Transition Towards Renewable Energy Supply – A System Dynamics Approach

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Agenda

Potential and Limitations of wind and photovoltaic power

A System Dynamics model for electricity supply

Results and Conclusion

Germany's energy transition plan is necessary but also challenging

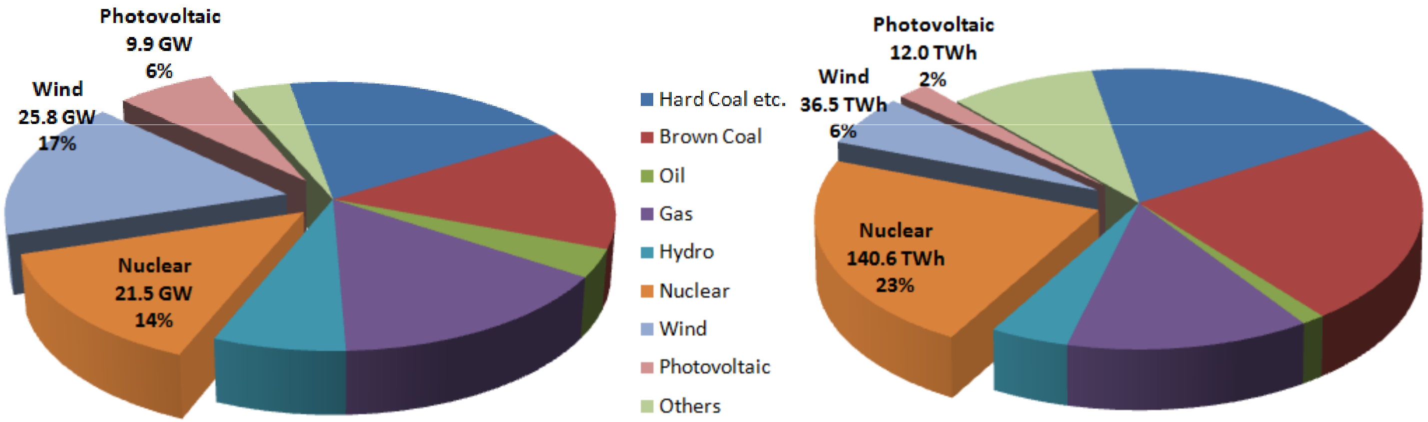
- Resources like fossil fuels or the storage capacity of atmosphere for CO_2 and other GHG are finite
- It's also indisputable that national economies, the developed ones in particular, are all facing their substantial energy transitions.

Germany's Energy Transition Plan is challenging

- Reduction Greenhouse Gas emissions in Germany about 40% in 2020 compared to 1990
  - In combination with the decision to phase out nuclear power supply till the end of 2022
  - The reliability of energy supply must be kept at a high level
- Moreover, it is aimed to established an electric energy supply system fully on the basis of renewable resources till 2050
- Supported by the public, However, a substantial income loss or even an economic down turn will not be accepted in this context

SRU 2010, UBA 2010

Wind and photovoltaic in Germany provide more than 23% of capacity but less than 8% of production in 2009



BMWT 2011, SRU 2010

- Wind and photovoltaic (WDPV) have a potential of 380 GW in Germany but cannot deliver dispatchable or even continuous power supply, at least in a national scale
  – Pumped storage power plants of 30 GW and 10 TWh in *Norway* are therefore a central part of the energy plan presented by SRU (German Advisory Council on Environment)
  – along with 150 GW WDPV and 65 GW dispatchable (in the most cases conventional) capacity in 2025

We are developing highly aggregated System Dynamics models depicting the development of energy market

- Based on our previous work in the area of emissions trading under uncertainties
- Intention: System Dynamics makes the modeling process transparent and intuitive in approaching the politically active public
- Dynamic behavior is key for understanding of electricity supply
- Resource consumption and reliability of electricity supply over the course of a year are simulated
- Different decision options and technologies, for example, SNG (Synthetic Natural Gas), are compared to each other

Key findings:

- The SRU concept will only achieve 33% GHG mitigation despite the high costs due to planned huge storage and power line capacity
- 40% GHG mitigation can be achieved at lower cost thanks higher wind, photovoltaic and SNG capacities

Forrester 1994, Andersen 1997, Ghaffarzadegan 2011

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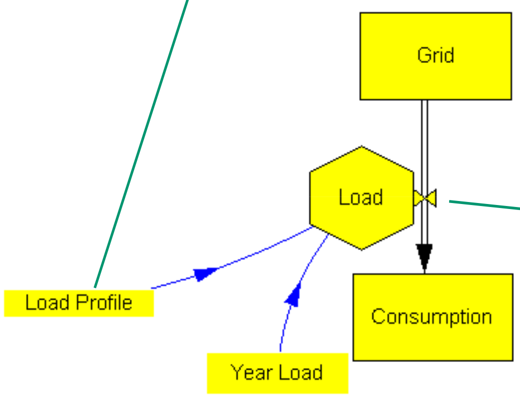
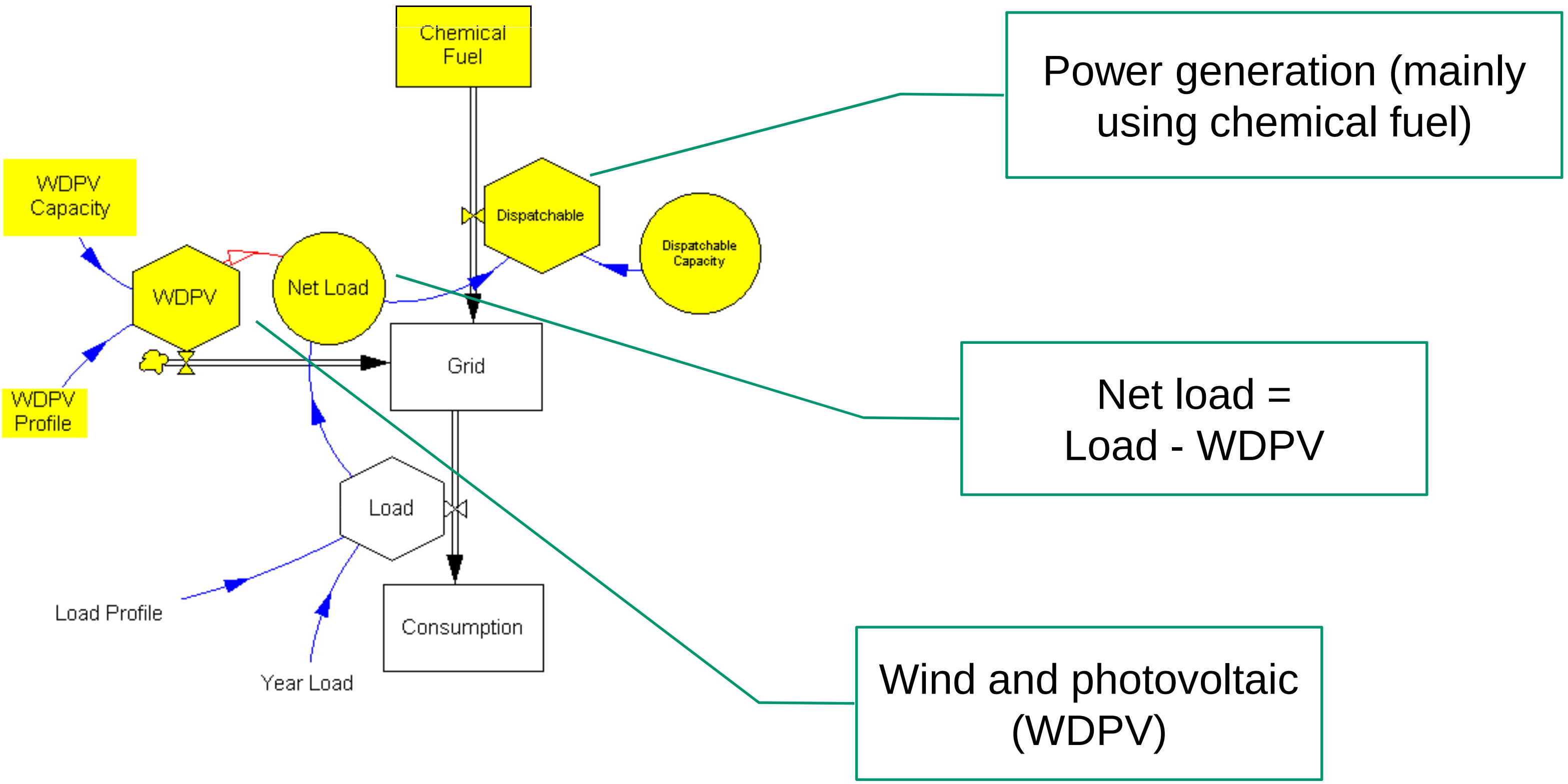
A System Dynamics model for electricity supply system

Not only the total consumption but also the load profile (in a hourly resolution) is key to understand an electricity supply system



Electricity is delivered from the grid

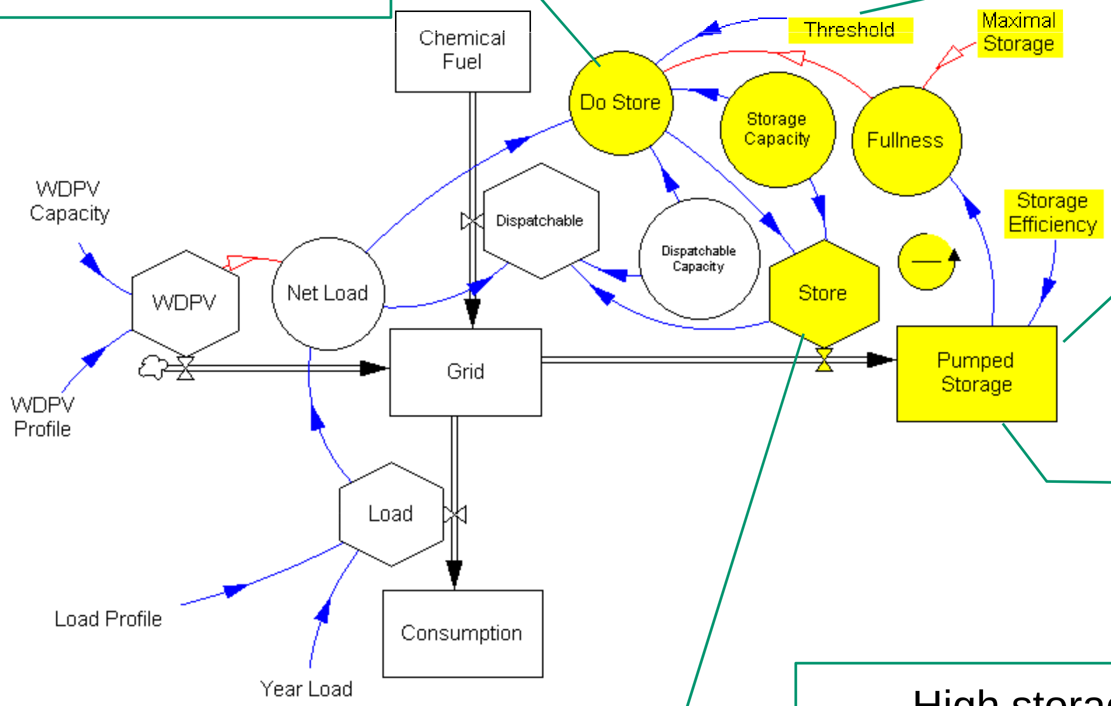
A System Dynamics model for electricity supply system



A System Dynamics model for electricity supply system

When Net Load < 0 …

Using this parameter an optimized strategy of storage management can be achieved

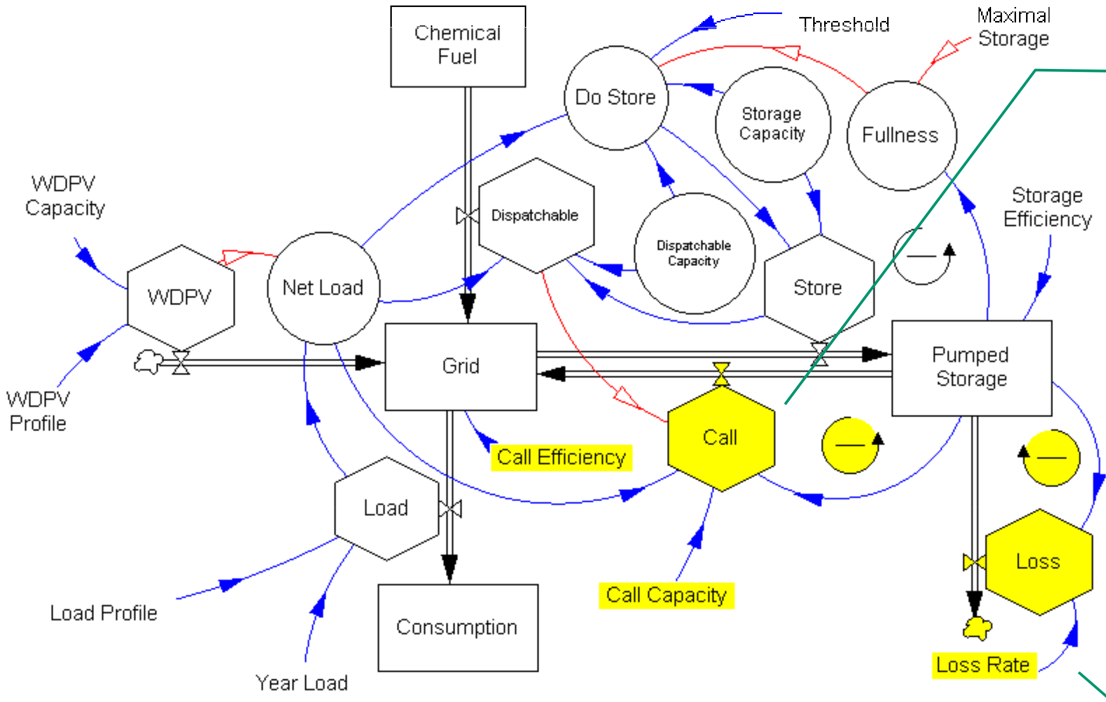


SRU concept: 22 TWh in 2050

1 GWh ≈ 4 x 10^8 m^4 Water Water in a storage lake of 1 km^2 area and 4 m depth at the height of 100 m

High storage power is necessary to benefit from timely overcapacity of WDPV

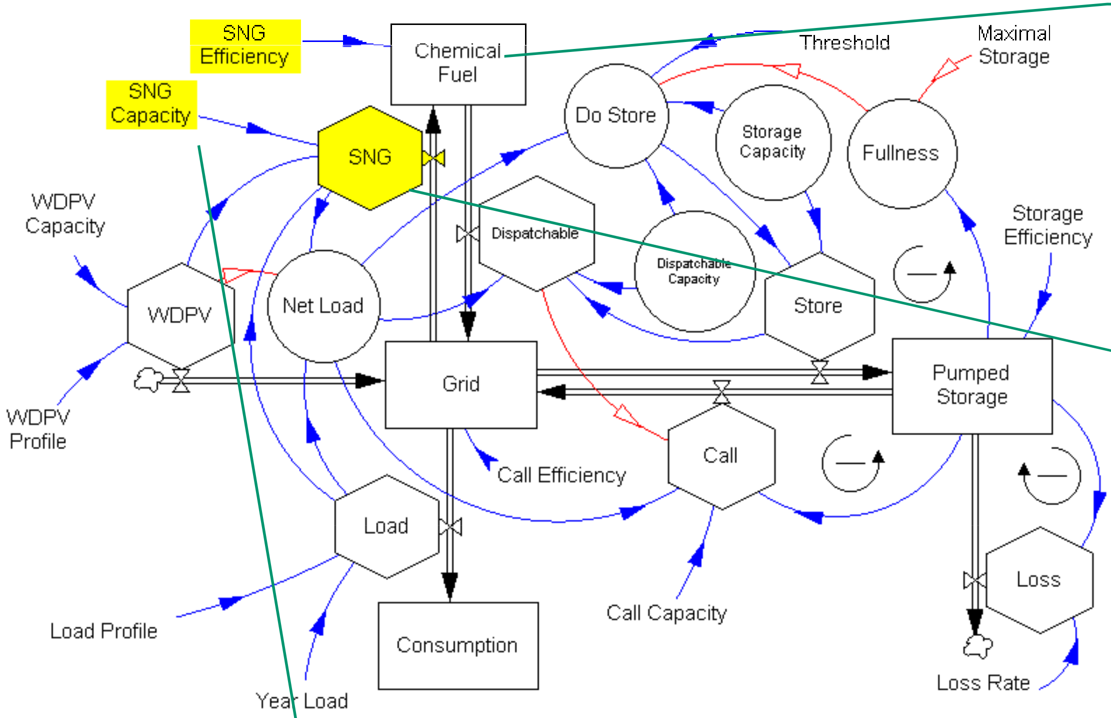
A System Dynamics model for electricity supply system



High call power is necessary to compensate fluctuations of Net Load

A pumped storage has a very low loss rate

A System Dynamics model for electricity supply system

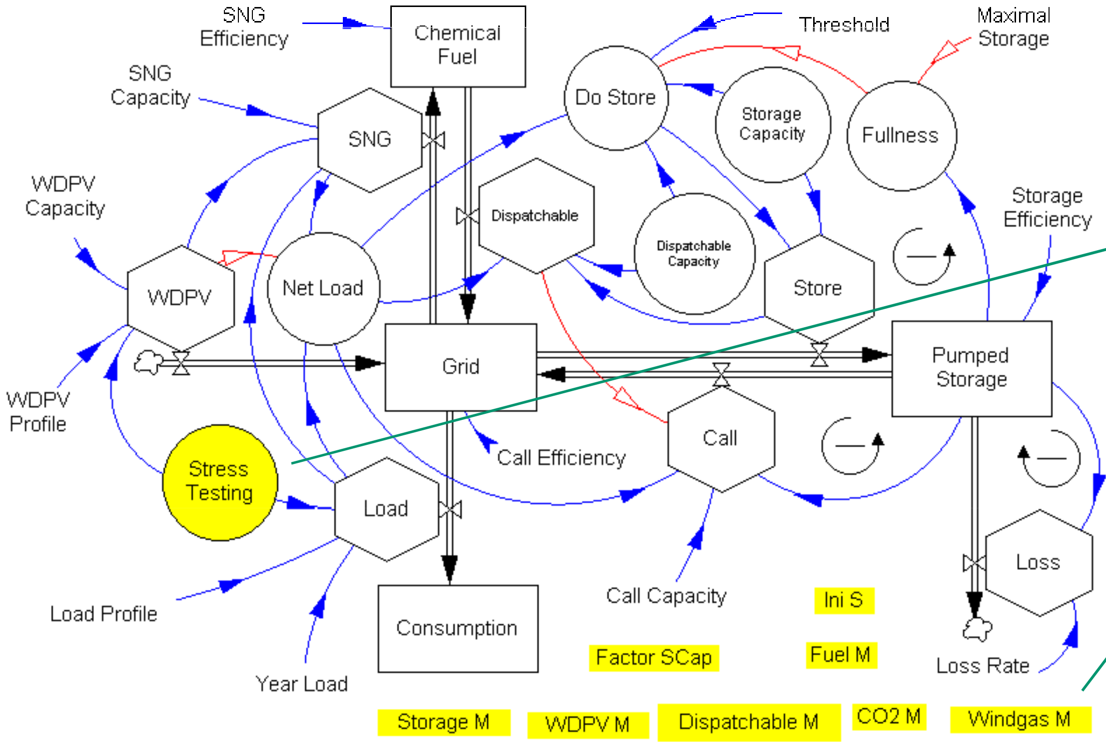


1 GWh ≈ chemical fuel in 5 tanker trucks

Substitute Natural Gas (SNG) can be produced when Net Load is negative

Both efficiency and capacity are essential

A System Dynamics model for electricity supply system



This parameter is used to increase Load and to reduce WDPV power for “Stress Testing”.

Scenario parameters like the prices of fossil fuels or emission permits are used in simulations

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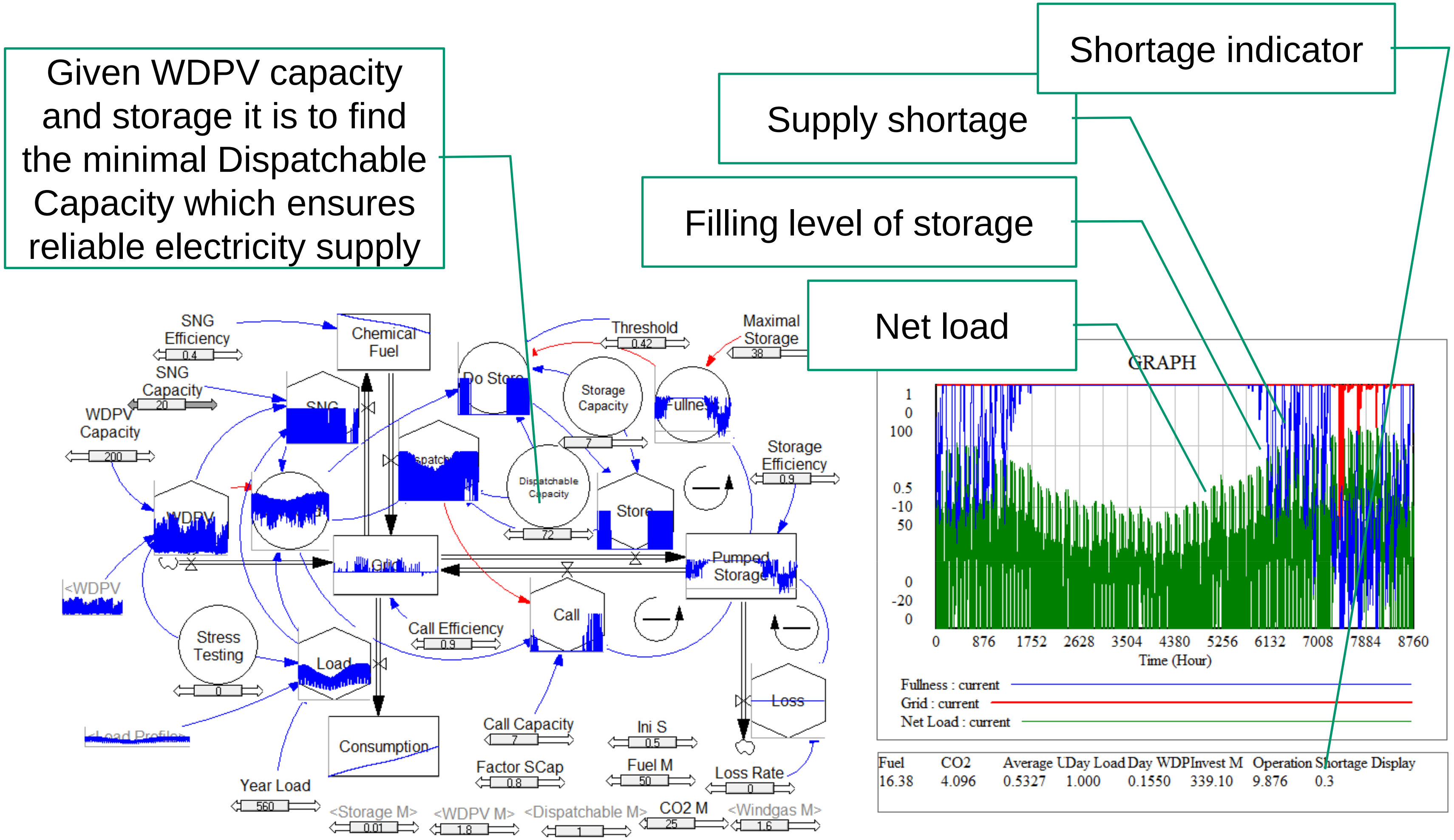
System Dynamics modeling and simulation of electricity supply as a decision support method



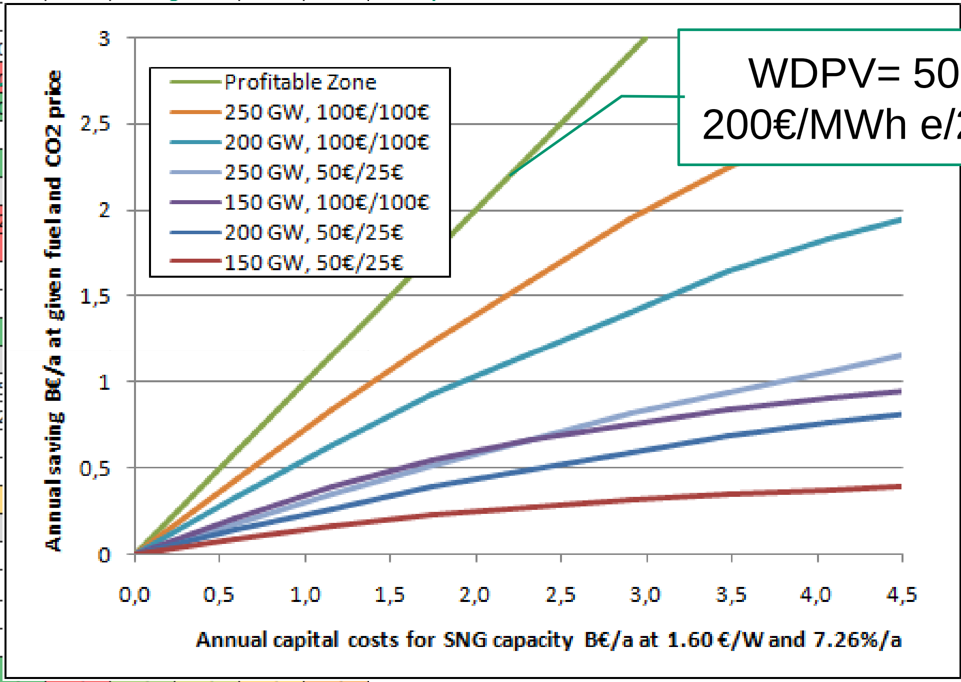
BMWT 2011, SRU 2010, UBA 2010, Ventana Systems 2009

Different decision options and technologies, for example, SNG, are compared to each other

		TWh/a	1990	2010	Cnv	SRU	Rnw	SNG	Rnw+	SNG+
	Load	TWh/a	550	625	560	560	560	560	560	560
1,0 €/W	Dispatchable	GW	102,2	96	82	60	74	74	72	72
?	Nuclear	GW	23,7	22	0	0	0	0	0	0
1,8 €/W	WDPV	GW		36	36	150	150	150	200	200
0,80 €/W	Cap Storage	GW		7	7	37	7	7	7	7
0,80 €/W	Cap Call	GW		7	7	37	7	7	7	7
0,1 €/Wh	Max Storage	GWh		38	38	11000	38	38	38	38
	Threshold	1			0,94	0,10	0,60	0,60	0,42	0,44
1,6 €/W	SNG	GW								
	Shortage	GW								
	5% Stress	GW								
	Utilization	1								
	Operation	B Euro/a								
	Invest M	B Euro								
50 €/MWh_e	Fuel	B Euro/a								
25 €/tonCO2	CO2	B Euro/a	*6,81*	*6,15*						
7,26%	Capital Cost	B Euro/a								
Scenario I	Sum	B Euro/a								
		€/KWh								
200%	Fuel	B Euro/a								
400%	CO2	B Euro/a								
7,26%	Capital Cost	B Euro/a								
Scenario II	Sum	B Euro/a								
		€/KWh								
200%	Fuel	B Euro/a								
400%	CO2	B Euro/a								
10,61%	Capital Cost	B Euro/a								
Scenario III	Sum	B Euro/a								
		€/KWh								

Capital and operating costs are included in the simulations

Costs for fuel and emission permits are taken into account using three scenarios



WDPV= 500 GW or 200€/MWh e/200 €/tCO_2

BMWT 2011, SRU 2010, UBA 2010

System Dynamics provides a transparent decision support method regarding different energy concepts

Moderate mitigation despite huge storage capacity

High mitigation thanks high WDPV and SNG

Low GHG mitigation without further WDPV

2025			CNV	SRU	Rnw	SNG	Rnw+	SNG+
Wind and Solar Power		GW	36	150	150	150	200	200
Dispatchable Power		GW	96	65	74	74	72	72
Pumped Storage		GWh	36	10 000	36	36	36	36
SNG Capacity		GW	0	0	0	10	0	20
GHG Mitigation compared to 1990		%	6.5	32.3	31.2	31.7	38.4	39.8
Cost scenarios	50 €/MWh, 25 €/tCO_2, 6% annual interest rate	€/KWh	0.088	0.123	0.102	0.105	0.112	0.116
	100 €/MWh, 100 €/tCO_2, 6% annual interest rate		0.167	0.180	0.161	0.163	0.164	0.167
	100 €/MWh, 100 €/tCO_2, 10% annual interest rate		0.177	0.210	0.182	0.185	0.190	0.196

BMWT 2011, SRU 2010, UBA 2010

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SRU 2010 100% erneuerbare Stromversorgung bis 2050: klimaverträglich, sicher, bezahlbar. Sachverständigenrat für Umweltfragen (SRU)

UBA 2010 Umweltbundesamt Deutschland Energieziel 2050: 100 % Strom aus erneuerbaren Quellen

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Questions?

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