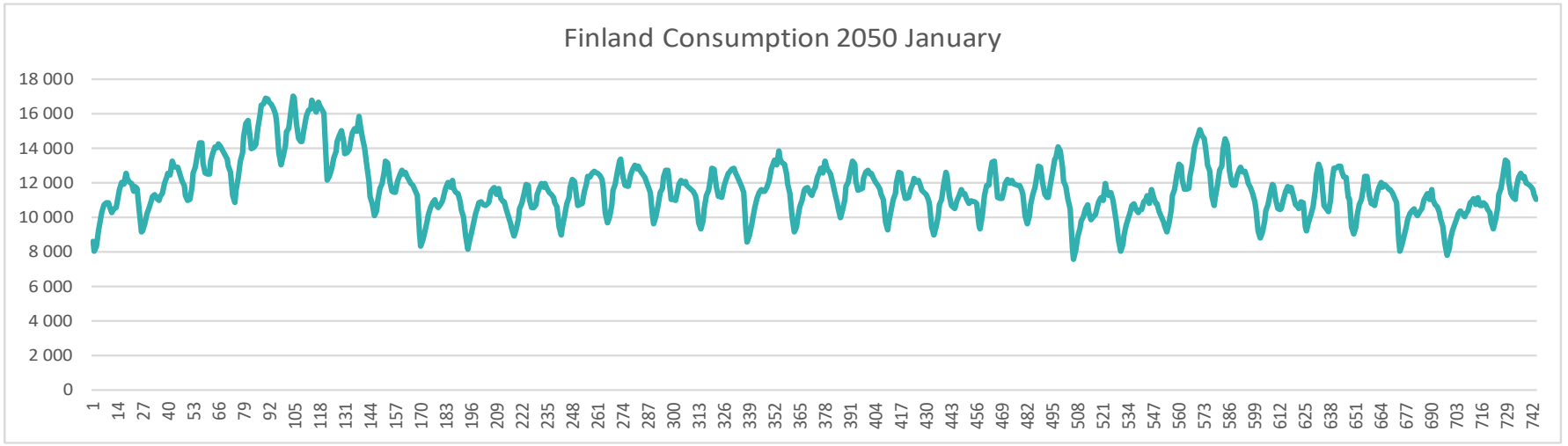


SCENARIOS

- When we have consumption profile eg. In 2050 we can make scenarios about hourly production of intermittent sources (wind and solar)
- We can calculte hourly ’Residual load’ (= consumption – wind production – solar production)
- This ’Residual load’ has to be covered with other production (or import-export or storage)
- Future ’Residual load duration curve’ shows what kind of power plants are needed in the future (baseload, variable load, peak load)

SCENARIO

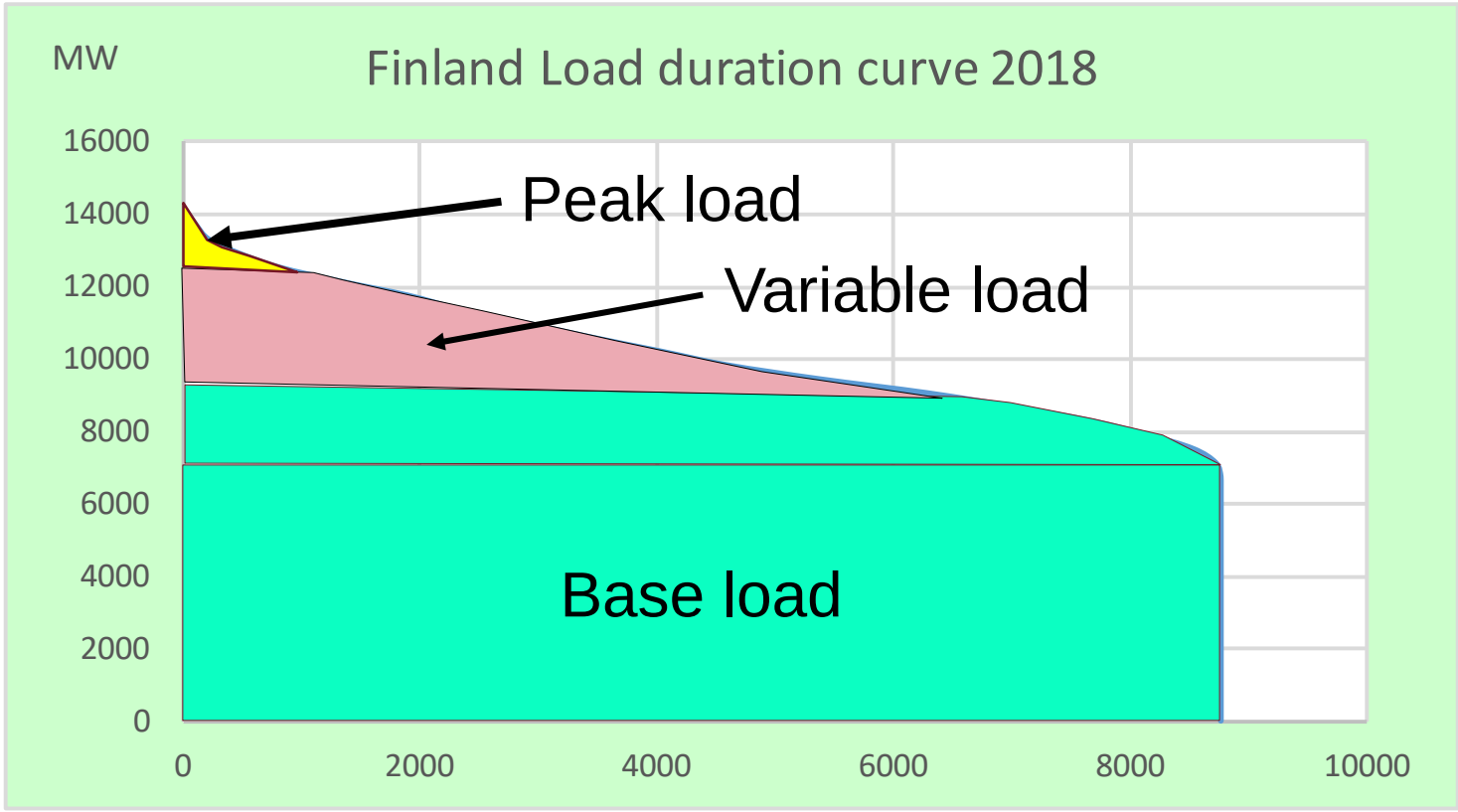
- Consumption January 2050 using 2018 temperature profile



- The peak load seems to be about 17 000 MW

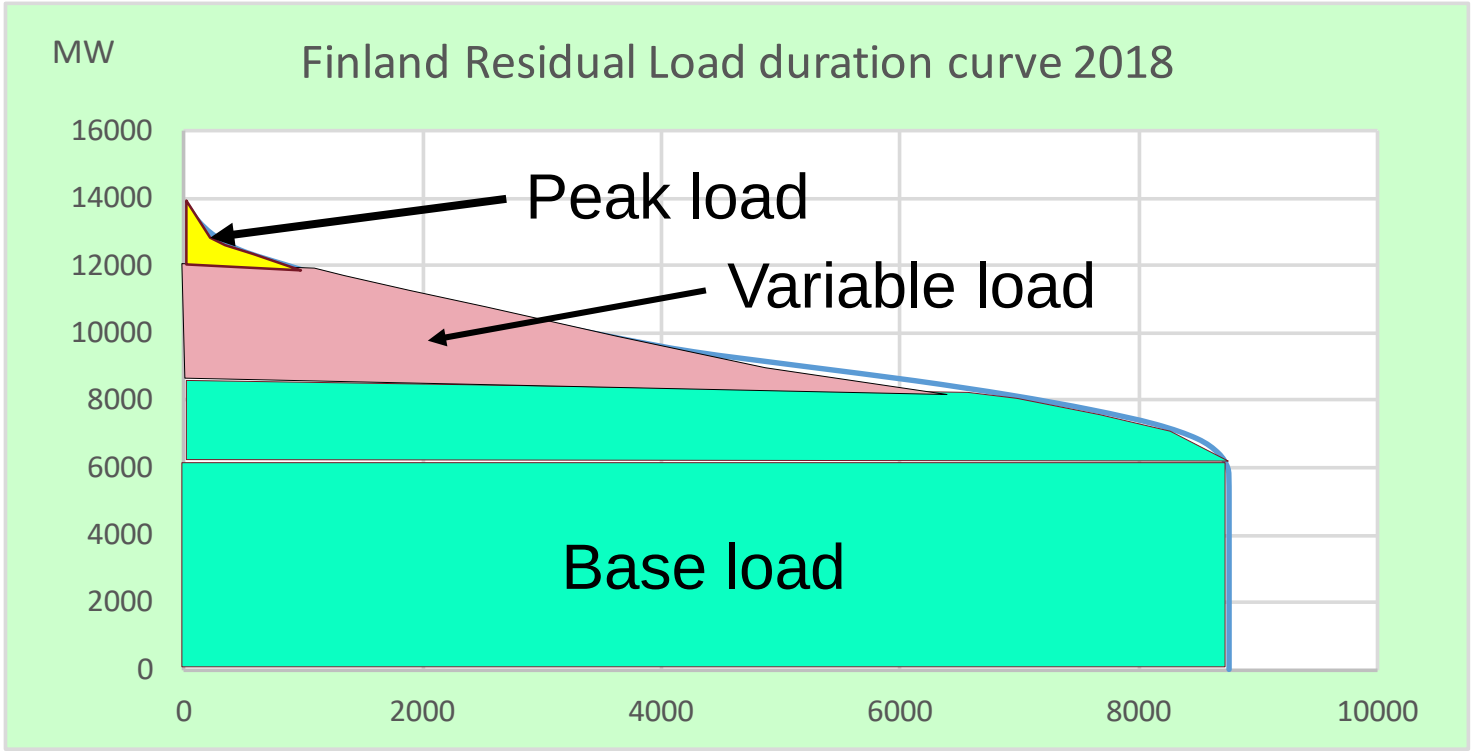
LOAD DURATION CURVE (LDC)

- **Base load can be defined as 8760 hour or 6500 hour operation**



RESIDUAL LOAD DURATION CURVE

- **Residual load duration curve becomes important if we have lots of variable (not controlled) production**



Turun yliopisto
University of Turku

WIND POWER

provided by the owners.

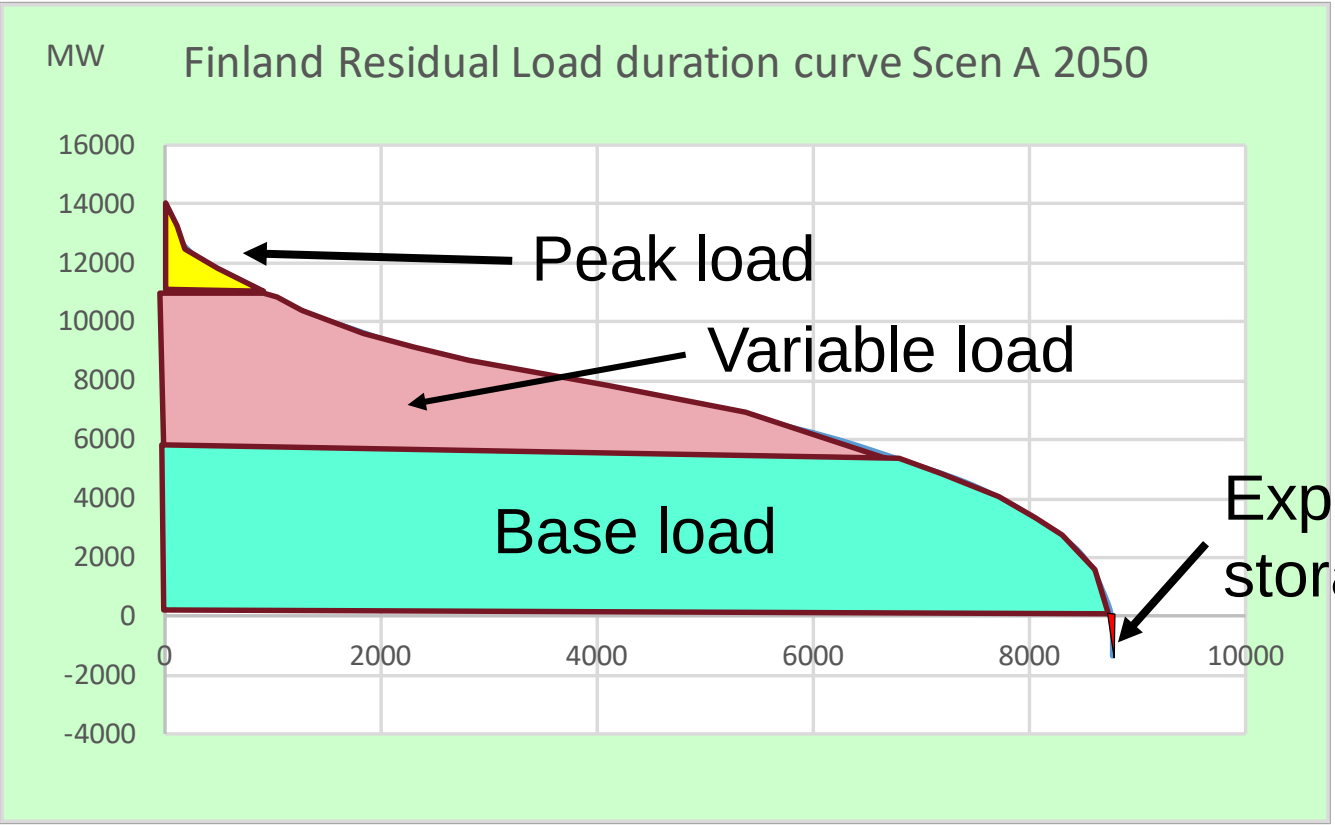
Suomen Tuulivoimayhdistys

First year of production/Planned start of production	Min Total MW	Max Total MW	Min nr. of Turbines	Max nr. of Turbines	Turbine Type	Owner
2019	0	60	14	14		wpd Finland Oy
2020	18	30	4	6	Vestas/Nordex/SiemensGamesas/GE	Winda Power Oy
	0	25	5	5		TuuliWatti Oy
2020	0	81	18	18	Nordex N149	PROKON Wind Energy Finland
2019	30	30	7	7	Nordex	OX2
2019	0	30	7	7	Nordex	OX2
2019	0	23	5	5	Nordex	OX2
2019	27	27	6	6	Nordex	OX2
2019	21.8	21.8	5	5	Lagerwey L147	Energiequelle
2019	50.4	50.4	12	12	Vestas	CPC Lakiakangas 1 Oy
	0	48	16	16		Ålands Vindenergi Andelslag, Ålands Vindkraft Ab, Leov
2020	25	30	7	8		VSB Uusiutuva Energia Suomi Oy
	0	200	33	33		wpd Finland Oy
	24	24	8	8		wpd Finland Oy
2021	34	56	17	17		Voimamylly Oy
2021	60	120	14	20	Vestas/Nordex/SiemensGamesas/GE	Winda Power Oy
2021	30	45	6	9	Vestas/Nordex/SiemensGamesas/GE	Winda Power Oy

First year of production/Planned start of production	Min Total MW	Max Total MW	Min nr. of Turbines	Max nr. of Turbines
Total	**7081.2**	**16516.5**	**2389**	**3296**

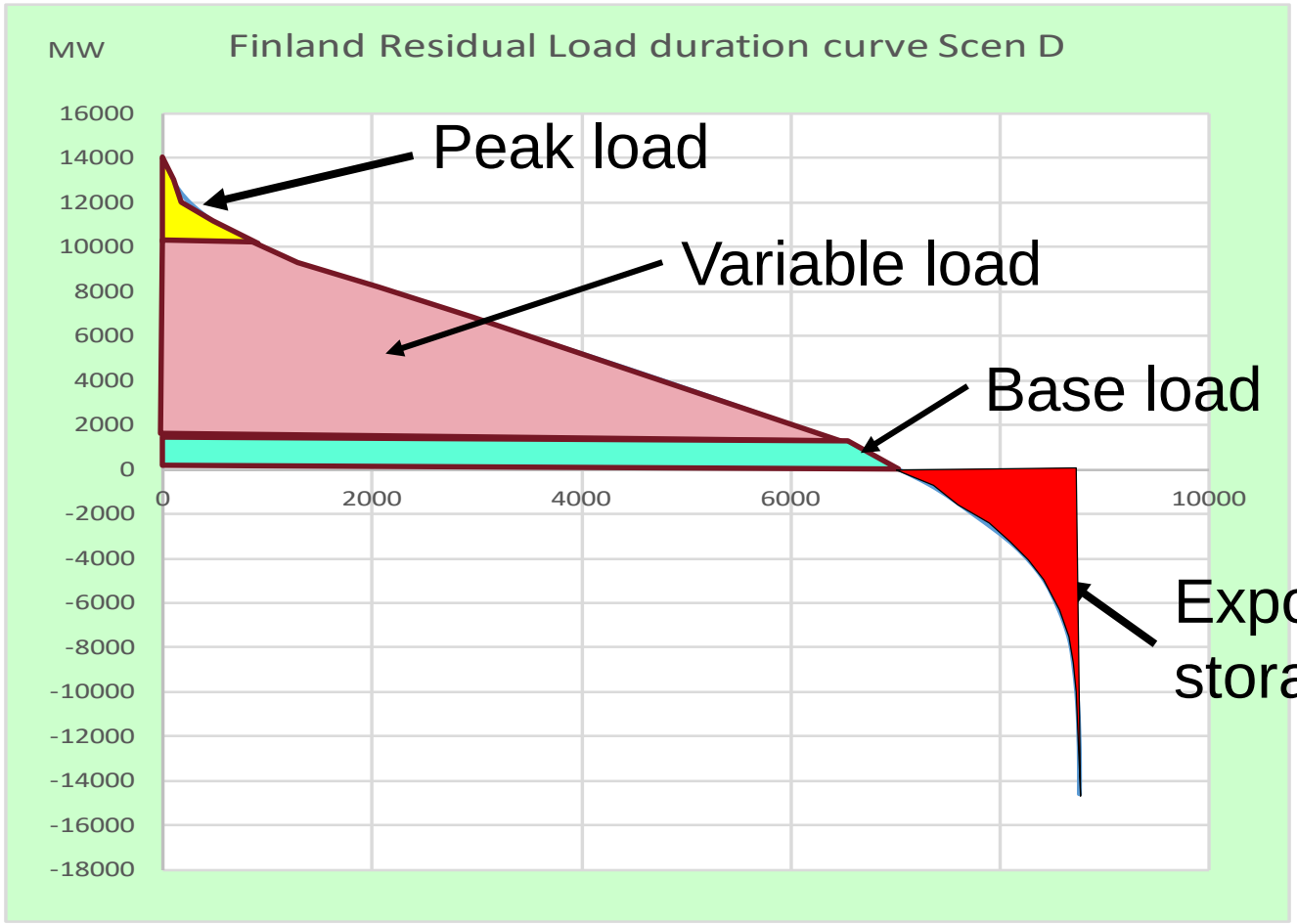
RESIDUAL LOAD DURATION CURVE

- **Scenario for 2050 consumption, wind and solar hourly profiles similar to 2018**
- **Scenario A 2050: wind capacity 9 000 MW and solar 1 200 MW**



RESIDUAL LOAD DURATION CURVE

- **Scenario D for 2050: wind capacity 18 000 MW and solar 7 500 MW**



CONCLUSIONS

- **Electricity consumption may not increase dramatically if there is no remarkable shift from fuel use to electricity in:**
  1) **heating,**
  2) **process industry,**
  3) **transport,**
  4) **or if there is no new electricity intensive industry**
- **Increase in intermittent power production (wind and solar power) will cause remarkable changes in the future electricity production system**

CONCLUSIONS (CONT.)

- **Balancing supply and demand will be of significant concern**
- **New transmission lines for regional balancing will be required**
- **Required ramping rates can be considerable**
- **Storage capacity will be needed**
- **Export/import capacity need to be increased**
- **Baseload power plants (like nuclear) will have economic problems due to reduced capacity factor**

Turun yliopisto
University of Turku

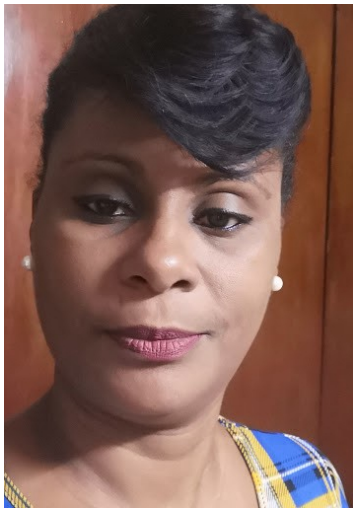
Tampere University

Technological University of Habana José Antonio Echeverría

cujae

Thank you






Jyrki Luukkanen (FFRC)

Yrjö Majanne (Tampere University)

Anaely Saunders (CUBAENERGIA)

Burkhard Auffermann (FFRC)

Contact information:
Jyrki Luukkanen
jyrki.luukkanen@utu.fi