Why we need battery swapping for the future energy and transport systems

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References:

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- *The transition: Why we need battery swapping for the future energy and transport systems*, A.M. Vallera, Universidade de Lisboa, Faculdade de Ciências, Instituto Dom Luiz, Lisboa, Portugal, 2023, ISBN 978-972-9348-24-2, https://doi.org/10.56526/10451/55274
- *Why we need battery swapping technology*, A.M. Vallera, P.M. Nunes, and M.C. Brito, Energy Policy 157, October 2021, 112481, https://doi.org/10.1016/j.enpol.2021.112481
- *Raising the limits to PV integration with a battery swapping model for mobility*, A.M. Vallera and M.C. Brito (to be published)

Outline:

A. A national system

1. The inspiration: carbon neutrality in Portugal 2050
2. The central problem of a system dominated by solar and wind generation
3. The impact of decarbonizing transport in a decarbonized electric system: the outcomes of different road transport models (ICE, Plug-in, H2 and BSwap)

B. A small region

- Served by the national transport grid, with PV the only local, viable, renewable resource
- How much PV may be installed?
- How is this affected by different road transport models?
- What impact will these have on costs and emissions?

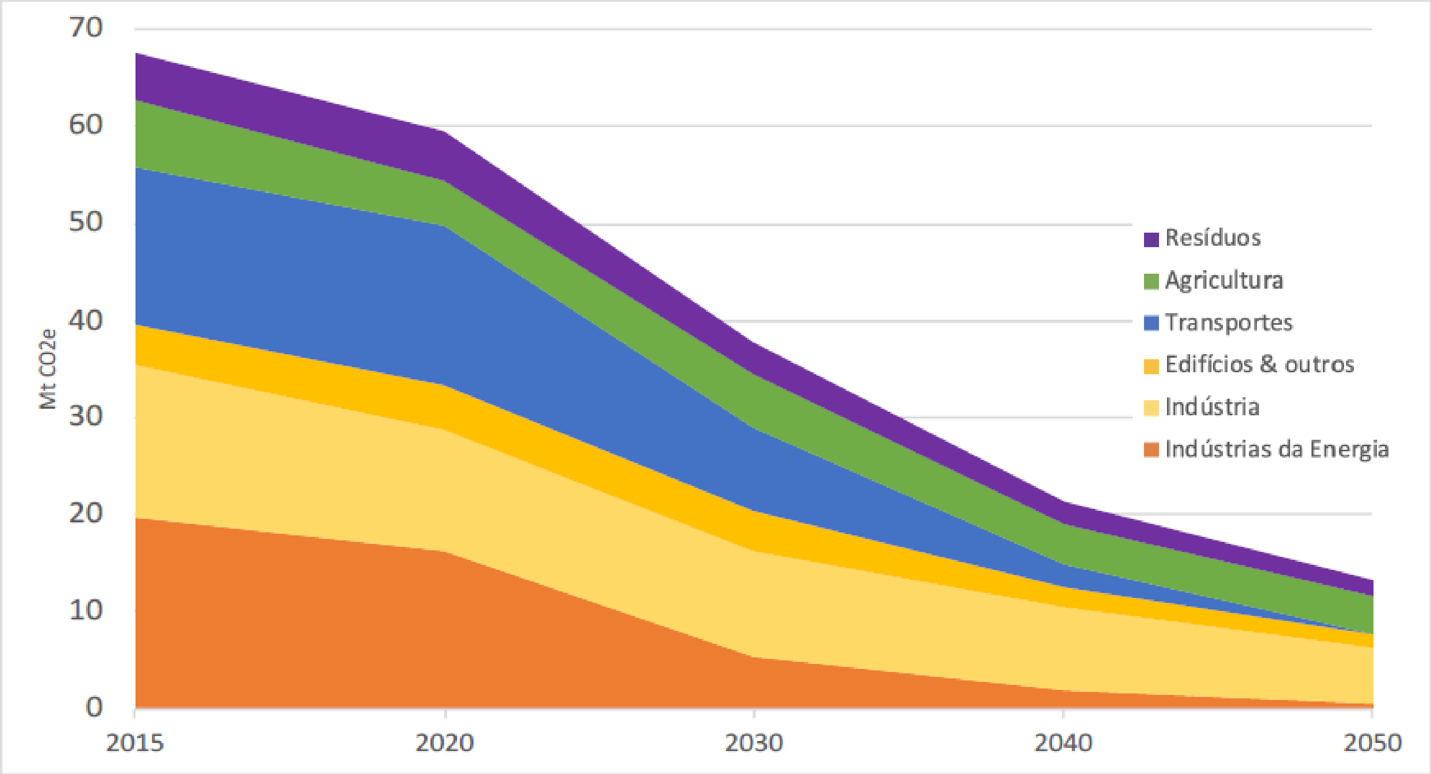
Portugal: present decarbonization policy

Redução de emissões por setor até 2050

> Trajetórias de neutralidade traduzem-se na descarbonização profunda da produção de eletricidade, da mobilidade e transportes e dos edifícios nas próximas duas décadas (2020-2040)

> Os setores da indústria e da agricultura apresentam um potencial de descarbonização mais reduzido, contribuindo ainda assim com reduções significativas no período 2020-2050, com especial ênfase no período 2040-2050

> A gestão agroflorestal eficaz é fator determinante para o objetivo da neutralidade carbónica em 2050



L| Gráfico da redução de emissões por setor até 2050

Our focus:

- **Power system**
- **Road Transport**

- In a country aiming at the simultaneous decarbonization of both systems

- Portugal 2050 as an example of a future electric system dominated by solar PV (45%) and wind (40%) generation

The energy matrix

		2015 TWh	2050 TWh
Consumption	Total Consumption	50	90
	General	50	70
	Mobility	0	20
Generation	Coal	14	-
	Gas	10	-
	Hydro	10	10
	Wind	12	37
	Solar PV	1	42
	WtE/Biomass	4	7
	Geothermal	0	0
	Wave	0	0
	Tidal	0	0
	Other	0	0

Main difference to RNC 2050:
No gas
(for simplicity purposes only; retaining gas for some years makes sense)

Generation is dominated by sun and wind, which are plentiful and cheap:

3 to 7 cents/kWh

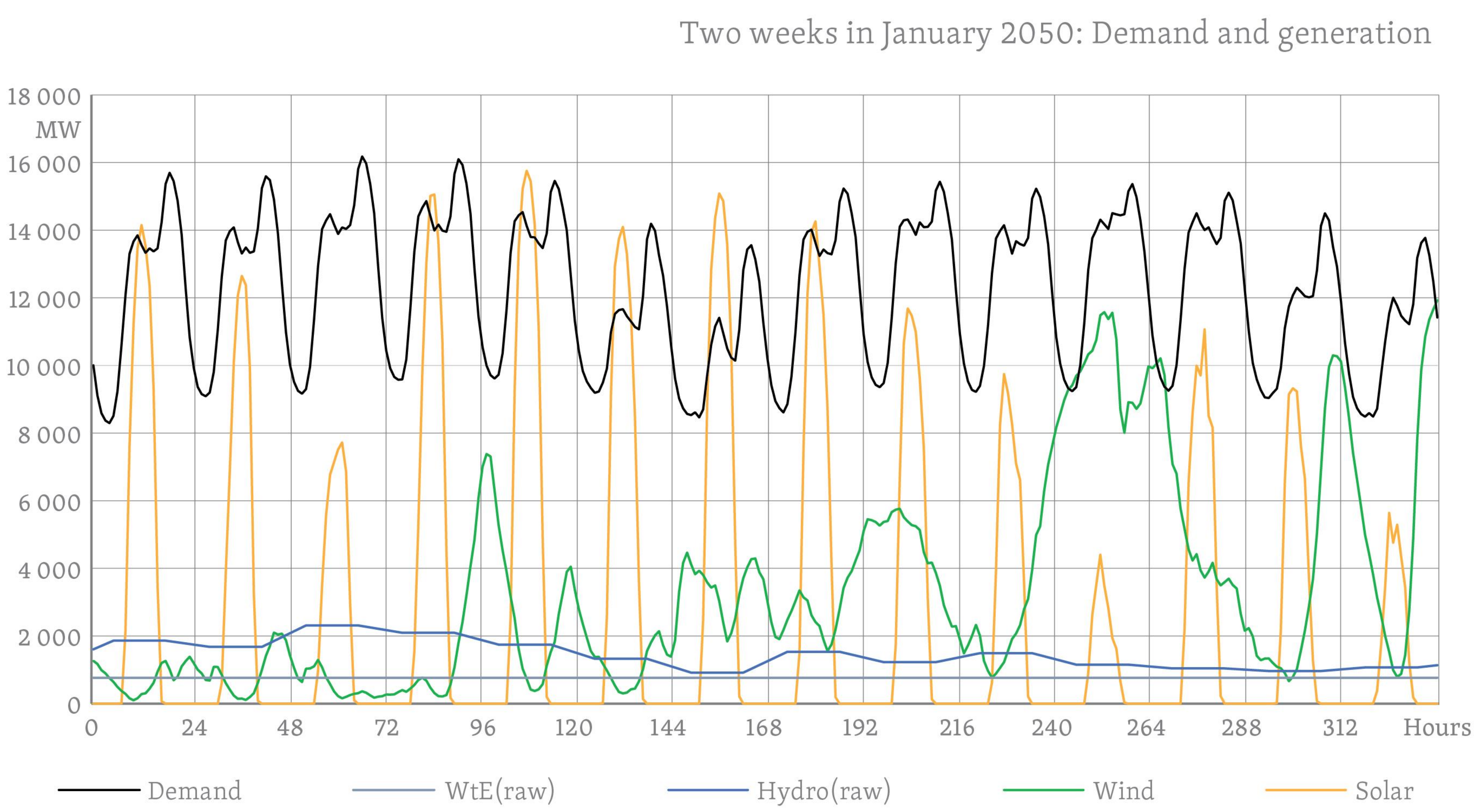
- The central issue of the power system isn't anymore the (economic, environmental) cost of generation,

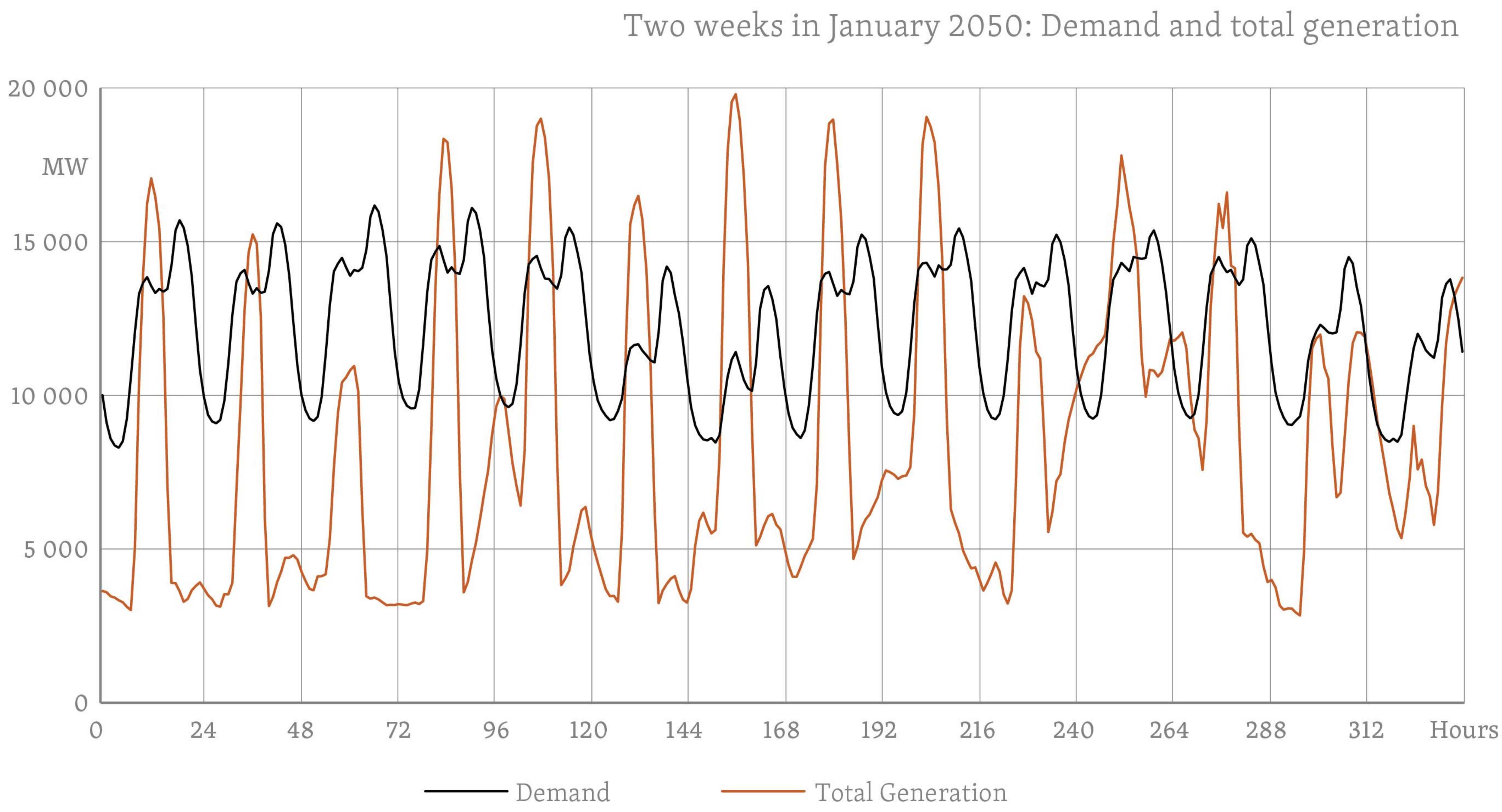
- The central issue is now

system balance

(a consequence of the dominance of solar and wind, variable and non-dispatchable)

Let us quantify this problem:


Two weeks in January 2050: Demand and generation
18 000
MW
16 000
14 000
12 000
10 000
8 000
6 000
4 000
2 000
0
0
24
48
72
96
120
144
168
192
216
240
264
288
312
Hours
Demand
WtE(raw)
Hydro(raw)
Wind
Solar

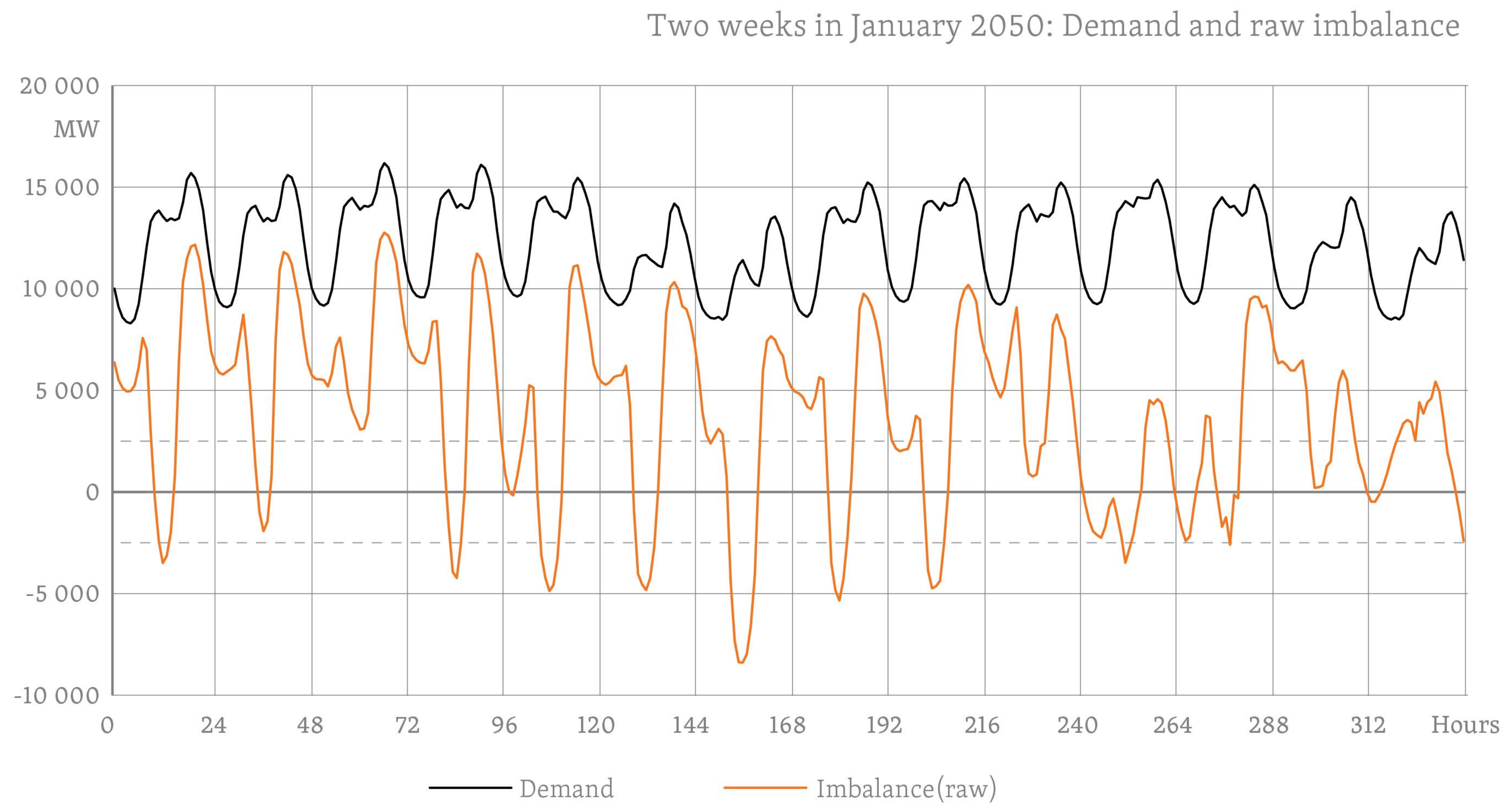


Two weeks in January 2050: Demand and total generation
20 000
MW
15 000
10 000
5 000
0
0
24
48
72
96
120
144
168
192
216
240
264
288
312
Hours
Demand
Total Generation

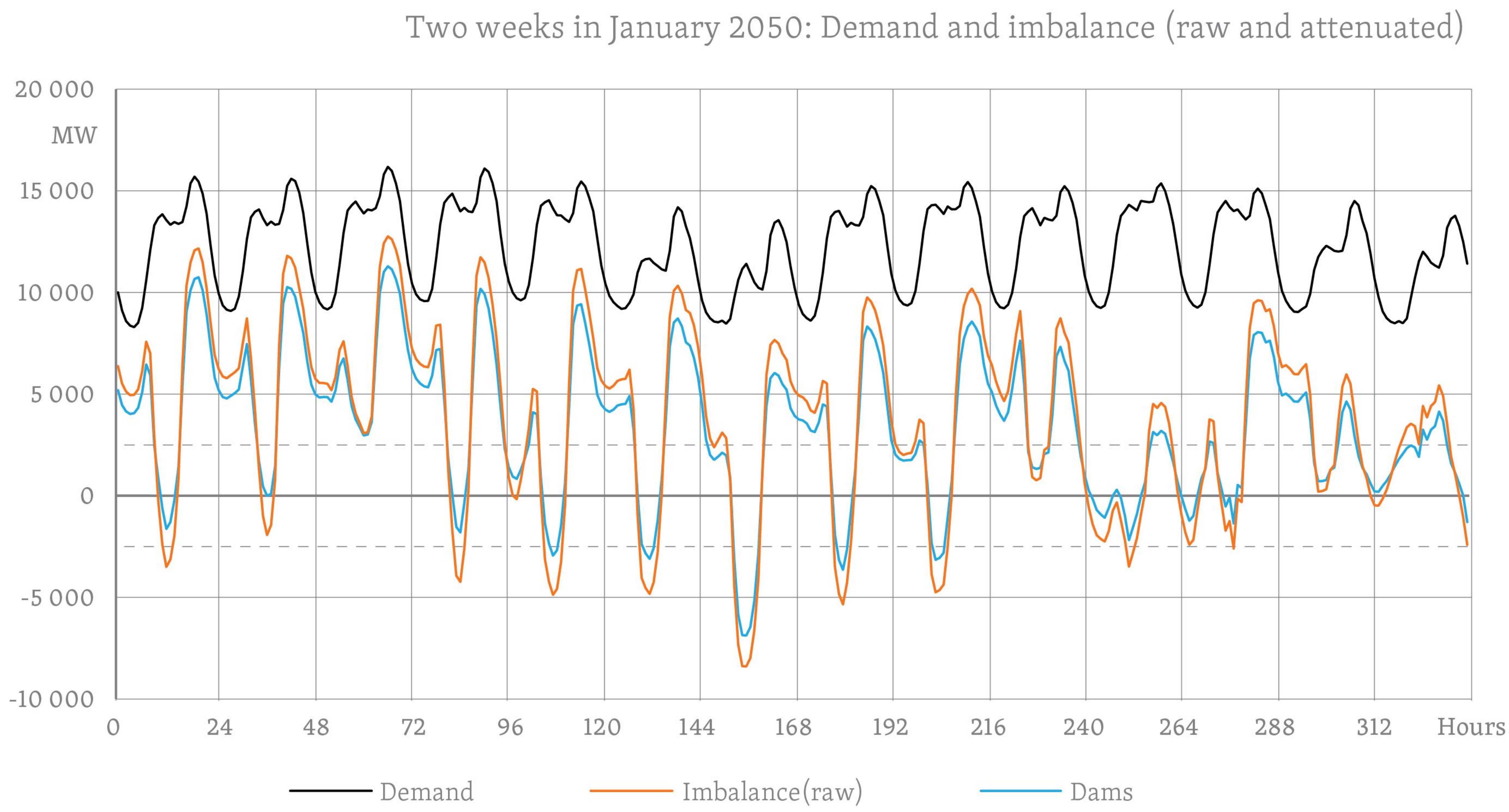
We define an *imbalance* function as

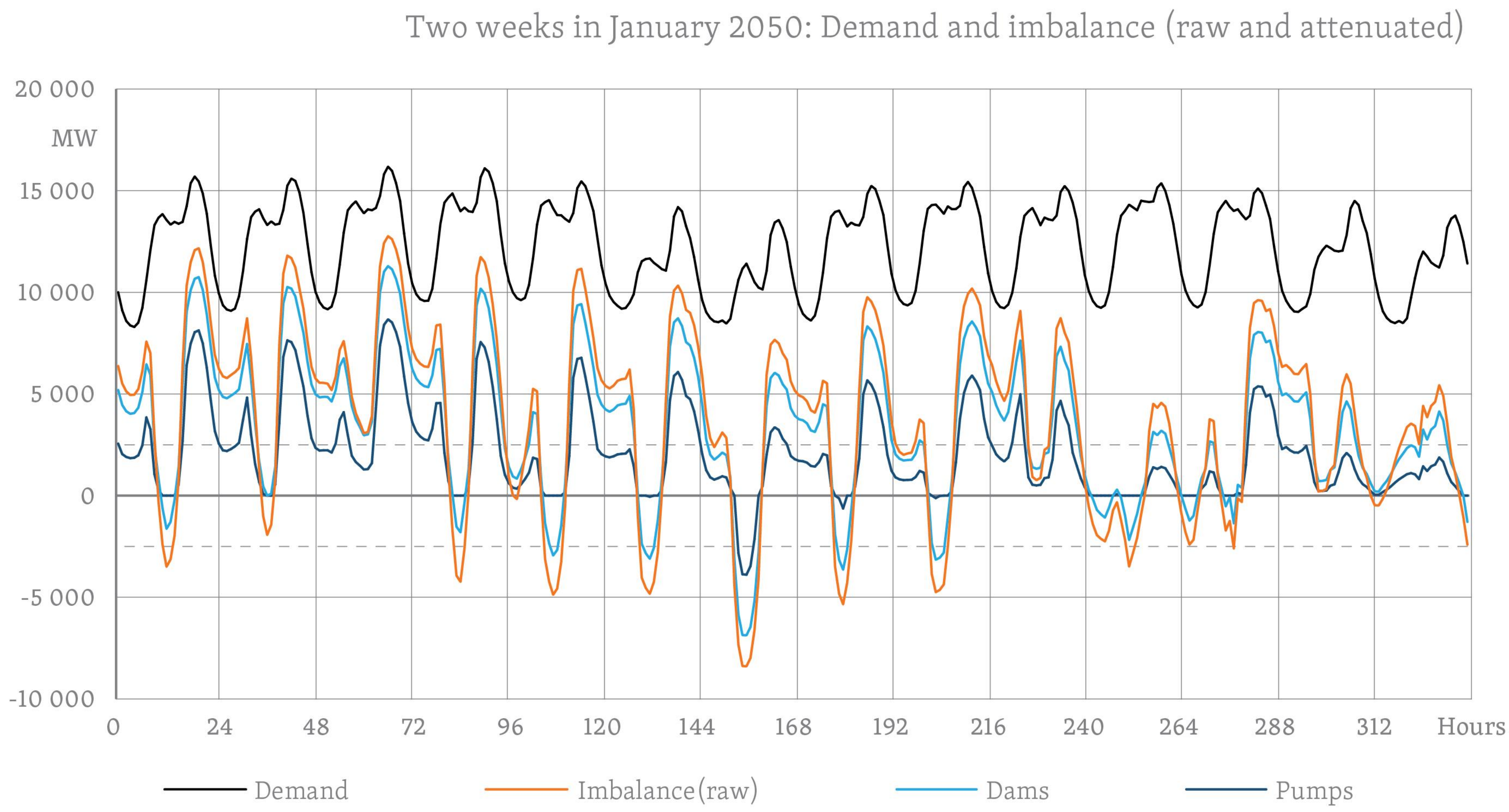
Imbalance = Demand – Generation

which must be brought to zero at all times:



Two weeks in January 2050: Demand and raw imbalance
20 000
MW
15 000
10 000
5 000
0
-5 000
-10 000
0
24
48
72
96
120
144
168
192
216
240
264
288
312
Hours
Demand
Imbalance(raw)


Two weeks in January 2050: Demand and imbalance (raw and attenuated)
20 000
MW
15 000
10 000
5 000
0
-5 000
-10 000
0
24
48
72
96
120
144
168
192
216
240
264
288
312
Hours
Demand
Imbalance(raw)
Dams


Two weeks in January 2050: Demand and imbalance (raw and attenuated)
20 000
MW
15 000
10 000
5 000
0
-5 000
-10 000
0
24
48
72
96
120
144
168
192
216
240
264
288
312
Hours
Demand
Imbalance(raw)
Dams
Pumps

Conclusion: After using all “classical” balancing means available,
we still have a massive problem;

Since we do not solve the imbalance problem by trying to adapt generation to demand, why don’t we look instead at demand flexibility, and try to adapt demand to generation?

Flexible demand possibilities:

- General demand management (*e.g.*, thermal systems): far too insufficient.
- Hydrogen: possible, but … (How much H_2 would be produced? How much would it cost?)
- Road transport

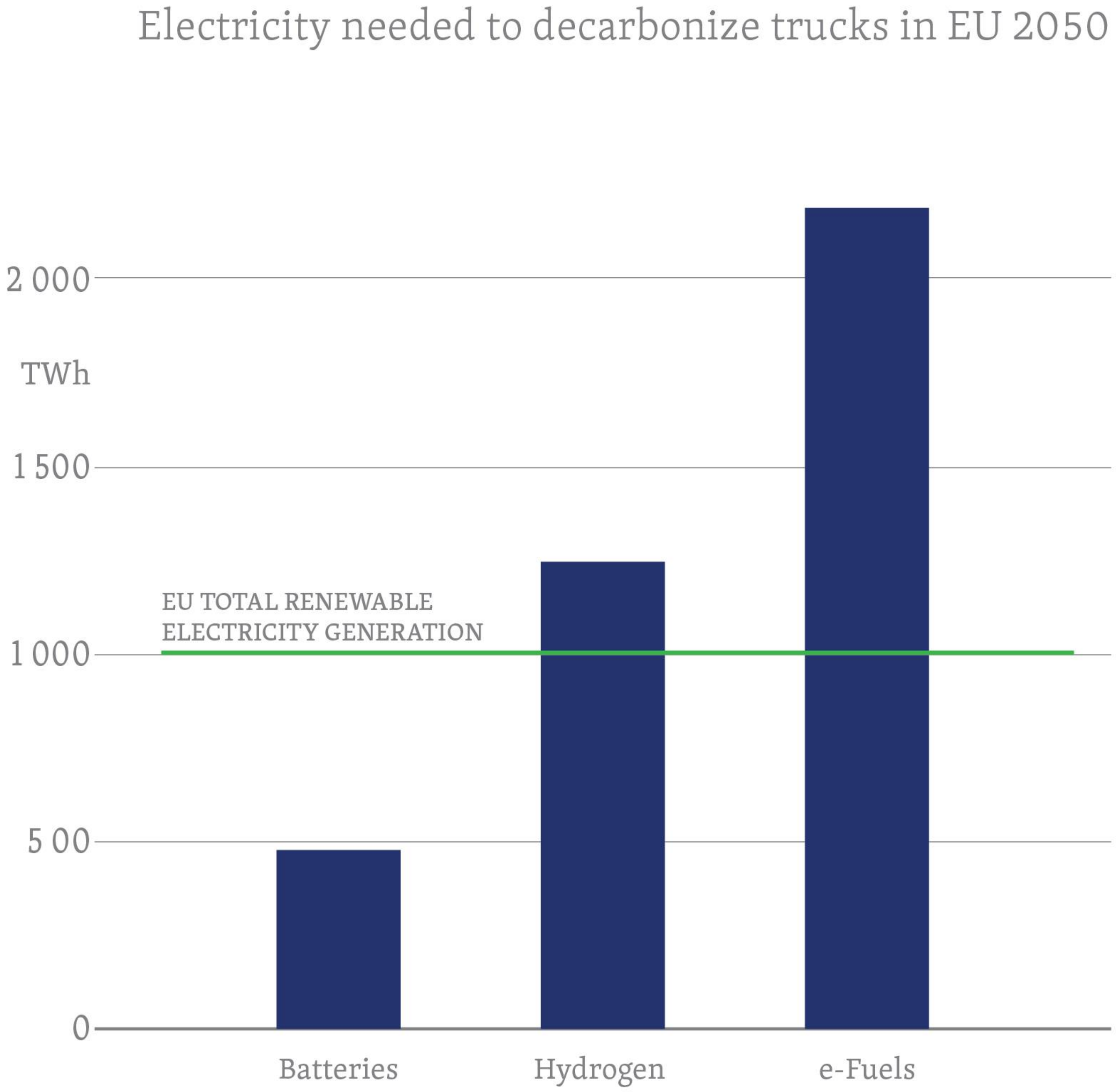
The impact of decarbonization of road transport in the electric system:

1. Energy for road transport

	Energy spent on road transport TWh	Electric energy consumption TWh	(Energy consumed in road transport) / (Electric energy consumption) %
World	32 230	24 881	130 %
Portugal	65	48	137 %
EU	3 556	2 647	134 %
USA	5 981	3 961	136 %
China	4 467	6 753	66 %

Need to increase generation by ~60% to satisfy this additional demand - if we adopt efficient battery electric vehicles

EU: The impact of decarbonization of Eurupean trucks on the electric system



Ref: Transport and Environment, 2018

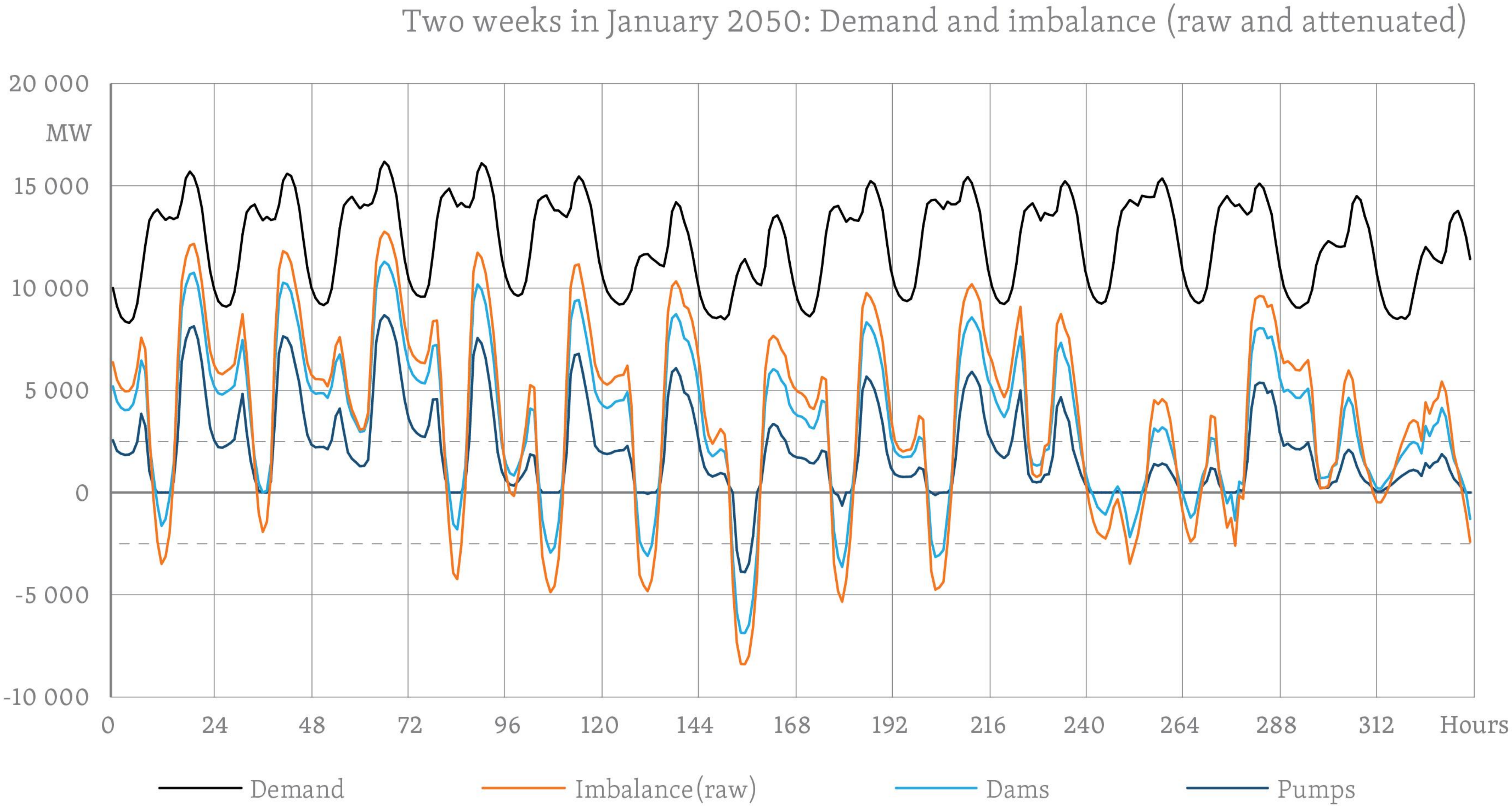
The impact of decarbonization of road transport in the electric system:

2. **Power**

- Power of motors on wheels is ~100 times the average power of electric demand.
- With substitution of present vehicles by battery eletric vehicles, the power capacity of batteries would be about the same.
- If 10% of these batteries were grid connected, their nominal power capacity would still be ~10 times the average electric demand

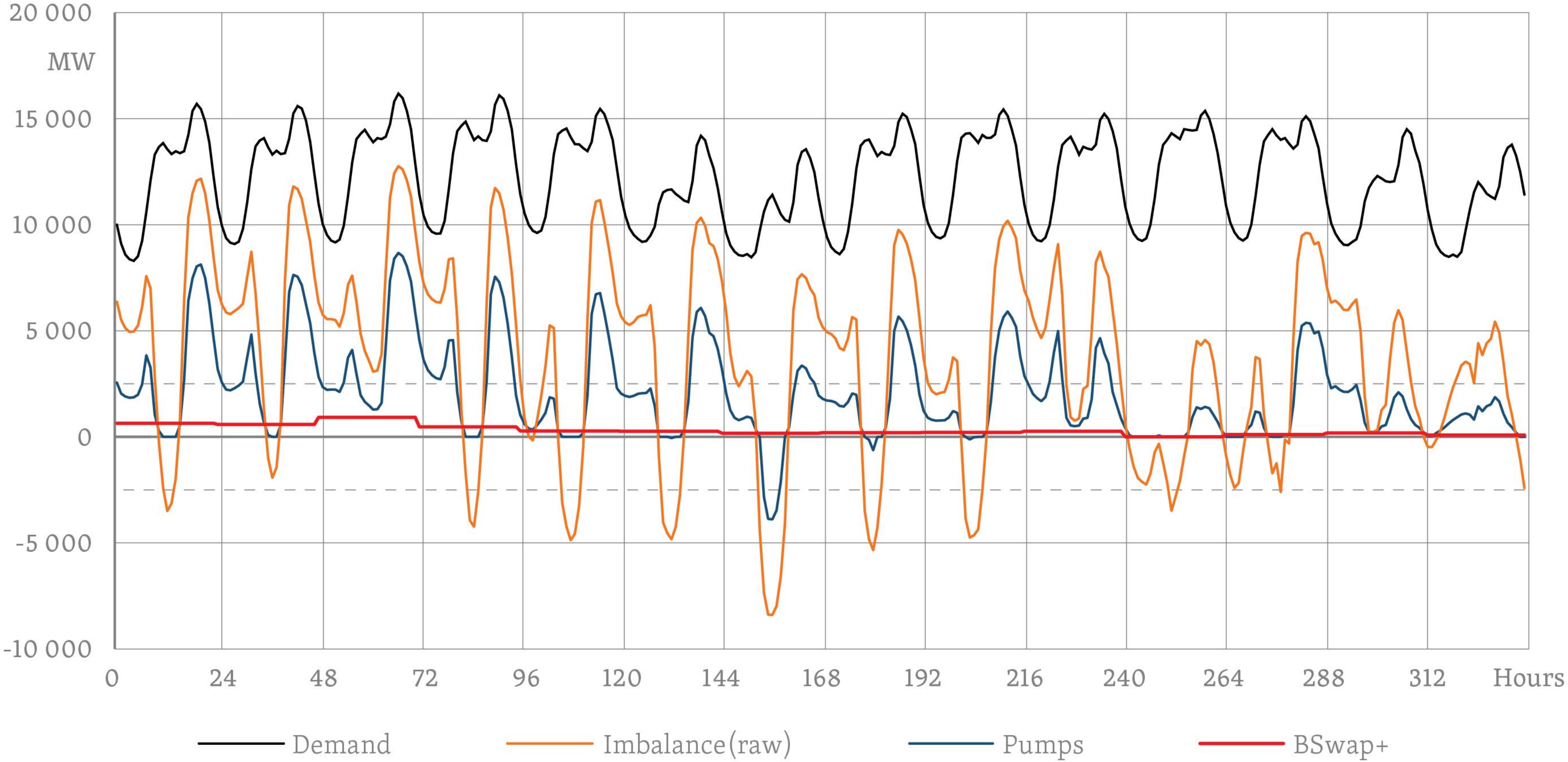
Road transport models studied:

1. **ICE** – Vehicles run on diesel or petrol
2. **Plug-in** – Vehicles are battery electric, and charge by connecting to a charger. Realistic charging flexibility and V2G are allowed.
3. **H2** – Vehicles are powered by fuel cells than run on electrolytic hydrogen.
4. **BSwap** – Vehicles are battery electric, and refuel by swapping their low-charge batteries by charged ones, at Battery Swapping Stations. Demand is fully flexible within battery residence time in BSS (*e.g.*, 24h). Storage and battery-to-grid are allowed with 2nd-life batteries.



Two weeks in January 2050: Demand and imbalance (raw and attenuated)
20 000
MW
15 000
10 000
5 000
0
-5 000
-10 000
0
24
48
72
96
120
144
168
192
216
240
264
288
312
Hours
Demand
Imbalance(raw)
Dams
Pumps

Two weeks in January 2050: Demand and imbalance (raw and attenuated)

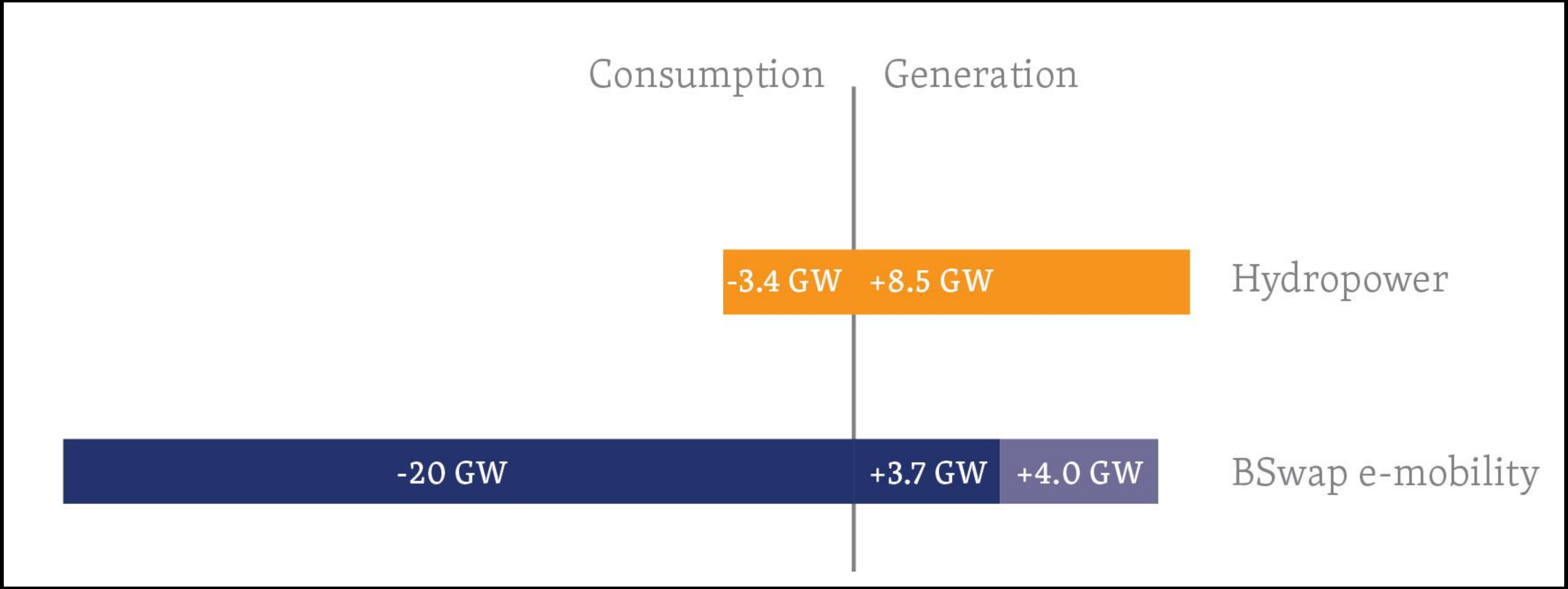


Is this a miracle?!

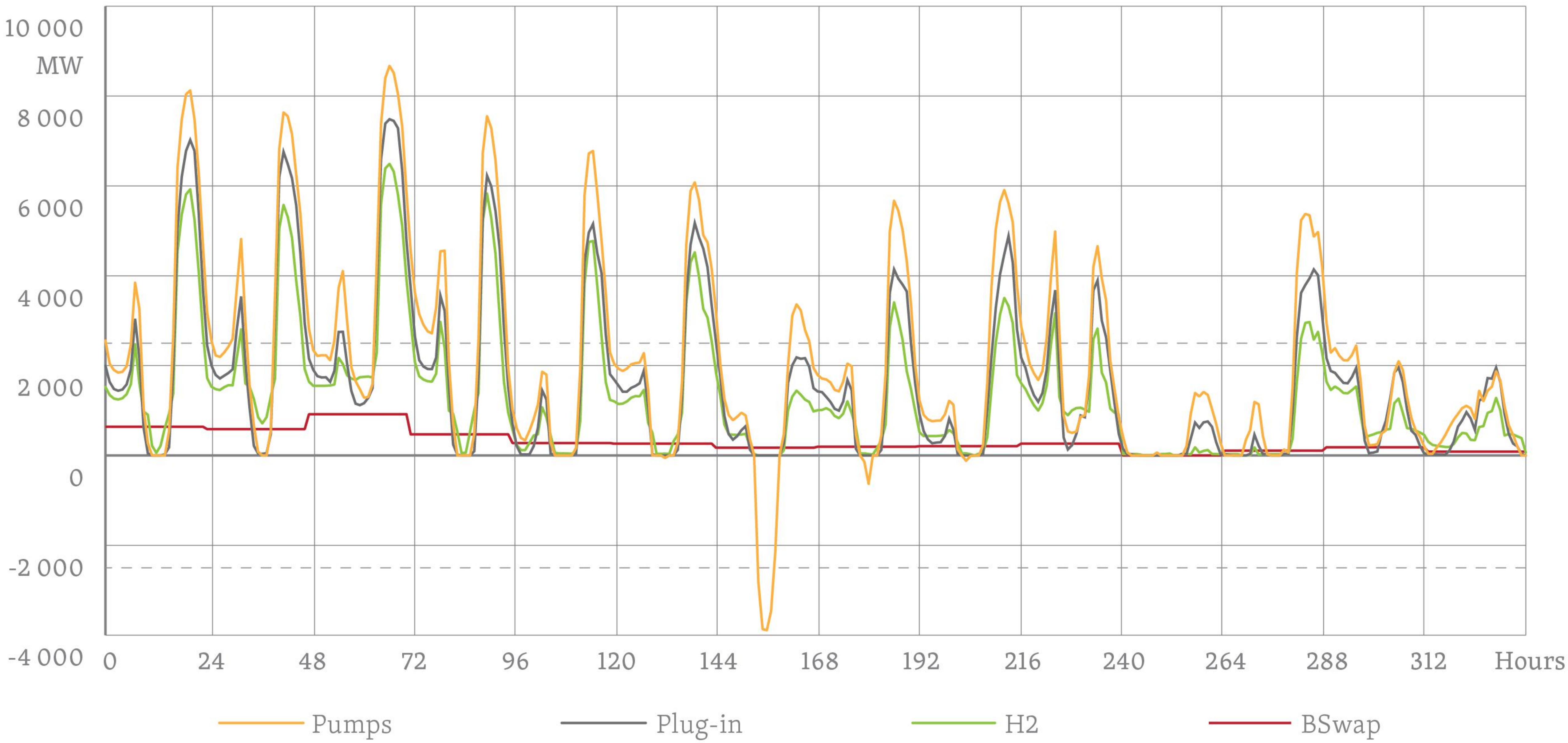
No, simply the result of applying to road transport a **Battery Swap** model.

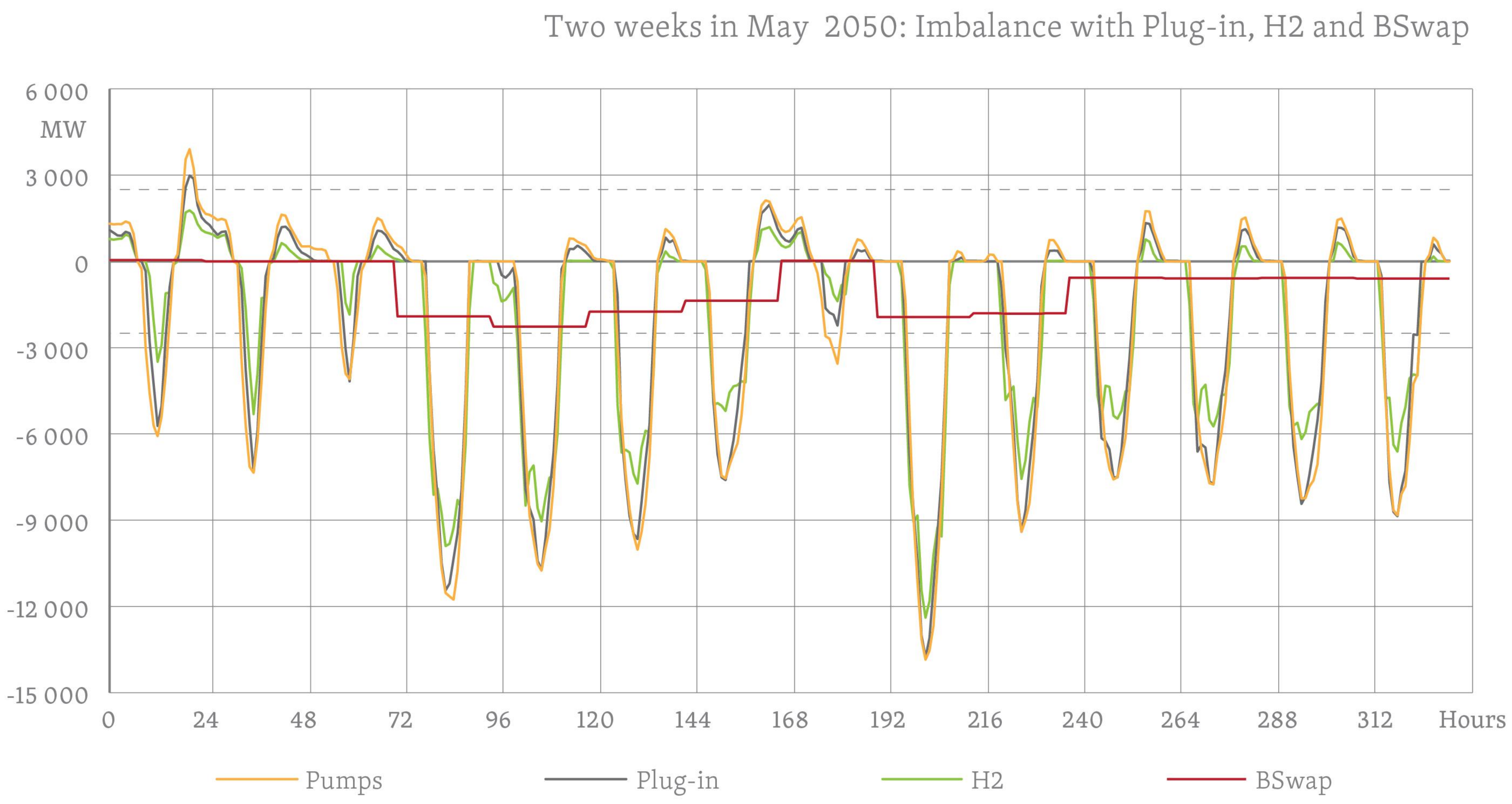
The Battery Swap model:

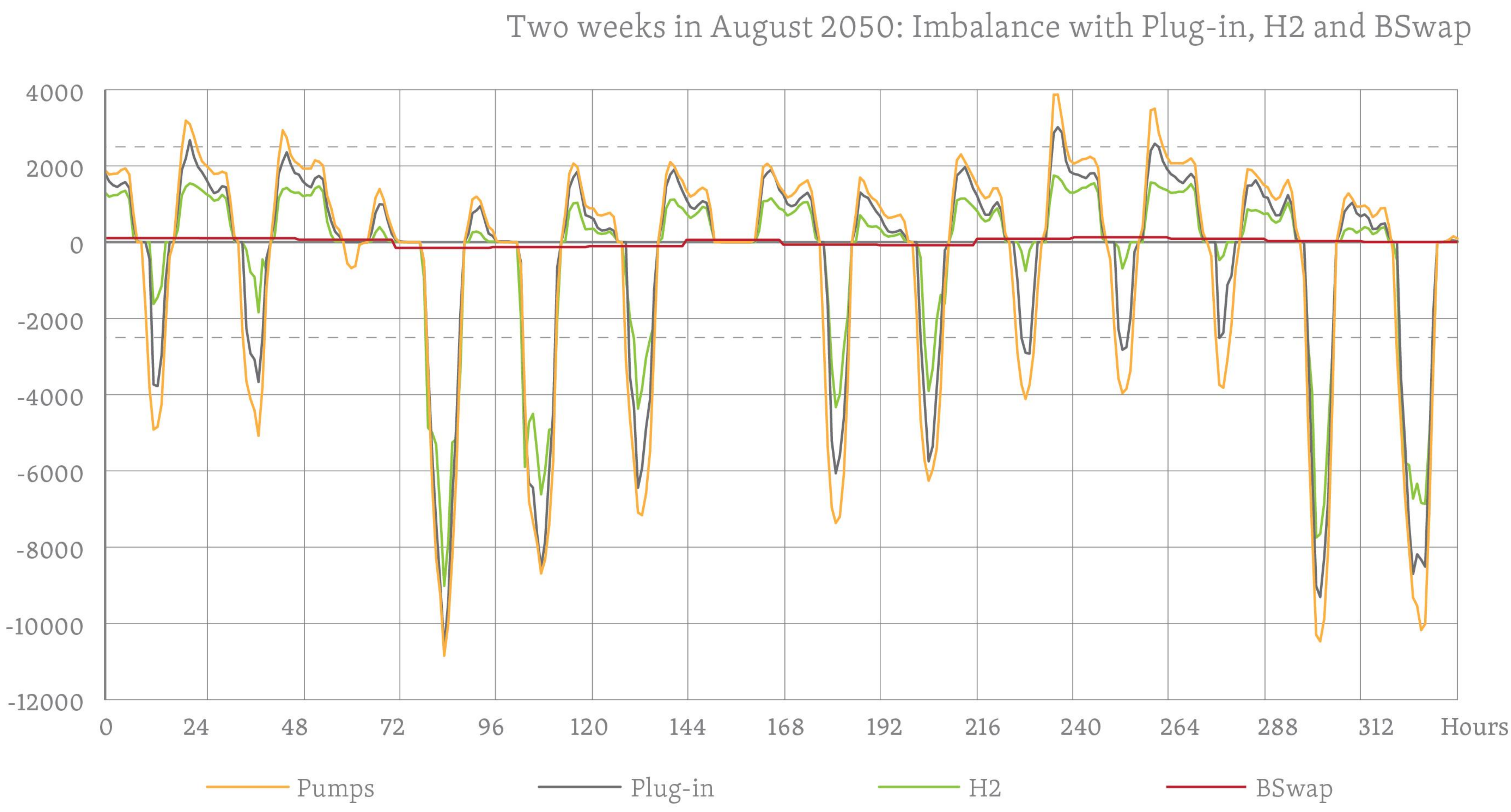
- Vehicles refuel by swapping their low-charge batteries for charged ones at Battery Swapping Stations (BSS).
- Discharged batteries are inserted into chargers, and reside in the BSS for *e.g.* 24h, and so are charged when most convenient (for grid balance and lowest price).
- A large fraction of demand (20-30%) becomes flexible, and its power capacity is sufficient to absorb all "excess" wind or solar peaks. Demand flexibility is the main cause of the improvement in grid balance.
- 2nd-life battery storage is a second order effect, but important for economic and for security of supply reasons.
- Together with longer term hydro pumped storage, the result is a balanced grid. No need for further large-scale storage.
- The beauty of it: this benefit to grid stability is paid for by transport.
- The result: electricity will be cheap.


Consumption
Generation
-3.4 GW
+8.5 GW
Hydropower
-20 GW
+3.7 GW
+4.0 GW
BSwap e-mobility

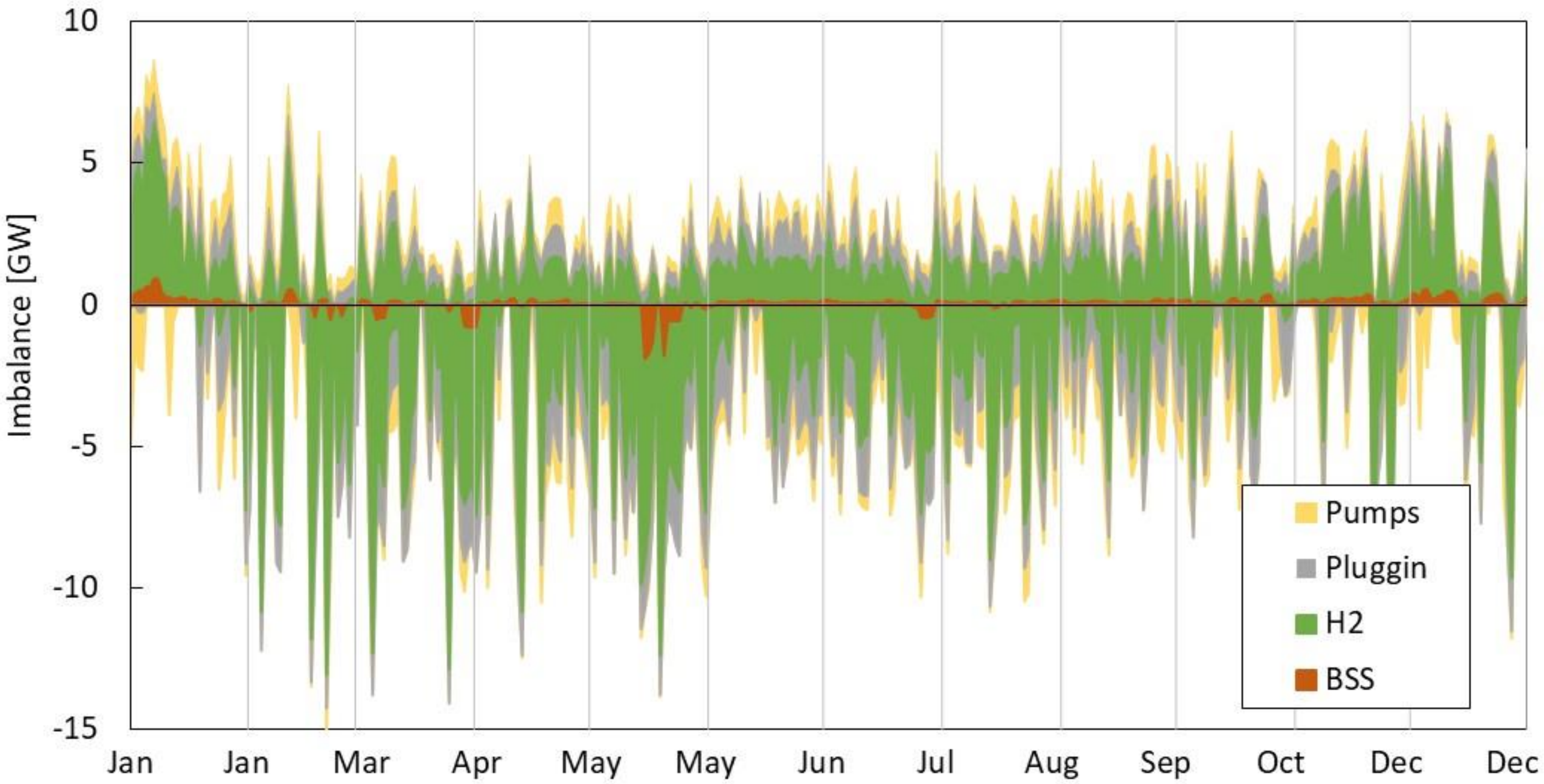
Two weeks in January 2050: Imbalance with Plug-in, H2 and BSwap

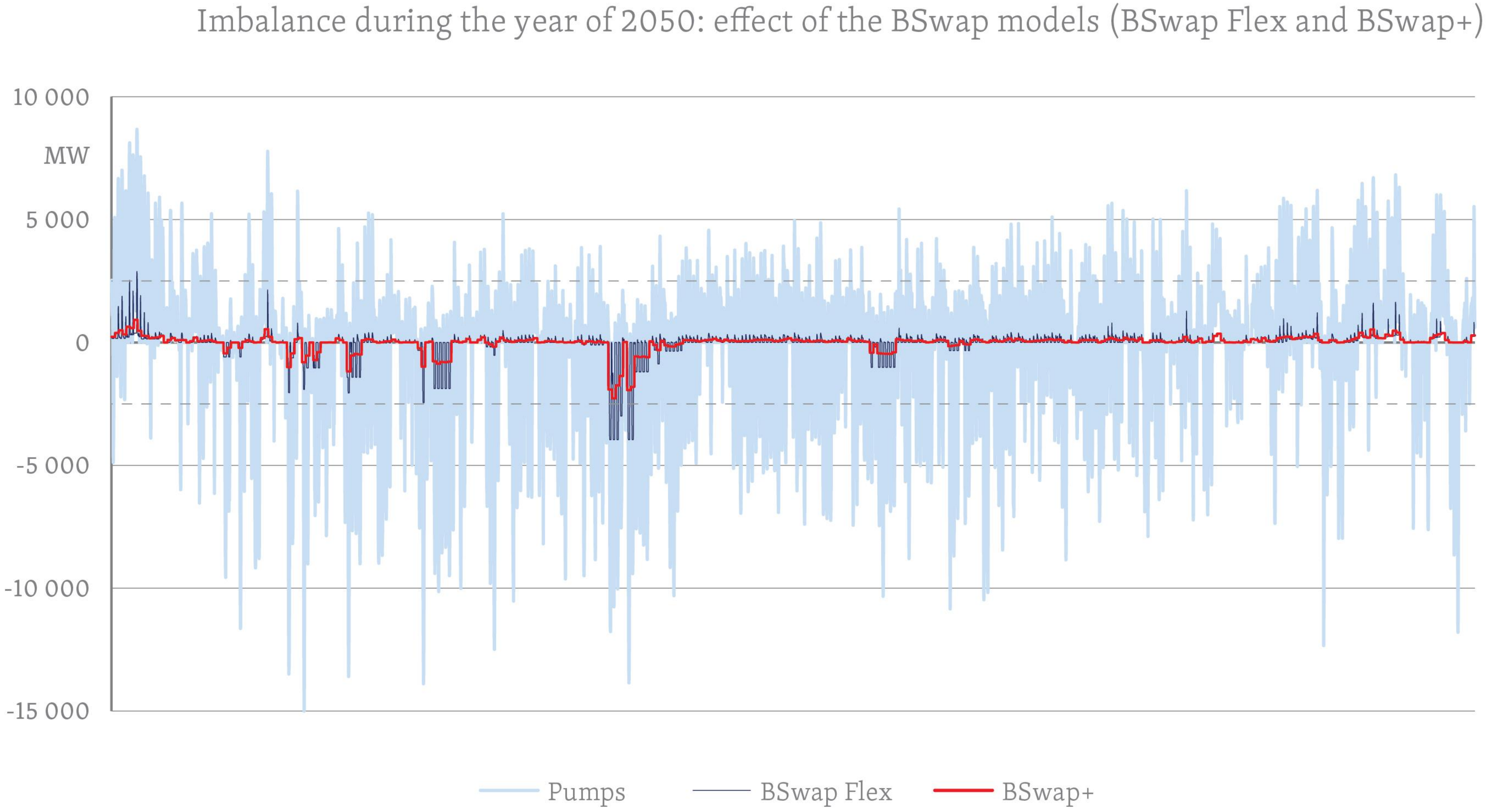



Two weeks in May 2050: Imbalance with Plug-in, H2 and BSwap
6 000
MW
3 000
0
-3 000
-6 000
-9 000
-12 000
-15 000
0
24
48
72
96
120
144
168
192
216
240
264
288
312
Hours
Pumps
Plug-in
H2
BSwap



Two weeks in August 2050: Imbalance with Plug-in, H2 and BSwap
4000
2000
0
-2000
-4000
-6000
-8000
-10000
-12000
0
24
48
72
96
120
144
168
192
216
240
264
288
312
Hours
Pumps
Plug-in
H2
BSwap


10
5
0
-5
-10
-15
Imbalance [GW]
Jan
Jan
Mar
Apr
May
May
Jun
Jul
Aug
Sep
Oct
Dec
Dec
Pumps
Pluggin
H2
BSS

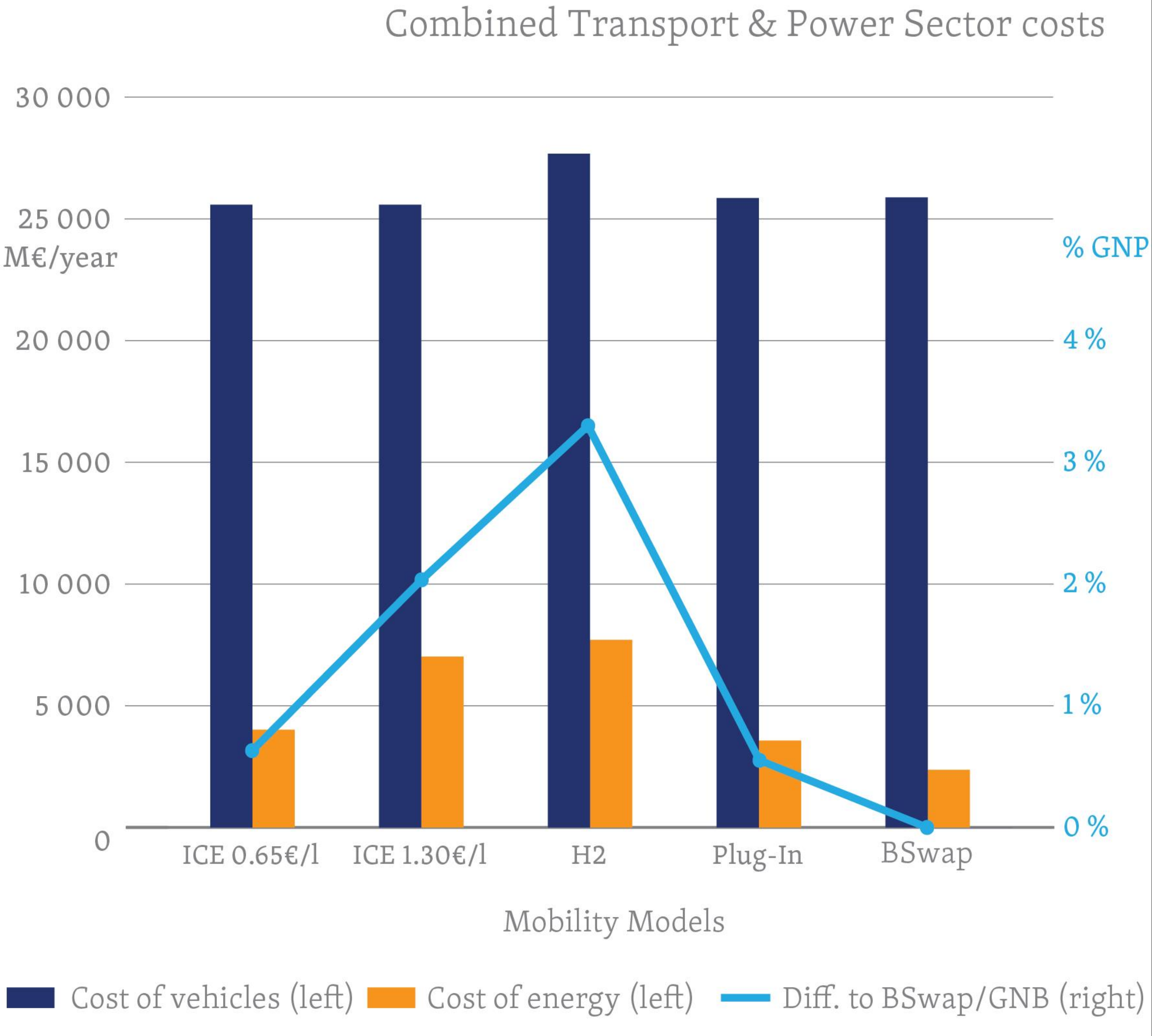


Imbalance during the year of 2050: effect of the BSwap models (BSwap Flex and BSwap+)
10 000
MW
5 000
0
-5 000
-10 000
-15 000
Pumps
BSwap Flex
BSwap+

Conclusion:

Intelligent satisfaction of road transport demand solves the imbalance problem.

What about **costs**?


Combined Transport & Power Sector costs
30 000
25 000
M€/year
20 000
15 000
10 000
5 000
0
% GNP
4 %
3 %
2 %
1 %
0 %
ICE 0.65€/l
ICE 1.30€/l
H2
Plug-In
BSwap
Mobility Models
Cost of vehicles (left)
Cost of energy (left)
Diff. to BSwap/GNB (right)

With the Battery Swapping model

- The electric system becomes essentially balanced
  - No need to curtail, or sell at very low prices, a large fraction of solar and wind generation; nor to buy massively at peak demand times
  - No need for further large-scale storage
  - The need for high capacity cross-border connections is limited
- The grid becomes resilient
- Electrification of heavy vehicles is easily achieved
- Acceleration of transport electrification occurs
- Costs are lowest
- Low cost electricity from a stable electric system encourages electrification of many other human activities

Conclusion:

The 2 great structural changes in the future energy system by 2050,

- The decarbonization of the electric system (with dominance of non-dispatchable renewables),

  and

- Electric mobility

Taken together, with the right model, are the most efficient, lowest cost, and potentially faster, solution for

- A road transport system with ease of use, lowcost, and totally descarbonized,

  and

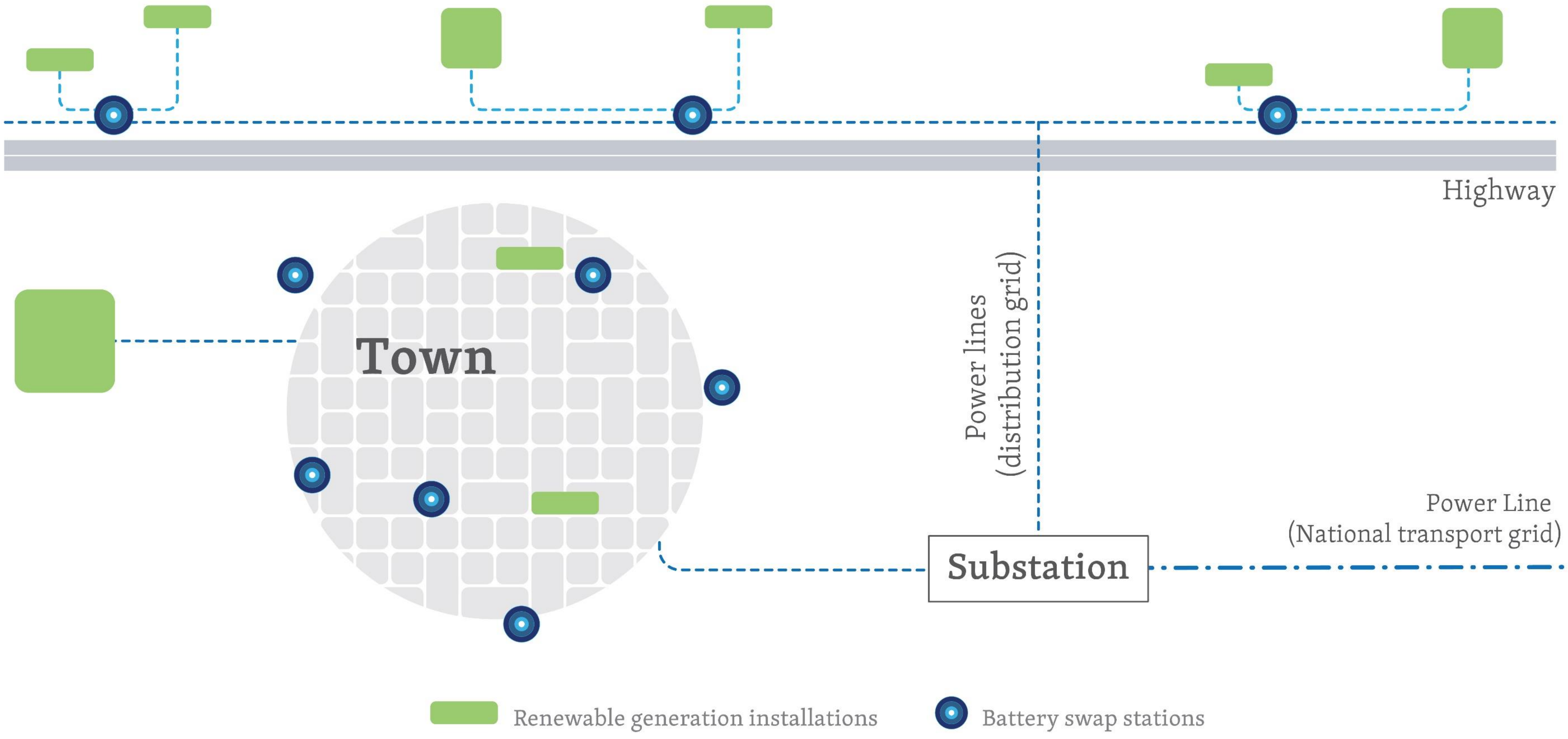
- A stable, decarbonized, power system, supplying energy at lowest cost.

B. A smaller region (say, 200 000 people)

Assume that PV is the only local energy resource.

Questions: **How much PV may be economically installed?**
How does this depend on road transport model?
What are the outcomes of each option?

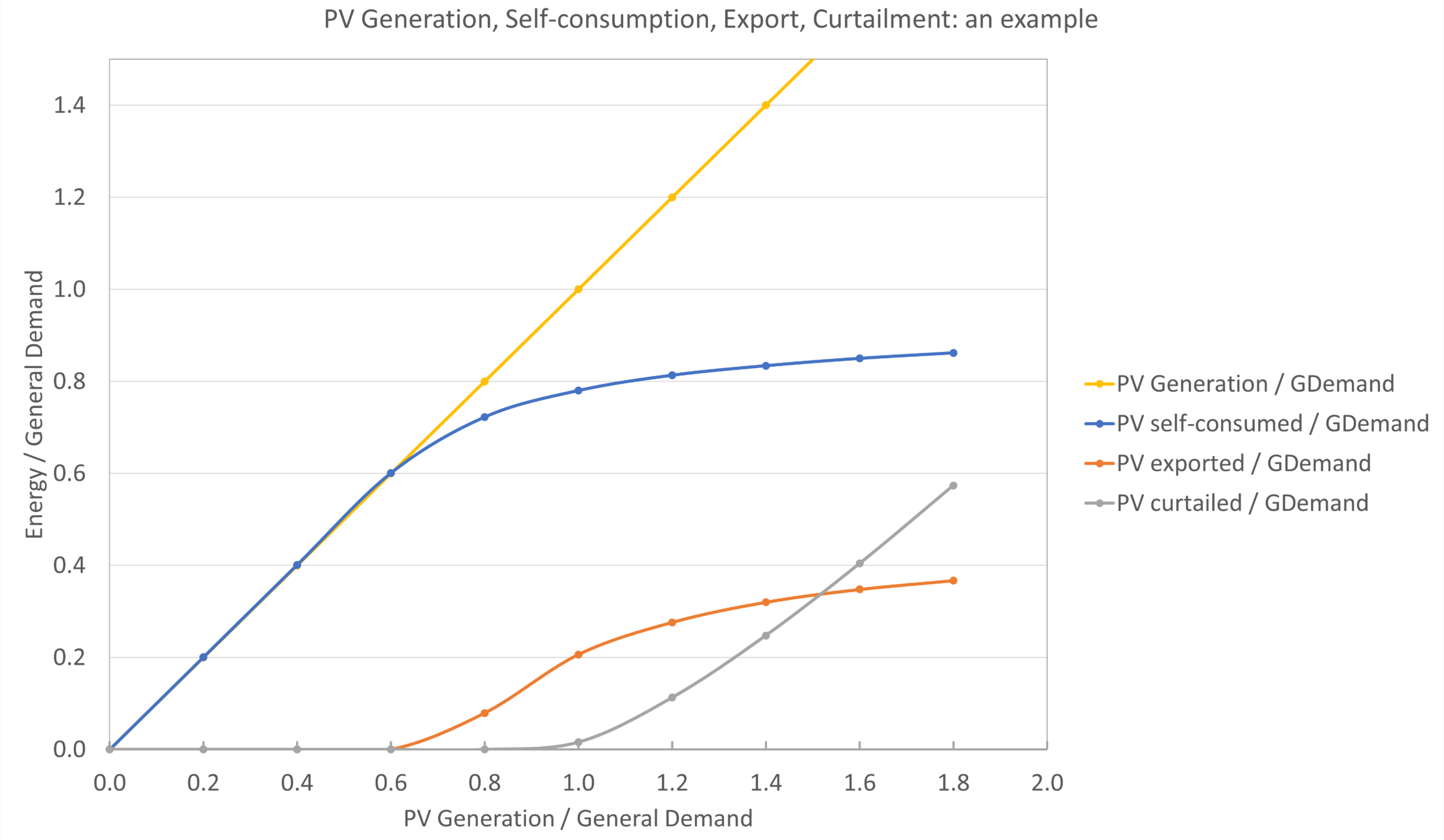
B. A smaller region (say, 200 000 people)

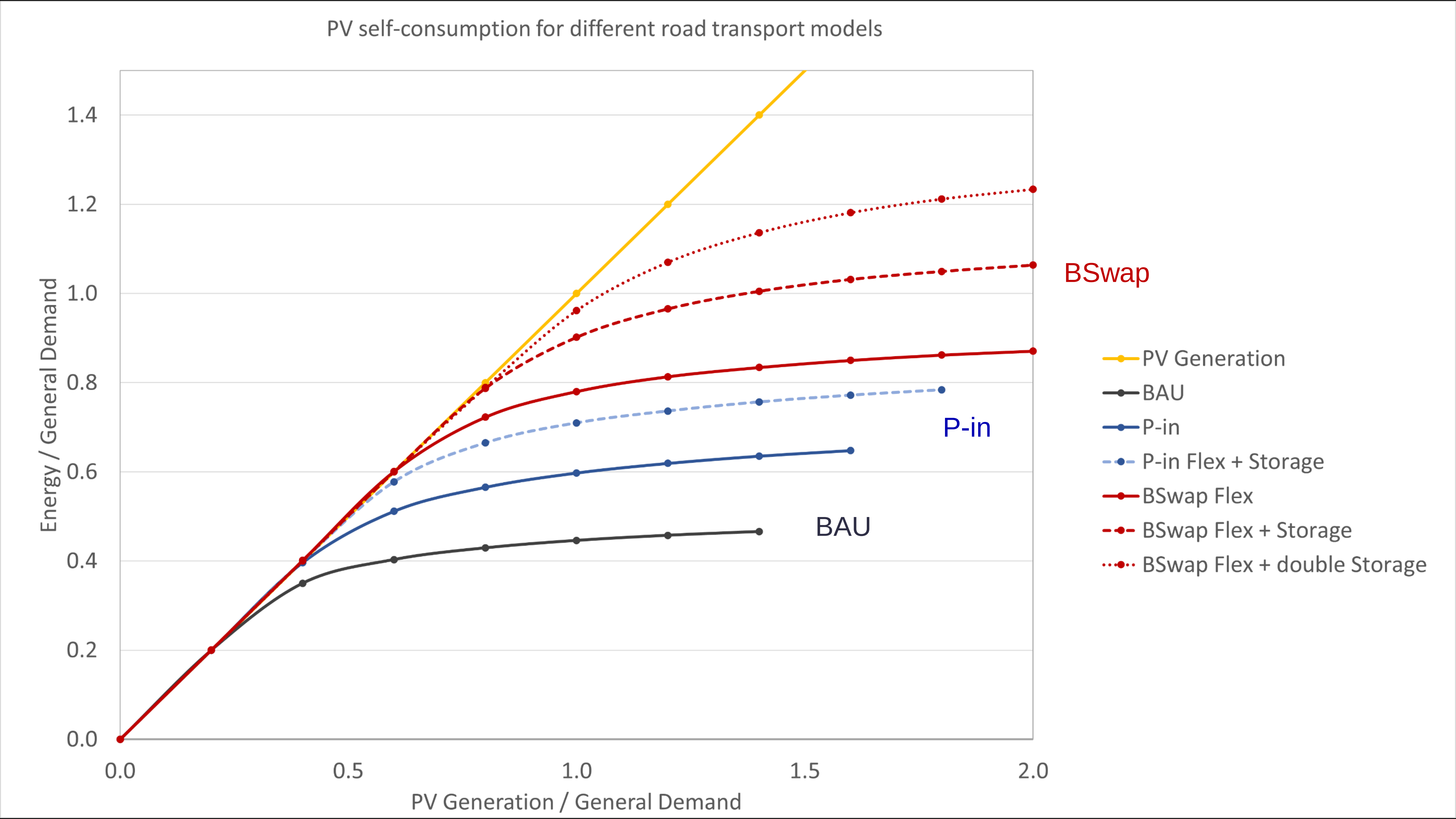


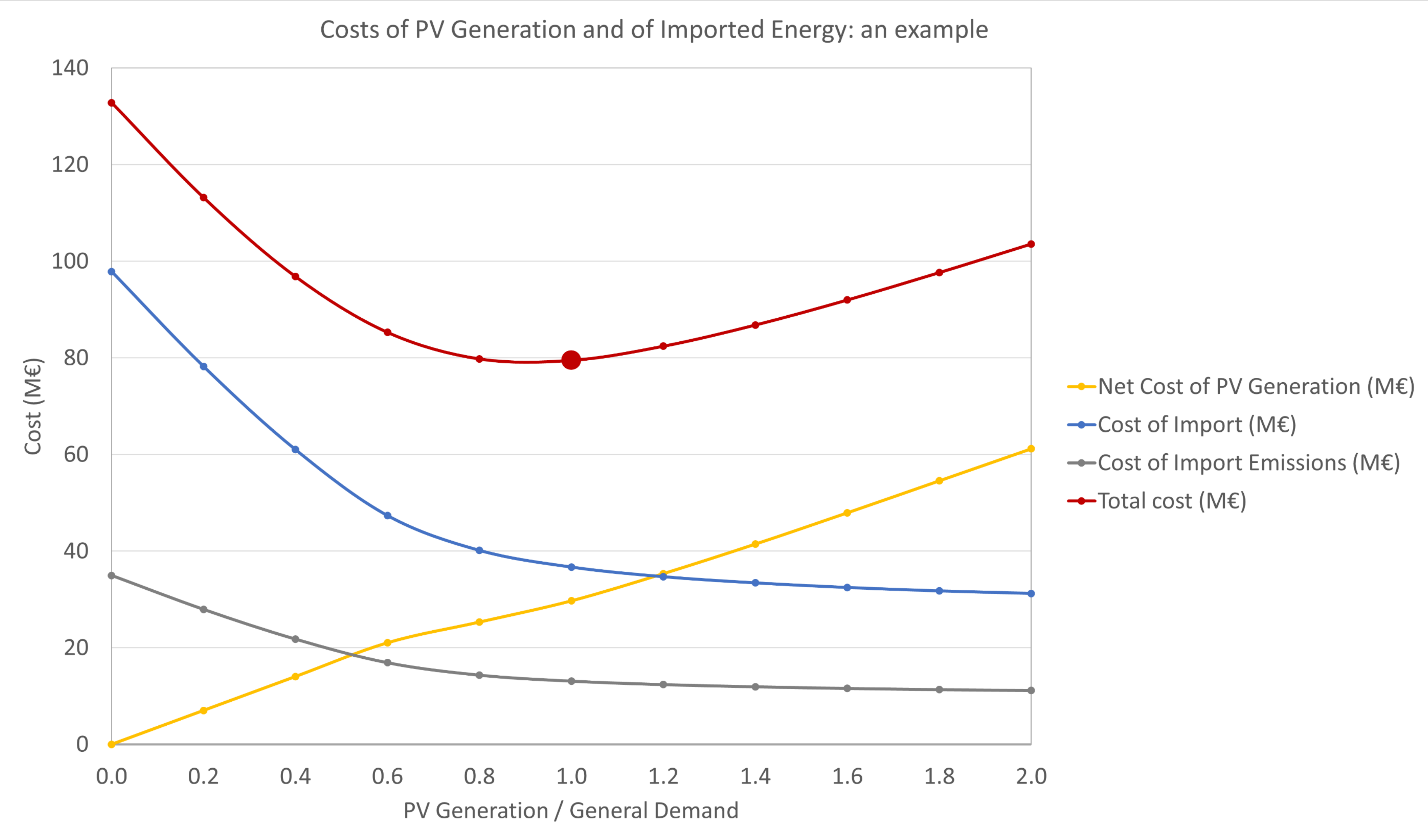
Road Transport models considered:

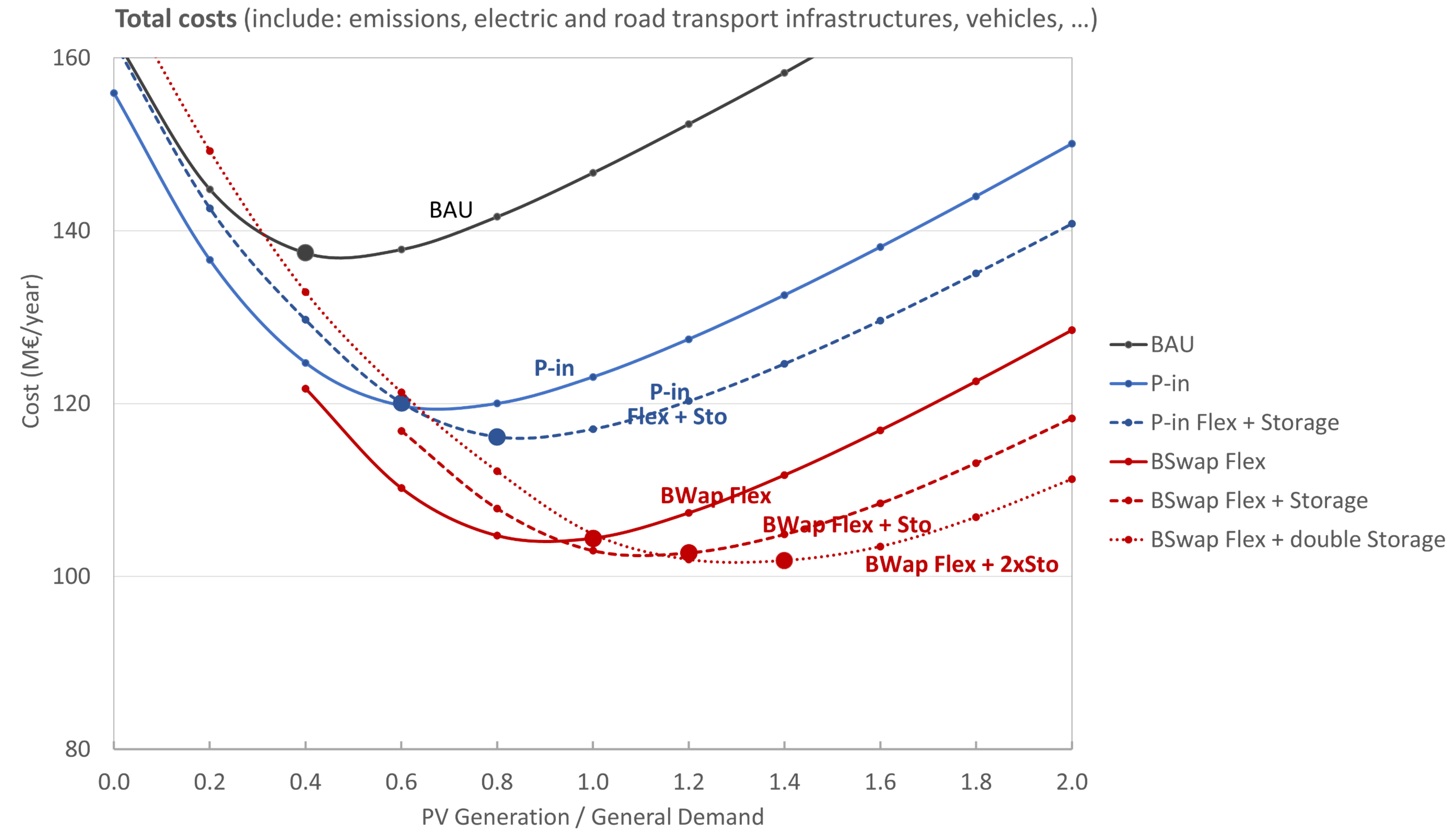
1.	BAU (or ICE)	- Transport relies on fossil oil, mostly diesel and petrol.
2.	Plug-in	- Vehicles are all battery electric, and charge by connecting a plug into the socket of a charger.
3.	Plug-in Flex + Storage	- " , with 10% demand flexibility and added 2nd-life battery storage.
4.	BSwap Flex	- Vehicles refuel by swapping their low-charge batteries by charged ones, at Battery Swapping Stations.
5.	BSwap Flex + Storage	- " , with added 2nd-life battery storage.
6.	BSwap Flex + double Storage	- " , with twice the previous storage capacity.

(A Hydrogen powered transport model was not considered in detail because its cost was estimated as far too high.)

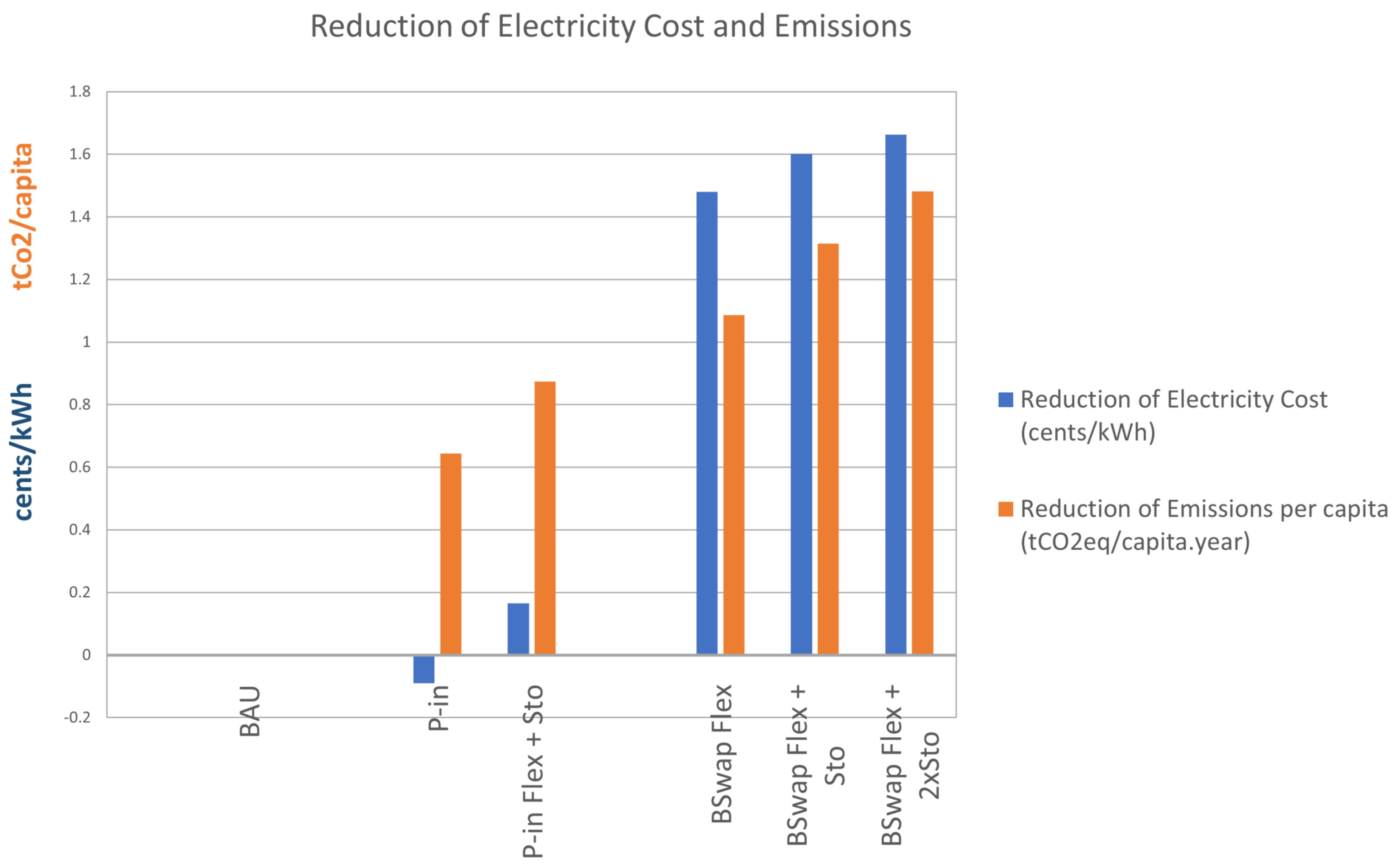

PV Generation, Self-consumption, Export, Curtailment: an example
Energy / General Demand
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
PV Generation / General Demand
PV Generation / GDemand
PV self-consumed / GDemand
PV exported / GDemand
PV curtailed / GDemand


PV self-consumption for different road transport models
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Energy / General Demand
0.0
0.5
1.0
1.5
2.0
PV Generation / General Demand
BSwap
P-in
BAU
PV Generation
BAU
P-in
P-in Flex + Storage
BSwap Flex
BSwap Flex + Storage
BSwap Flex + double Storage


Costs of PV Generation and of Imported Energy: an example
140
120
100
80
60
40
20
0
Cost (M€)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
PV Generation / General Demand
Net Cost of PV Generation (M€)
Cost of Import (M€)
Cost of Import Emissions (M€)
Total cost (M€)



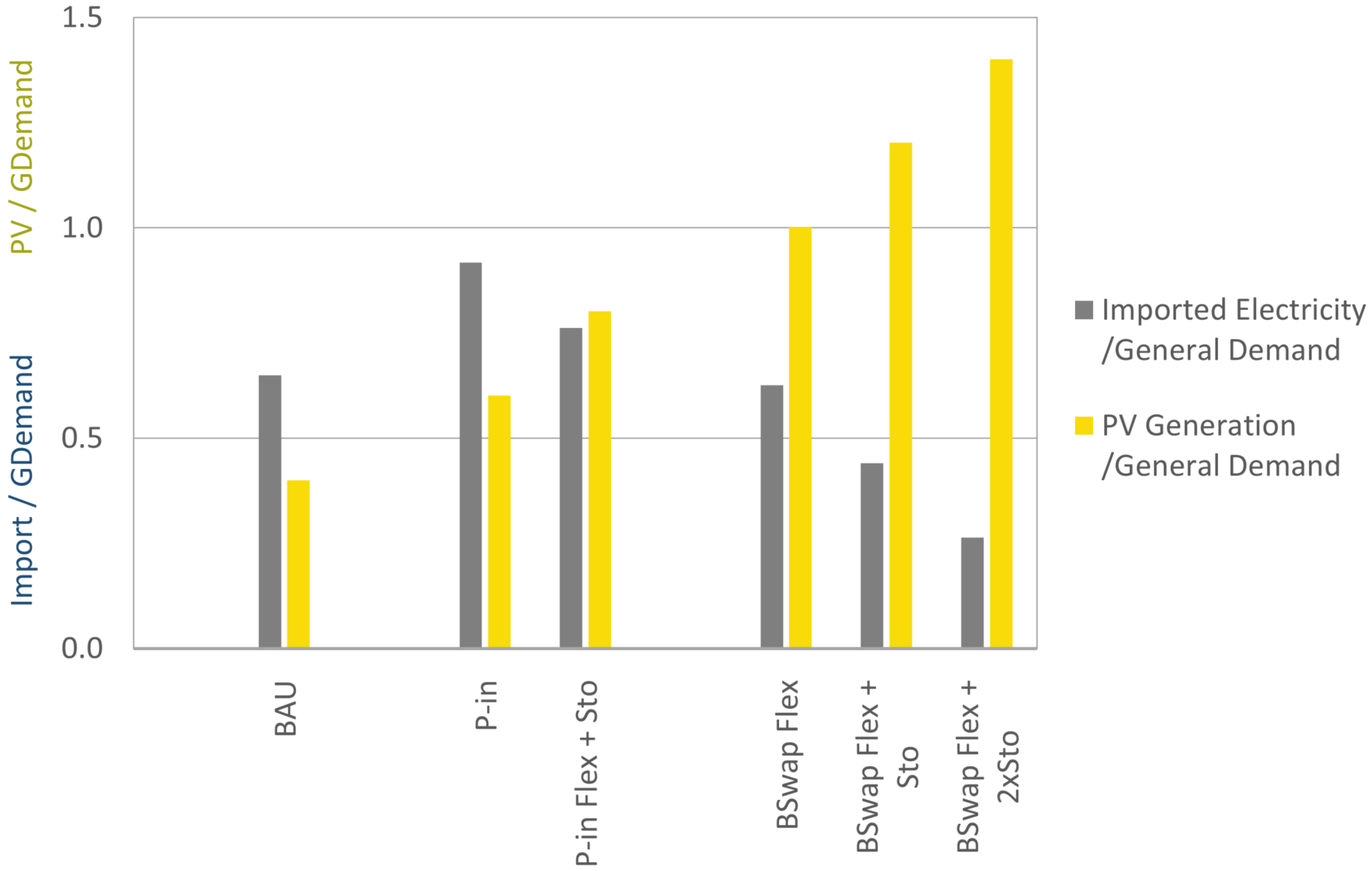
Total costs (include: emissions, electric and road transport infrastructures, vehicles, …)
Cost (M€/year)
160
140
120
100
80
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
PV Generation / General Demand
BAU
P-in
P-in
Flex + Sto
BWap Flex
BWap Flex + Sto
BWap Flex + 2xSto
BAU
P-in
P-in Flex + Storage
BSwap Flex
BSwap Flex + Storage
BSwap Flex + double Storage



Emissions reduction by **85%** (down from BAU+PV)

Electricity cost reduction by **23%** (down from BAU+PV)

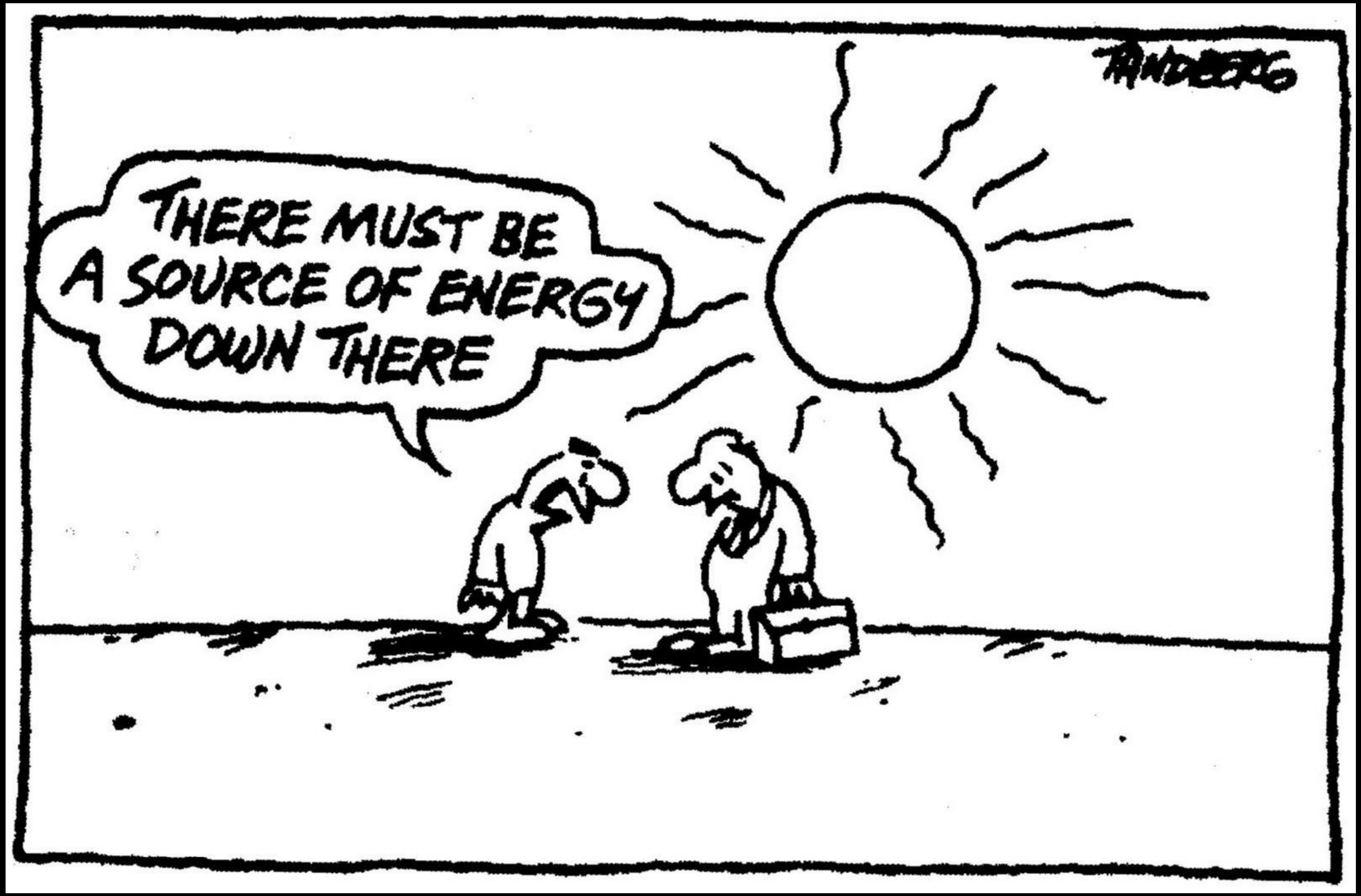
At minimum cost points: Imported and PV generated Electric Energy



Imported electricity is **18.5%** only of total consumption

The outcomes of the decision to adopt the BSwap model:

- PV integration reaches values previously thought impossible; emissions decrease dramatically
- Local grid capacity expands without having to wait for very large, far-away, investments in centralised plants, it is decided and managed locally
- Power quality becomes high, with a stable and resilient local grid. (The old power line of the national grid is no longer congested, delaying the need for a new line.)
- High quality and lower cost electric energy attract new businesses, and promote decarbonization of other actvities.
- Quality of life improves



Thank you