Electricity market impacts of increased demand flexibility enabled by smart grid

Åsa Grytli Tveten, Iliana Ilieva, and Torjus Folsland Bolkesjø

Presenting: Iliana Ilieva, Business PhD Candidate

Norwegian University of Life Sciences/Brady Energy Norway AS

Demand flexibility as a resource

What is demand flexibility?

Adjusting the consumption pattern to variations in supply on a short-term basis.

“The power system flexibility option with the highest benefit cost ratio” (IEA)

Purpose of the scientific work

Analyze how increased demand flexibility will affect the power system in Northern Europe in terms of:

- technology mix/need for peak power
- electricity prices
- system costs
- producer revenues

Method

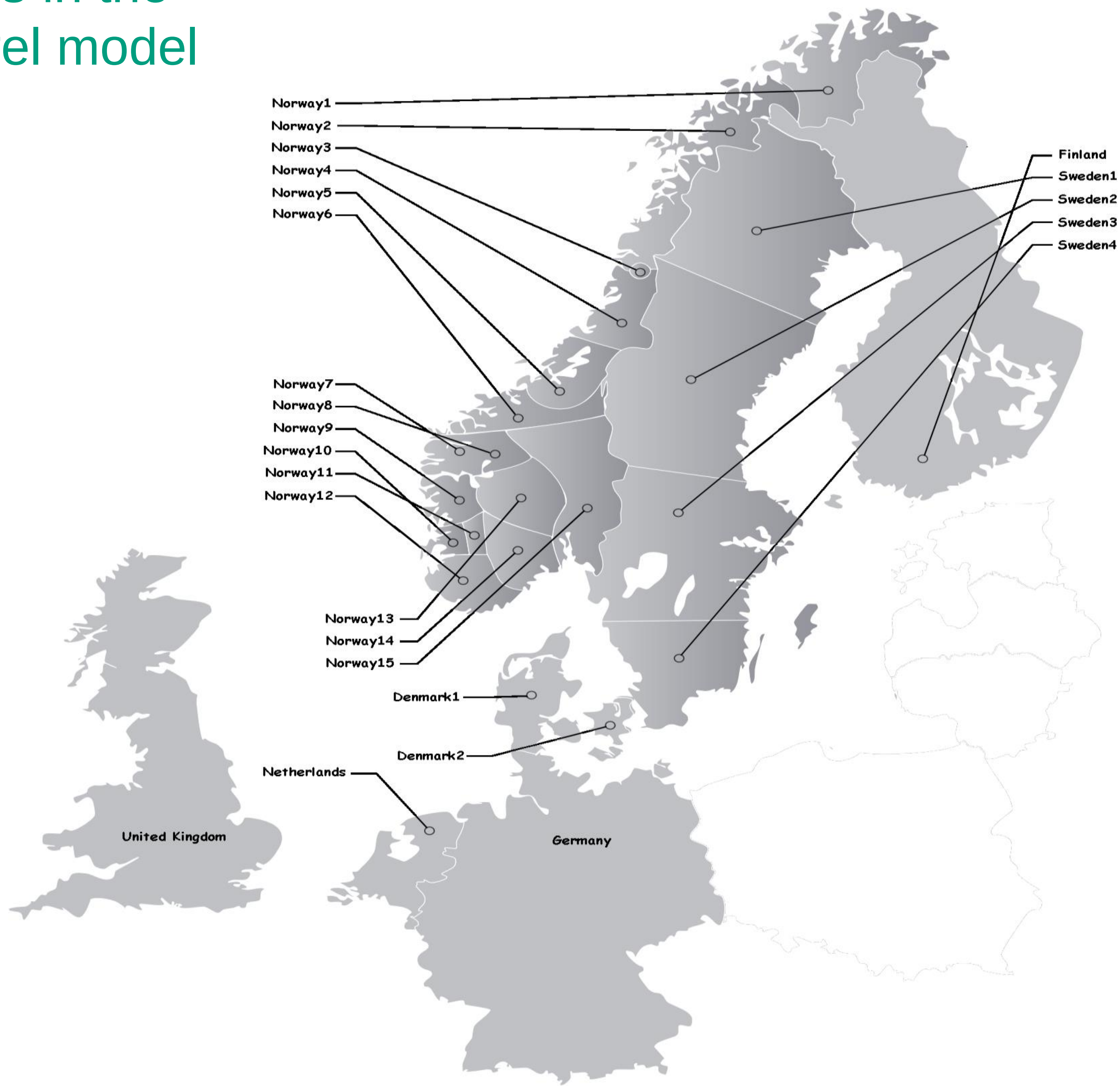
The analysis is made by applying a comprehensive power market model – **Balmorel**

- Simulates generation, transmission and consumption of electricity
- Hourly resolution
- Input data
- Four scenarios with flexibility as % electricity consumption moved within a day:

Scenario	DK	FI	NO	SE	GE	UK	NE
Baseline	-	-	-	-	-	-	-
Moderate response	4.0 %	10 %	12 %	7.5 %	6.0 %	6.0 %	6.0 %
Full response	8.0 %	19 %	24 %	15 %	12 %	12 %	12 %
High response	16 %	38 %	48 %	30 %	24 %	24 %	24 %

"Empowering Customer Choice in Electricity Markets"
"Impact of Smart Grid Technologies on Peak Load to 2050" (IEA 2011)

Regions in the Balmorel model



About the Balmorel model

- Linear partial equilibrium model
- Calculates the electricity production per technology, time unit and region

$$max\left[\sum_{s\in S}\sum_{t\in T}\sum_{r\in R(C)}\left\{D_{r,t,s}(d_{r,t,s})-\left(\sum_{i\in I}K_i^P(g_{r,i,t,s})+\sum_{A\in R,A\neq r}K_{A,r}^T\left(X_t^{(A,r)}\right)+K^D\sum_{i\in I}g_{r,i,t,s}\right)\right\}\right]$$

- A set of linear constraints:

✓Energy balance $\sum_i g_{r,i,t}+\sum_{A\in R,A\neq r}\left(X_t^{(A,r)}-X_t^{(r,A)}\right)=d_{r,t},\ \ \forall i\in I$

✓Transmission capacity $X_t^{(A,B)}\leq\bar{X}_t^{(A,B)},\forall A,B\in R,\ A\neq B$

✓Maximum capacity per generation unit $g_{r,i}\leq\bar{g}_{r,i}$

✓Ramping

✓Min and max production levels

✓Hydro reservoir storage level and more

Demand flexibility in the model

Energy balance:

$$\sum_i g_{r,i,t} + \sum_{A \in R, A \neq r} \left(X_t^{(A,r)} - X_t^{(r,A)} \right) = d_{r,t} + \Delta d_{r,t}, \quad \forall i \in I$$

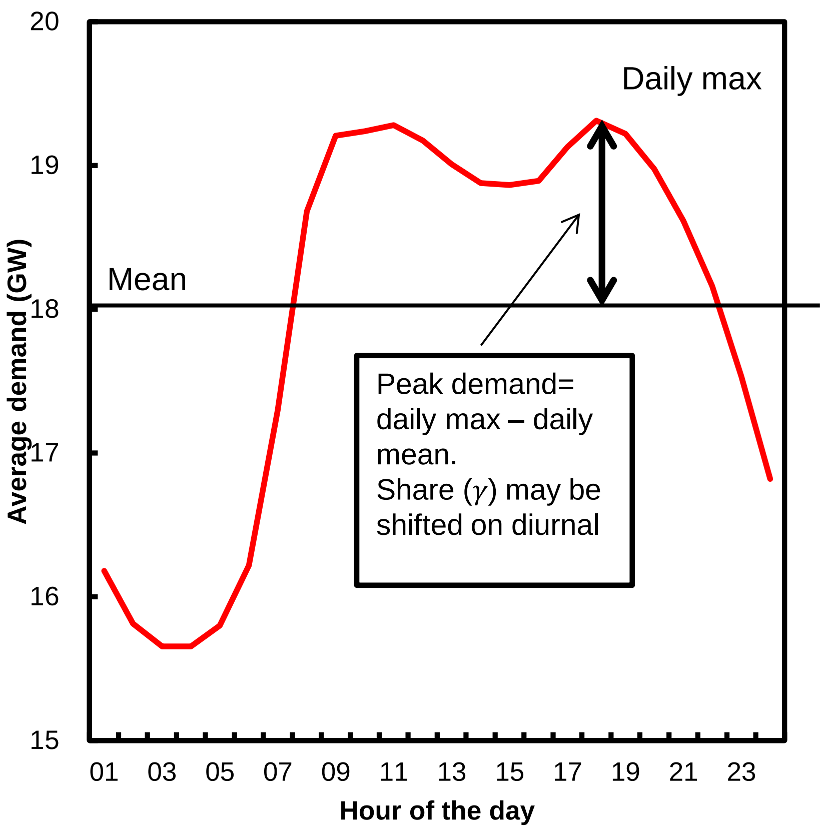
Limitations on maximum allowed shift in demand in hour t and day n:

$$|\Delta d_{h,n}| \leq \left(d_n^{max} - \overline{d}_n \right) \cdot \gamma$$
$$\left(\overline{d}_n = \frac{1}{H} \sum_h^H d_{h,n} \,, \; h = \{1,2,\ldots,H\}, H = 24 \right)$$

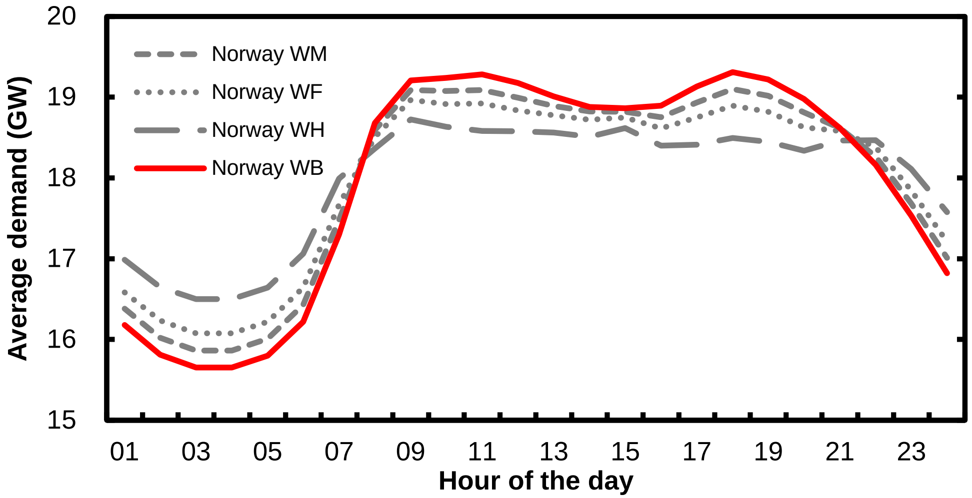
Total daily consumption is fixed:

$\sum_H \Delta d_{h,n} = 0$ or, analogously: $\sum_H \Delta \mathrm{d}_{h,n}^{up} = -\sum_H \Delta \mathrm{d}_{h,n}^{down}$

$h = \{1,2,\ldots,H\}, H = 24$

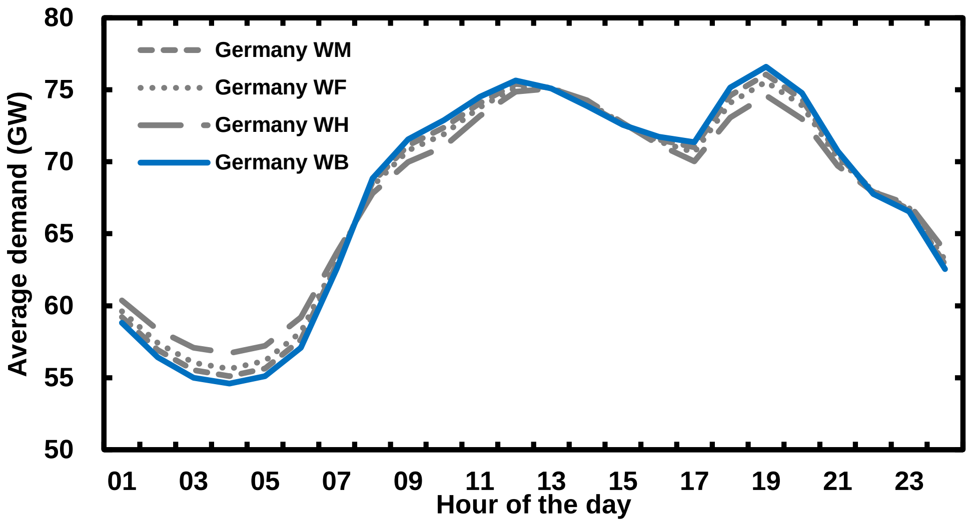


Results Part I:

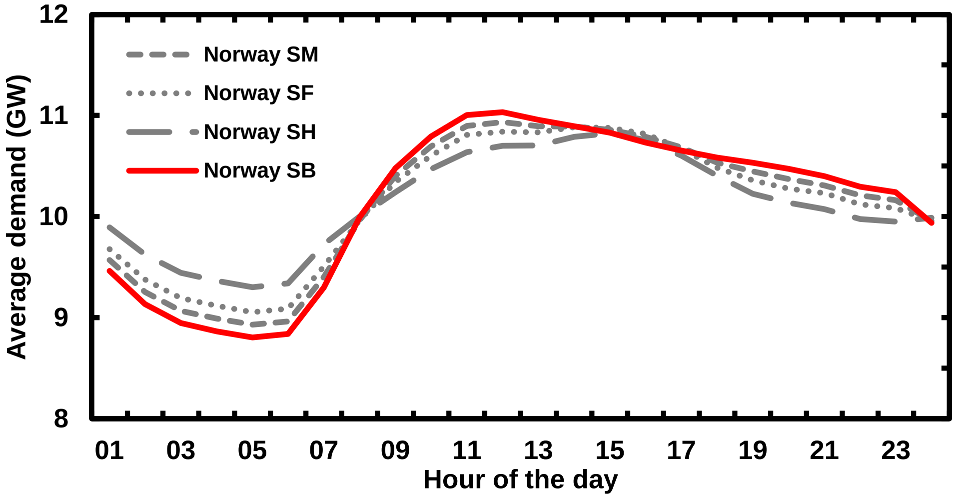


Changes in the hourly demand profile

Norway vs Germany Winter weeks

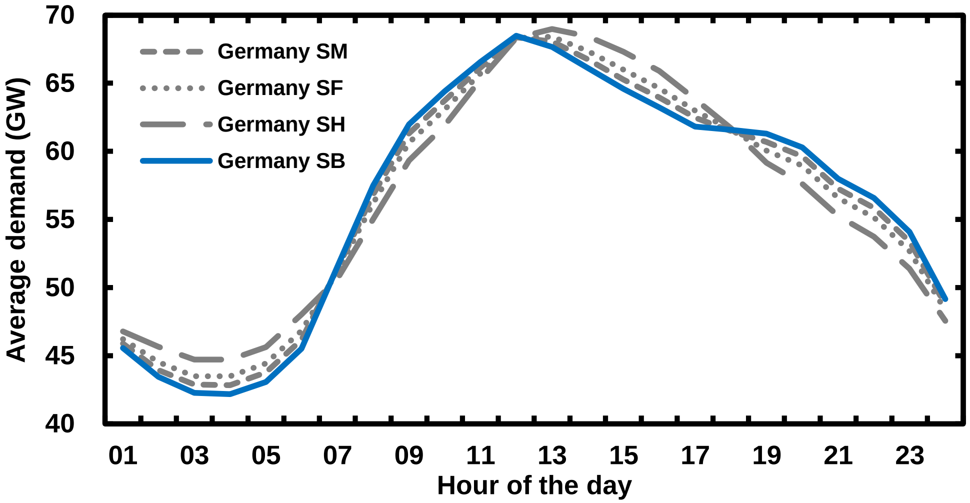


Results Part I:



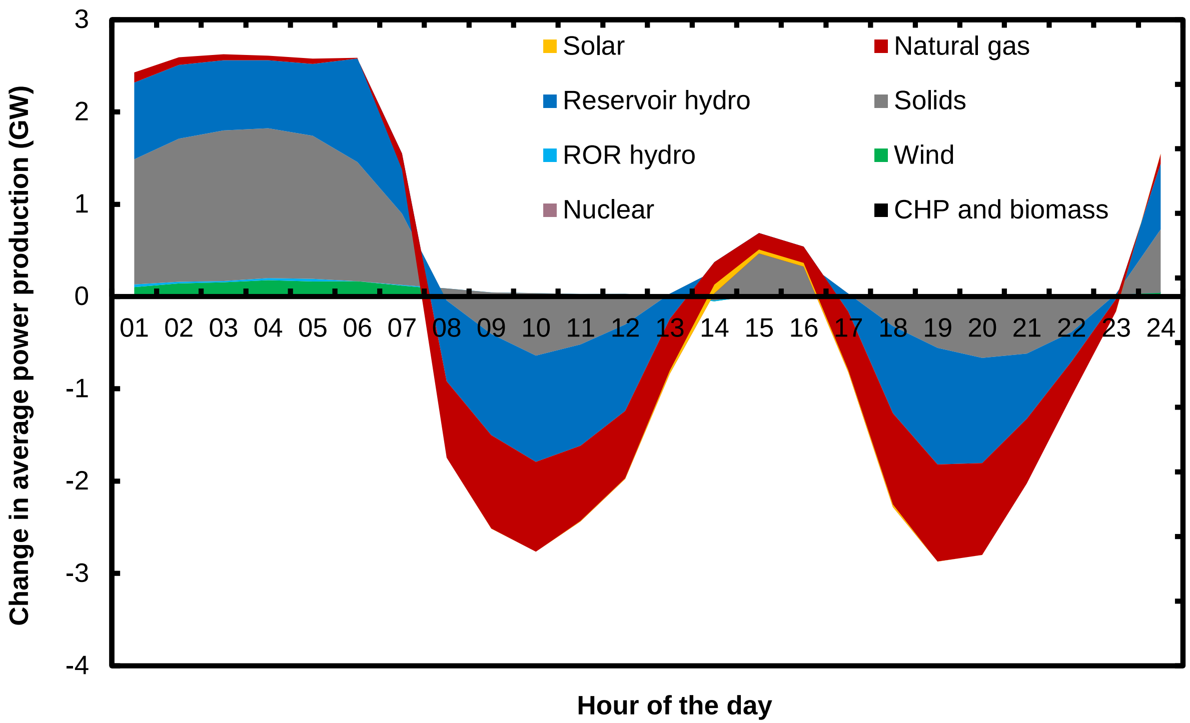
Changes in the hourly demand profile

Norway vs Germany Summer weeks



Results Part II - Production mix when flexibility increases

Change in the hourly Northern European production mix caused by the increase in demand response, Full flexibility scenario (all model countries, all-year average)



Reservoir hydro: Volumes moved from day to night

Nat. gas ⬇

IRE generation ⬆

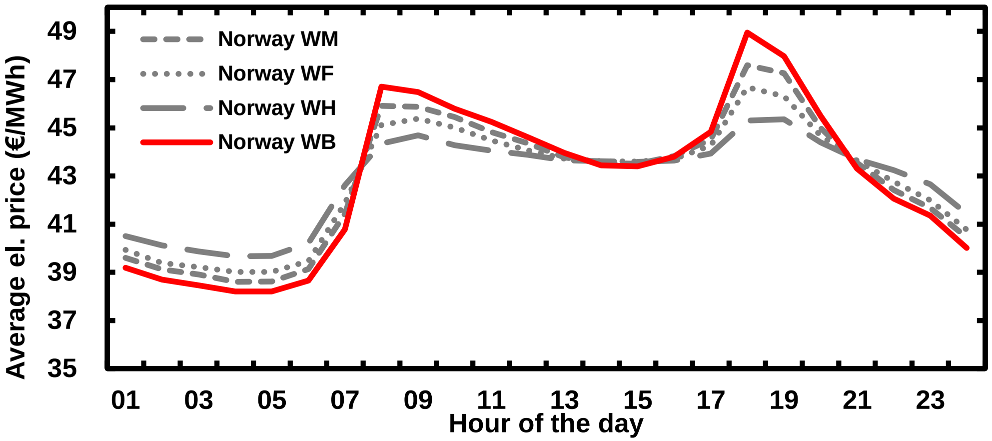
Solids (coal&lignite) ⬆

GHG ⬆

Results Part III: Price Effects

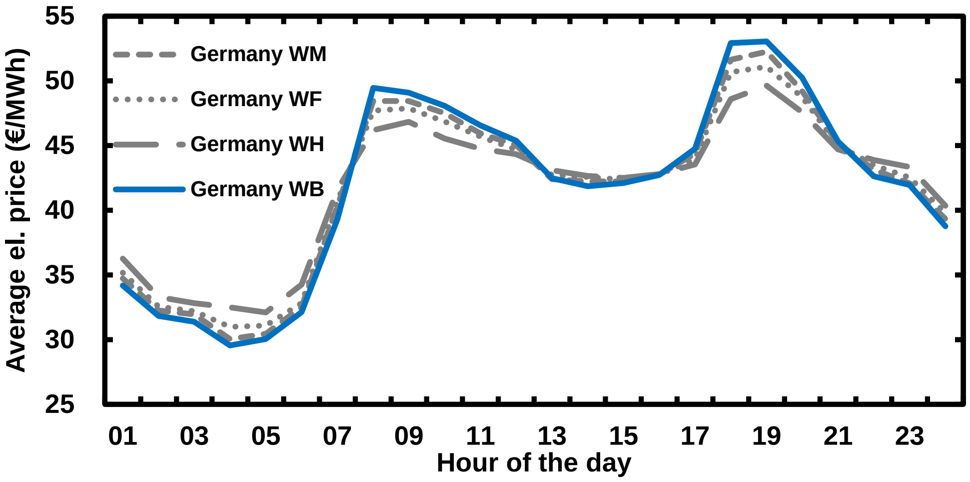
		Baseline scenario	Full flexibility scenario	Percentage change
Germany	Average prices (€/MWh)	36.3	+0.01	+0.02 %
	Consumption weighted price (€/MWh)	37.8	-0.2	-0.5 %
	Daily maximum price (€/MWh)	48	-1.6	-3.4 %
	Variance of price $(€/MWh)^2$	152	-17	-11 %
Norway	Average prices (€/MWh)	35.3	+0.2	+0.5 %
	Consumption weighted price (€/MWh)	36.4	+0.1	+0.2 %
	Daily maximum price (€/MWh)	38.8	-0.6	-1.6 %
	Variance of price $(€/MWh)^2$	37	-7	-18 %

Results Part III:



Changes in the hourly electricity prices

Norway vs Germany Winter weeks

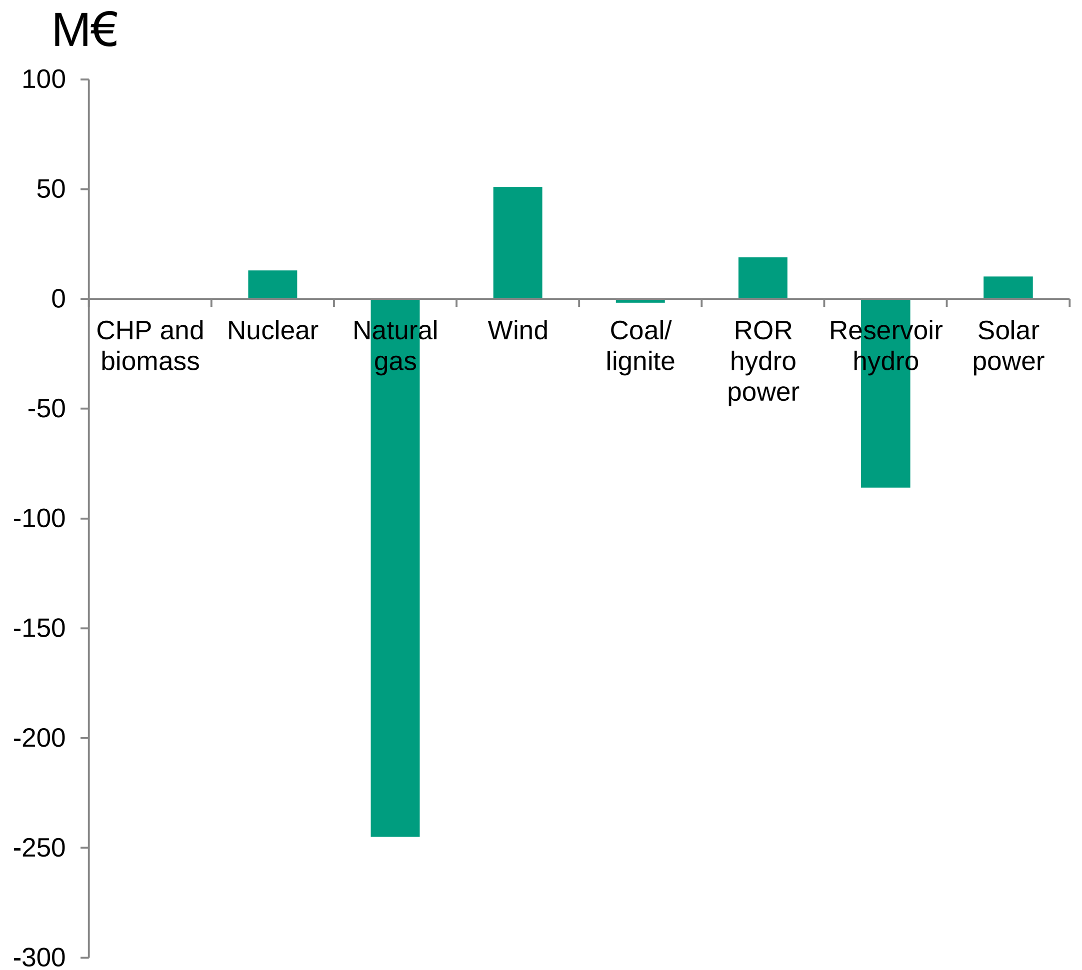


Results Part IV: Change in consumers' costs (M€) Full flexibility scenario

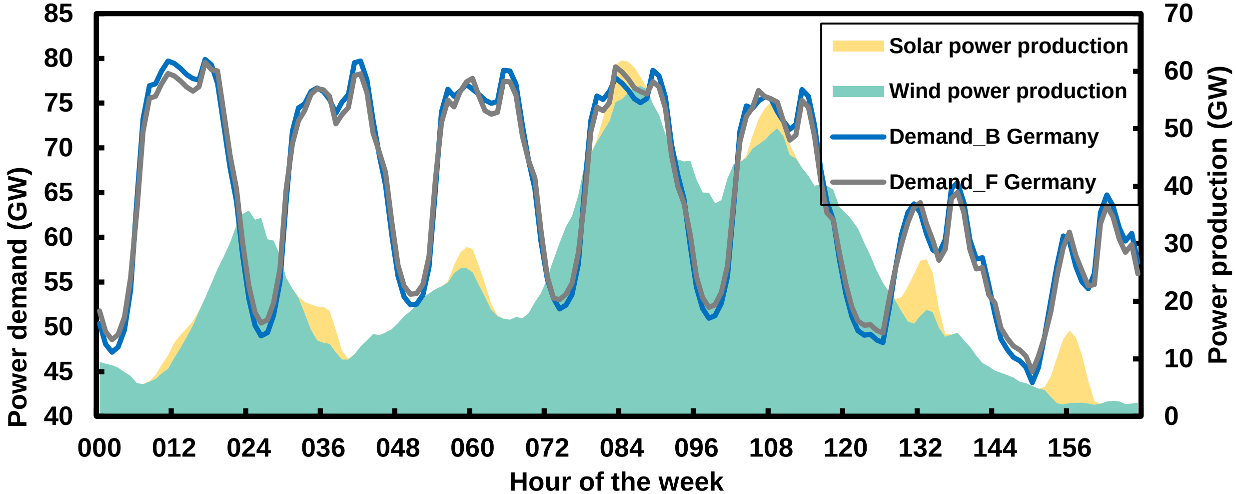
	Baseline scenario	Change in costs	%-change
All countries	582	-5.1	-1,0
Norway	102	-1.5	-1,5
Denmark	14	-0.2	-1,4
Germany	136	-2.9	-2,9
Netherlands	44	-0.7	-1,6
UK	133	-0.2	-0,2

Annual system cost reduction of 9 billion €

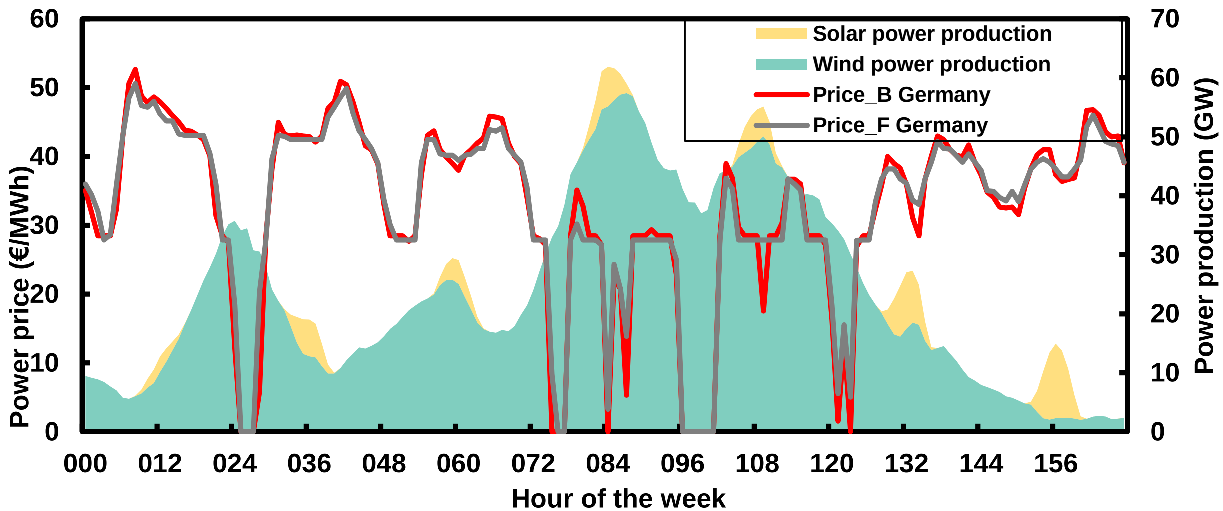
Results Part V:Producers' revenues



Market clearing conditions: The case for Germany, A winter week



Hourly variation in power demand for the Baseline and Full flexibility scenarios

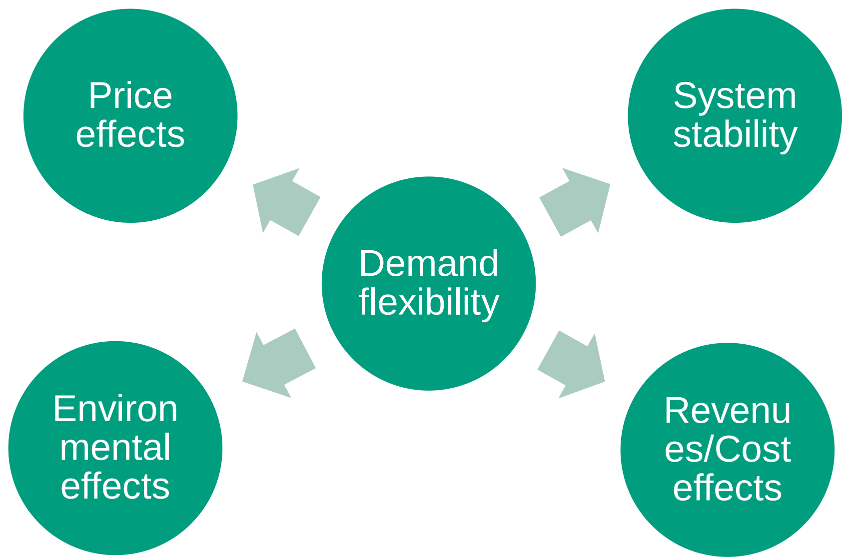


Hourly variation in power prices for the Baseline and Full flexibility scenarios

Summary

-Lower avg prices
-Reduced variability

-Less hours with peak power
-Reduced max residual demand
-Facilitate IRE



Lower GHG emissions?

-Different revenues per technology
-Consumer costs decrease slightly
-Reduced system costs

Symbol	Definition
s, S	Season of the year, $s = \{1,2,\ldots,52\}$, $S = 52$ (total weeks of the year)
t, T	Hour of the week, $t = \{1,2,\ldots,T\}$, $T = 168$ (total hours of the week)
h, H	Hour of the day, $h = \{1,2,\ldots,H\}$, $H = 24$ (total hours of the day)
c, C	Country, $c = \{DK, FI, GE, NE, NO, SE, UK\}$, $C = All\ model\ countries$
r, R	Region, r = $\{Denmark1, Denmark2, \ldots, UK\}$, $R = All\ model\ regions$
A	Alias for r (Region, a = $\{Denmark1, Denmark2, \ldots, UK\}$)
D(d)	Consumer's utility function
D	Electricity demand (MWh)
I	Power generation technology type, i = $\{i1, i2, \ldots, iI\}$, $I = All\ generation\ technologies$
G	Electricity generation (MWh)
$X^{(a,r)}$	Electricity transmission from region a to region r (MWh)
K^P, K^T, K^D	Electricity production, transmission and distribution cost (€/MWh)
$\overline{g}, \underline{g}$	Maximum and minimum power generation level
v_s	Water amount in reservoir at end of time period s (MWh)
ω_s	Water inflow in time period s (MWh)
i_{HY}	Reservoir hydro power generation units
i_{IM}	Intermittent renewable power generation units
$\underline{v}, \overline{v}$	Maximum and minimum level of hydro reservoir (MWh)
γ	Potential for demand shifting (percentage)