The duck curve bites back: When flexible demand overloads the grid

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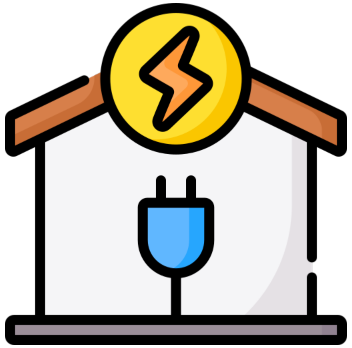
Two main trends are shaping the energy transition

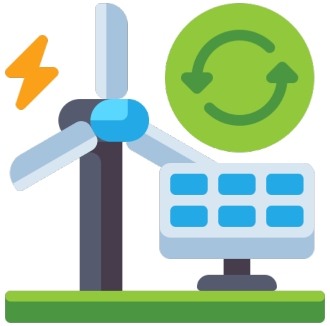


Electrification of Services

Increased efficiency

Higher power demand

Need to upgrade the infrastructure



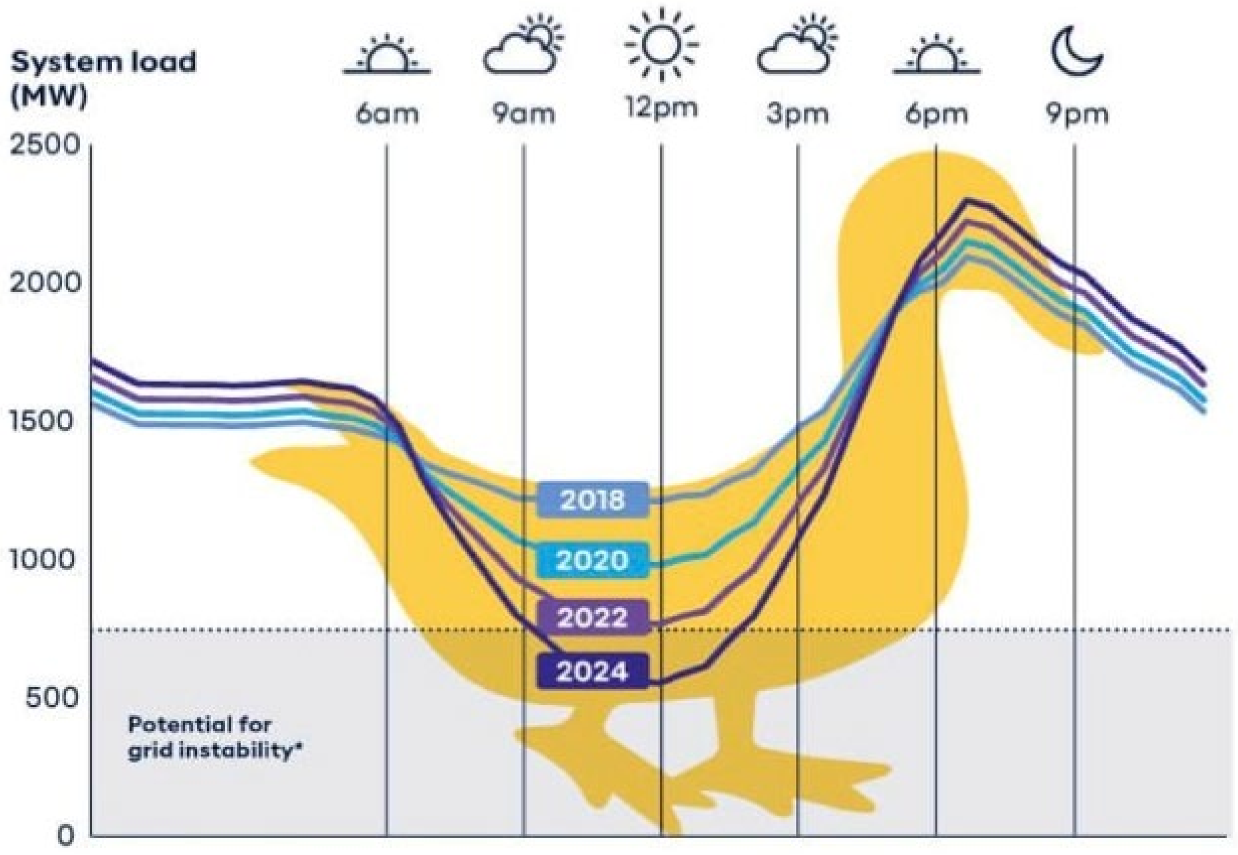
Renewable Energy Integration

Reduced direct emissions

Decentralisation of production

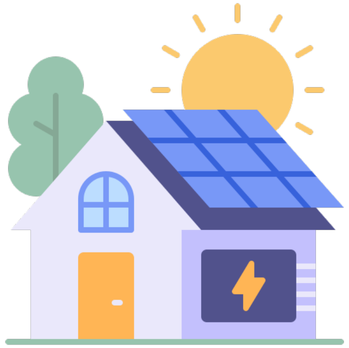
Intermittency

Supply and demand of electricity are becoming less aligned

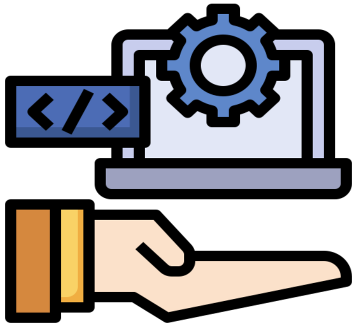


Flexibility can support the transition by addressing this issue

Households are set to increasingly engage in cross-sector prosumage flexibility



Increasing **adoption** of electric vehicles (EVs), heat pumps, photovoltaic (PV) systems, and storage



Automation enables real-time responses to market signals via shifting or reducing demand

Flexibility plays a key role in the EU and Luxembourg’s energy strategy, but…

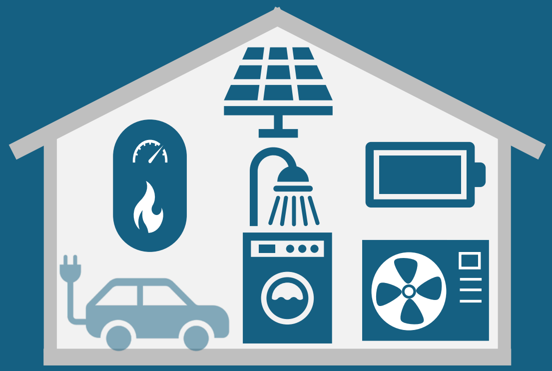
- How does it look like in practice?
- Will it help us **balance** the energy system? Or will it create new **issues**?

In collaboration with the main Luxembourgish grid operator, we use an **active building model** to understand what demand side flexibility might do to the grid

Methodology and Approach

- Active building model to simulate **hourly electricity consumption/supply** of a population of households over **a year in 2040**
- Based on a **Sociodemographic, Technological, Climatic and Energy-Economic Scenario** (TYNDP electricity prices)
- A variable share (0%, 30%, 60%) of households acts as **smart flexibility supplier**, reacting to wholesale market prices

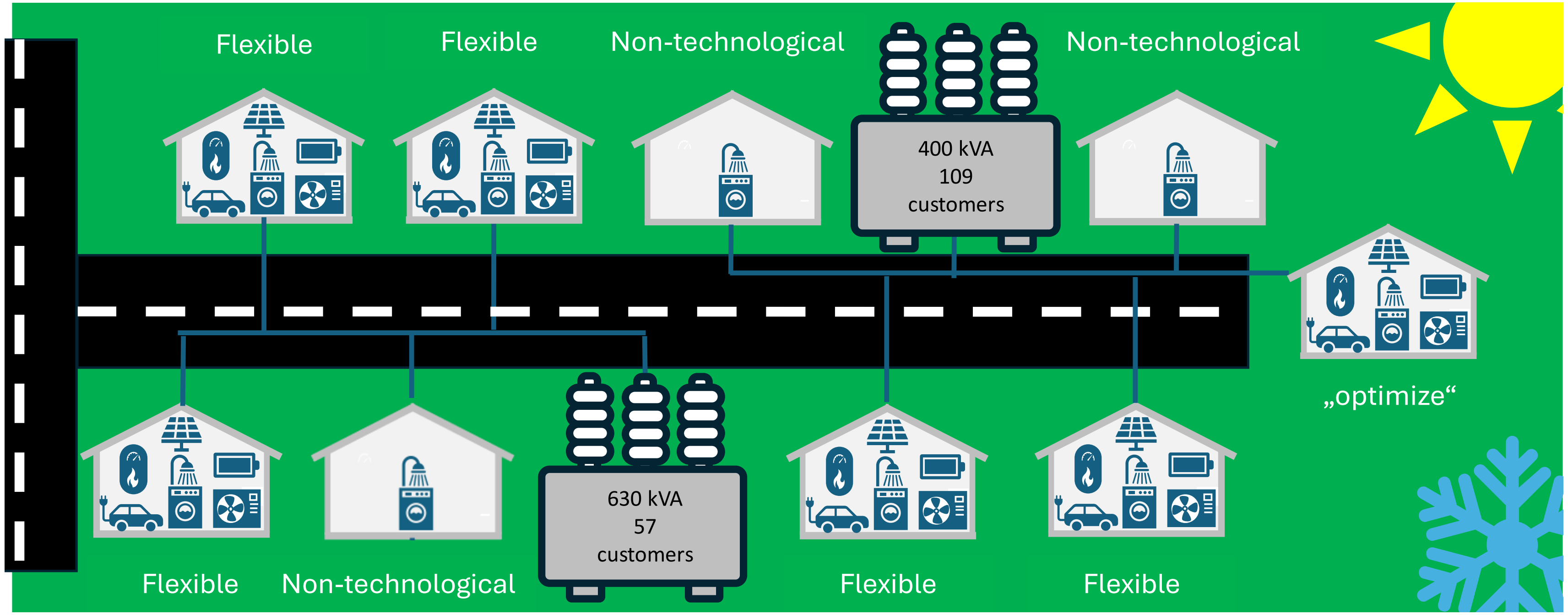
Structure of the Simulation: Types of Customers

	Non-technological	Technological and Flexible
Assets		
Behavioural Assumptions	Max SOCEV + minimize energy consumption Given: assets, schedules	Minimize cost of energy incl. trading Given: assets, wholesale market prices, schedules

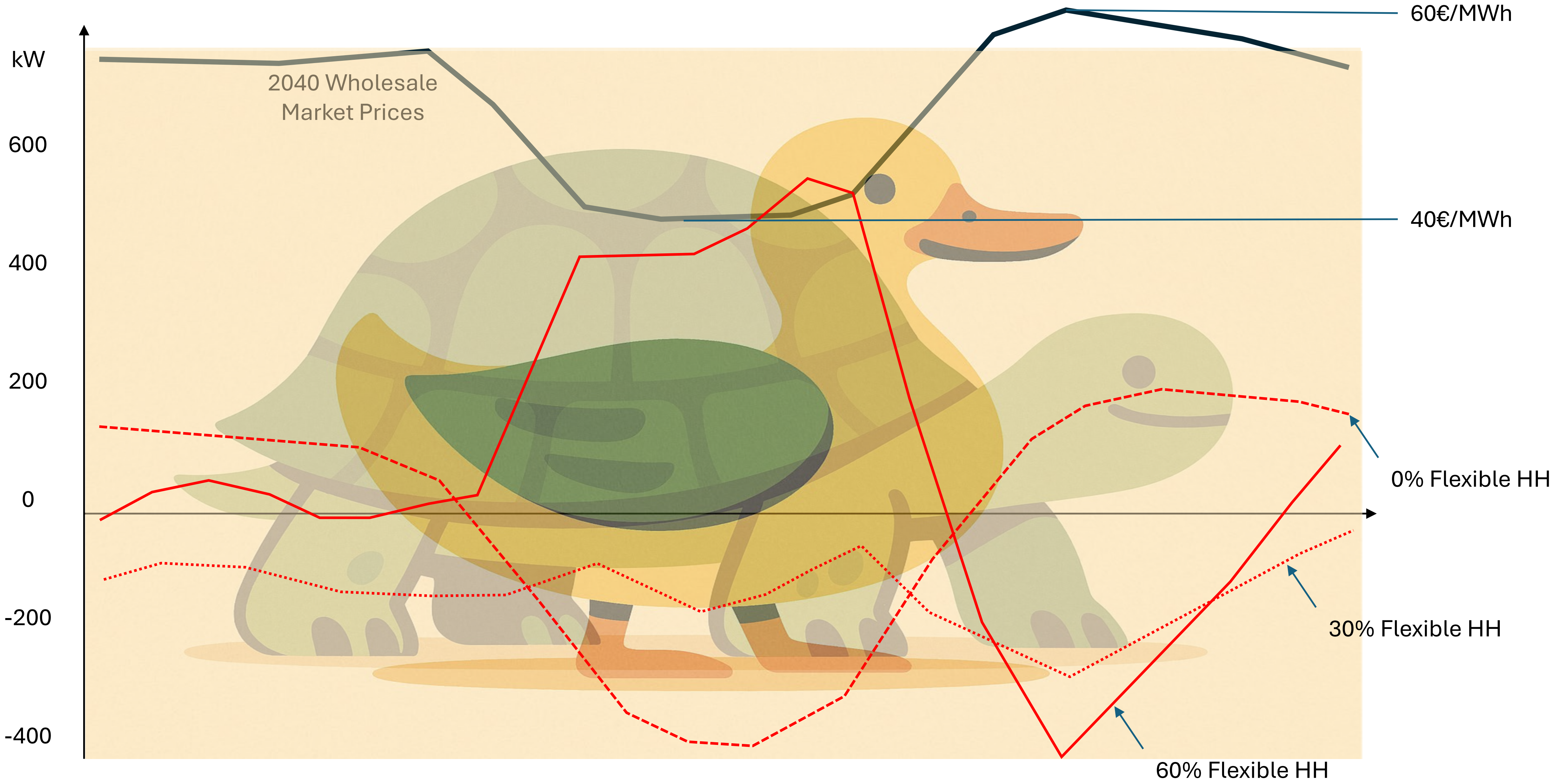
Structure of the Simulation: Technological household

Structure of the Simulation: Topology

- 166 rural households - each with same probability to be tech/flex in our scenarios
- We determine annual electricity demand/supply for each of the 166 households
- Sum them up over all households → transformer utilisation in each hour
- **And compare this to transformer capacities**



Weekday average demand profile - transformer – 2040



Demand duration - 2040

1. **Flexible households** can effectively **act as electricity traders**.
   - They have sufficient storage capacity such that their aggregated behaviour **inverts the duck curve, with price spikes exceeding transformer capacities**.

Transformer overload will become prevalent in 2040

Required transformer capacities reaching **2-4 times current levels**,
Albeit **for only a few hours annually**.

Transformer demand duration (h) relative to capacity (100%)	60% Flexibles						
	Transformers						
	1	2	3	4	5	6	7
200% > X > 100%	2383	2373	2144	1732	1149	1051	837
300% > X > 200%	611	478	271	142	51	45	30
400% > X > 300%	104	69	37	4			
400% > X > 400%	13	6	1				
# Transformer required	4	4	4	3	2	2	2
Av. Transformers req.							21/7 = 3

Results from sensitivity analysis

Revenue-optimising households, leveraging electric vehicles and thermal storage, exploit daily price fluctuations

- **Lower EV SOC and higher thermal storage levels**
- Increasing heat demand **by more than 15%**
- **Annual revenues of €500-€800 in 2040**

Discussion and Limitations

- Demand side flexibility supports solar integration by increasing midday consumption
- But it introduces **new stress points**, specifically at the distribution transformer level
- **If we do not account for its side effects**

- **Prices are not endogenous.** However, the flexibility at the wholesale level will not automatically transfer to the transformer level and won't solve the issue

- **Assumptions**: all flexible households have the same technologies, the households are country representative, flexible households are cost minimising, perfect foresight of electricity prices and weather → results are an upper bound

Conclusions and Future Research

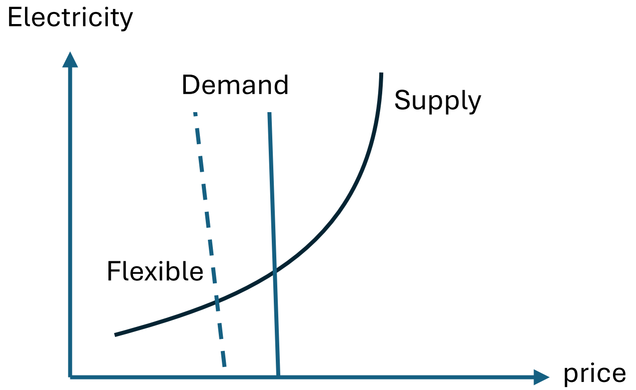
- The shape of electricity demand is evolving, **from duck to turtle**
- This will solve some, but introduce new grid challenges if not addressed correctly

- We need to:
  - **coordinate and localise flexibility** activation,
  - support consumer **empowerment without unfairly shifting costs** onto non-flexible households

- Future research:
  - **Individual** technologies in shaping the profitability of arbitrage,
  - Check the **profitability** of the investment in the assets,
  - Potential **unintended consequences** of flexibility (increased heating)
  - Significance of **out-of-home EV charging**, particularly at workplaces,
  - Effects of **mitigation mechanisms** like grid tariffs, curtailment, or local capacity markets

Bonus: Question to the Audience

- We use the TYNDP scenario ”2009 DE 2040” prices
- Our “turtle” demand will cause price adjustments on the wholesale markets (e.g. prices increase at lunchtime)
- We cannot run a TYNDP simulation accounting for this
- **Would you accept this procedure to account for endogenous prices, as a reviewer?**
  - We estimate a supply curve for dispatchable generation (from annual data).
  - We remove EV load shifting/add our flexibility to demand (possible).
  - We determine flexibility-adjusted prices from the “intersection“ of supply and demand.
  - … and so forth…
- Are there any things we should avoid?



Thanks for your attention!

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Backup: Structure of the Simulation: Data

Parameters	Unit	Value	Source
Battery Capacity	kWh	10	
Battery LFP	cycles	5000-10000	
EV Capacity	kWh	70	
EV NMC/NCA	cycles	1000-2000	
Hot Water	kWh	5	100 Liter
Heating Storage	kWh	9	150 Liter
U-Values (n/m/o)	kW/K	0.10/0.19/0.40	Source+ assumpt.
Thermal Mass	kW/K	40	Source
HP Power (n/m/o)	kWe	2.5/4.5/8	
Temp Min/Max	°C	20/30	Own assumptions
Import Limit	kW	± 27	
Solar PV	kW	10	
EV consumption	kWh	⌀2200-3000kWh	Profiles
Power in House	kW	Total d/charg. power EVs $\leq$ 11	Creos
COP HP	-	2.5	
Electricity cons.	kWh	$1150kWh + 950\frac{kWh}{pers} \cdot Pers$	Stat. Bundesamt
Hot water cons	kWh	0.20 · Electricity cons.	Stat. Bundesamt
EV/HH size distr.		Will be explained in the report	
Water Storage Losses		1% of stored energy/h	

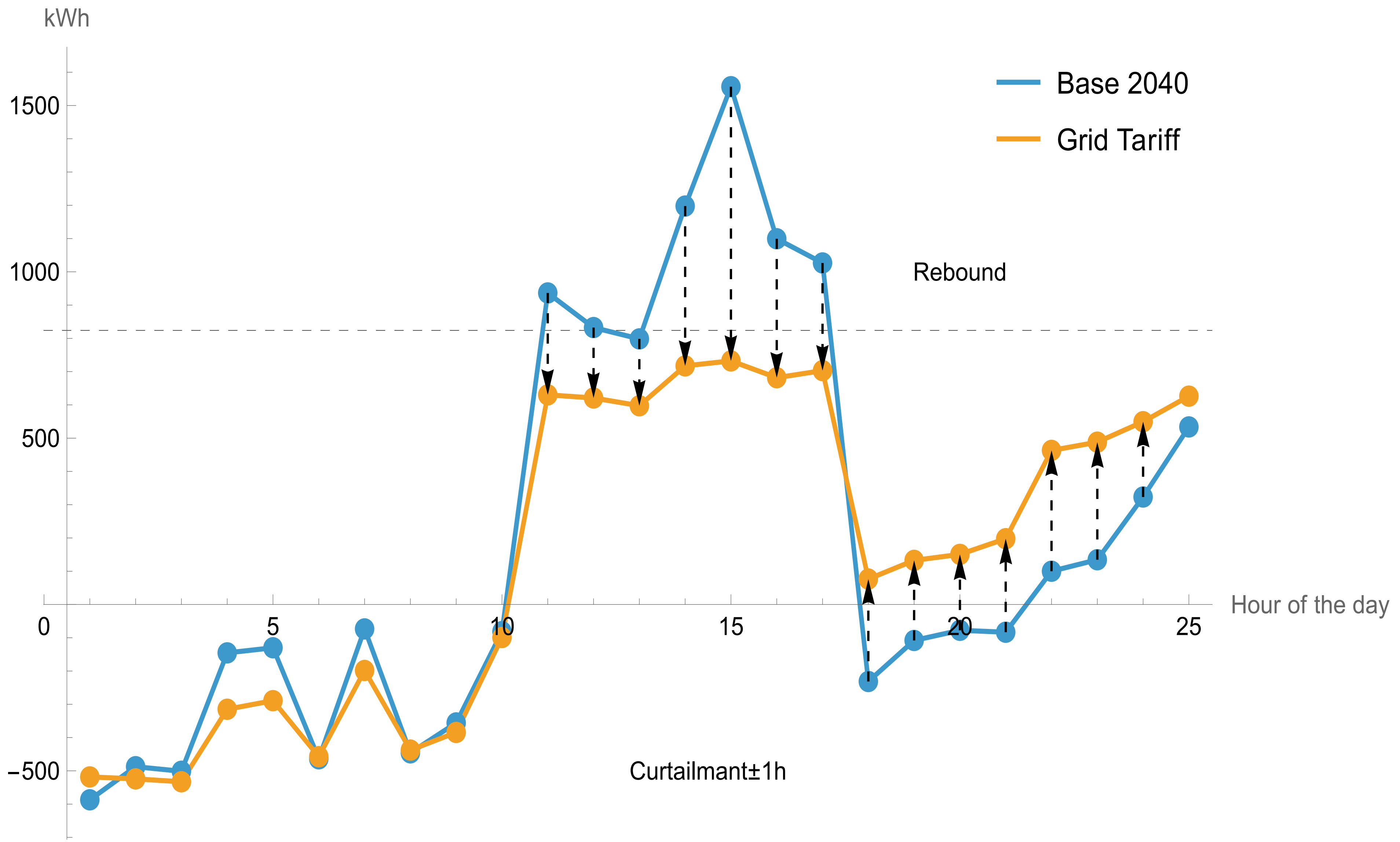
Annual Time Series	Source
Syntethic EV profiles	Gaete-Morales et al., 2021
Electricity Prices 2035, 2040	TYNDP (WY - 2009, DE)
Capacity Factors Solar	Renewables Ninja, Lux 2009
Residential Load Profile	H0 Creos, 2020
Outdoor Temperature	Renewables Ninja, Lux 2009

Parameters	Unit	Value		Source
Grid Tariff Penalty	€/kWh	0.1139		
Grid Tariff		Old	New	
Grid Tariff Capac	€/kWy	0.01	24.46	
Gird tarif cons markup	€/kWh	0.0759	0	
Grid Base	€/HH	60		
Curtail EV	kWe	5.5		
Curtail HP	kWe	4.2		
Curtail PV		30% of installed capacity		

Load duration of transformers under export grid tariff.

Load duration of transformers for import and export grid tariff

Comparison of the transformer load curves for hours 168-192 of the year. The dashed line indicates the capacity of the reference transformer nr 1



Comparison of the transformer load curves for hours 168-192. The dashed line indicates the capacity of the reference transformer nr 1