Modelling Electric Vehicles as an Abatement Technology in a Hybrid CGE Model: Applied to Austria

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Research Question and Motivation

- Quantification of **social costs** of an increased penetration of **electricity driven passenger vehicles** as one of the steps towards a low carbon transport system which still heavily relies on individual transport with electric cars as **endogenously** driven abatement technology

Development of a novel evaluation approach on the basis of a CGE model:

- Disaggregation of the transport sector:
  - ➢ individual transport and public transport separately
  - ➢ different passenger vehicle technologies (CV, HEV, PHEV, BEV)
- Detailed depiction of preferences in population w.r.t. vehicle purchase decision
- Electricity sector development
- Quantification of external environmental effects associated with emissions stemming from vehicle use, electricity generation, and economic production

Overview of the hybrid modeling framework

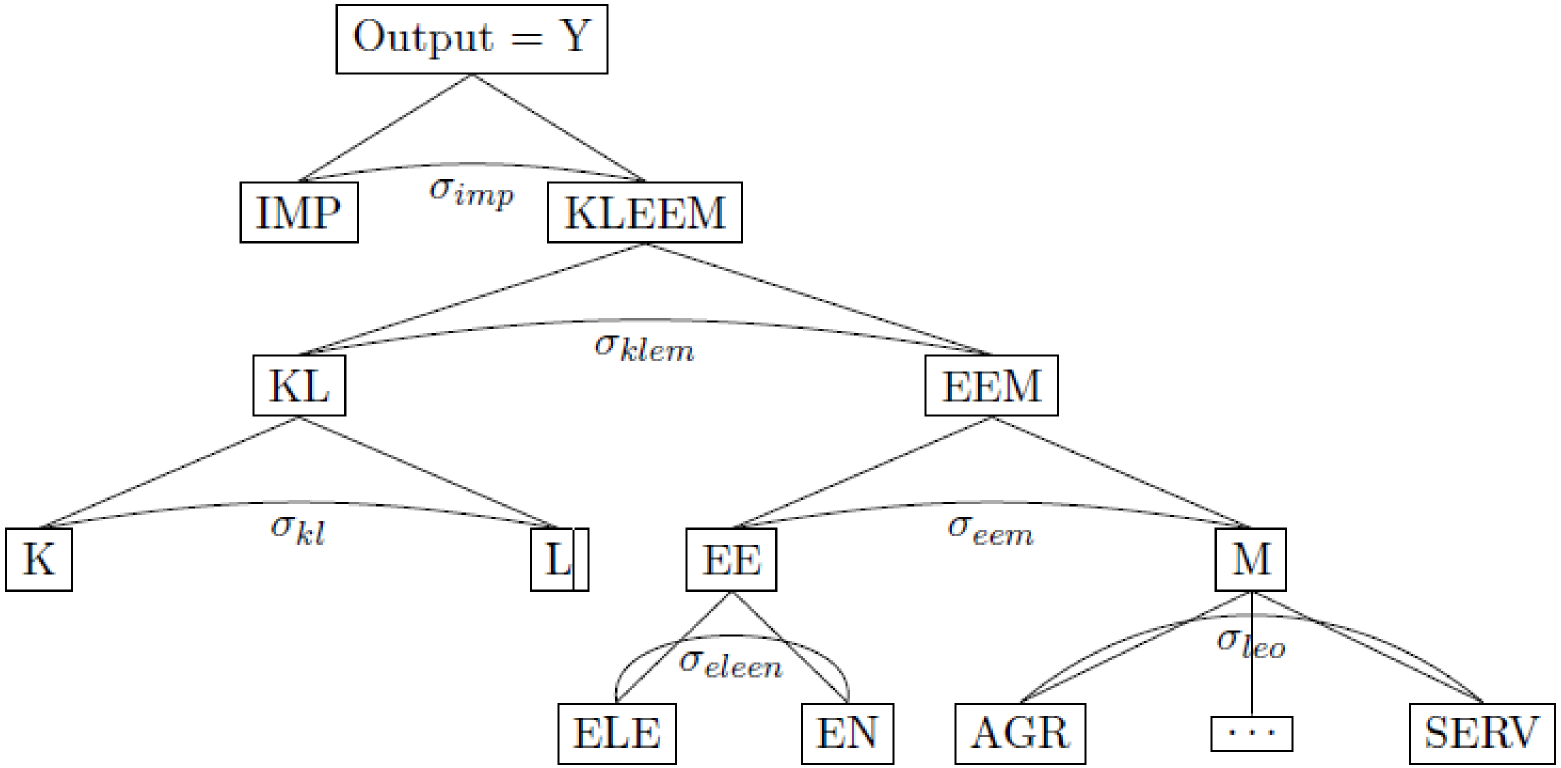
- consumer decisions on vehicles, firm decisions on power generating technologies, and modelling of economy-wide effects (Böhringer and Rutherford, 2009)
  - Dynamic CGE based on Böhringer and Rutherford (2008)
  - Incorporated discrete vehicle choice model
  - Enriched electricity sector with various energy producing technologies
  - detailed stock-flow consistent vehicle fleet accounting
  - Soft-link with environmental benefit assessment
- a **comprehensive simulation tool for assessing economy-wide impacts** of various tax and subsidy policy instruments – counterfactual scenario approach

Model overview, focused on vehicle choice

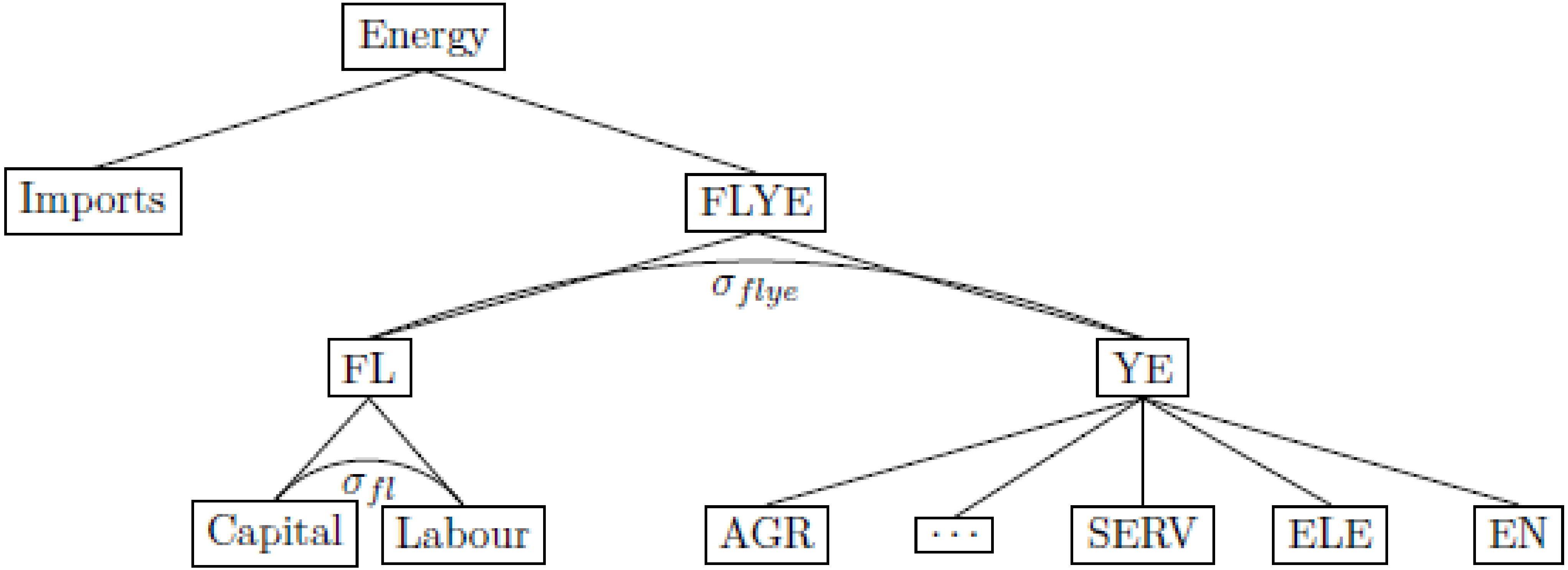
	Total costs optimisation	Consumer behaviour	Energy sector development	GE economy effects
[redacted]				
Agent-based		✓		
[redacted]				
PE energy system optimisation	✓	partly	✓	
[redacted]				
Hybrid CGE model (our model)	✓	✓	✓	✓

Computational General equilibrium model

- 22 production sectors *(ENG, CAR, VEH …, FUEL, CAR_SERV, ELE, ELE_INF,..)*
- production of sectoral goods and energy production **determined** via nested **CES** production function



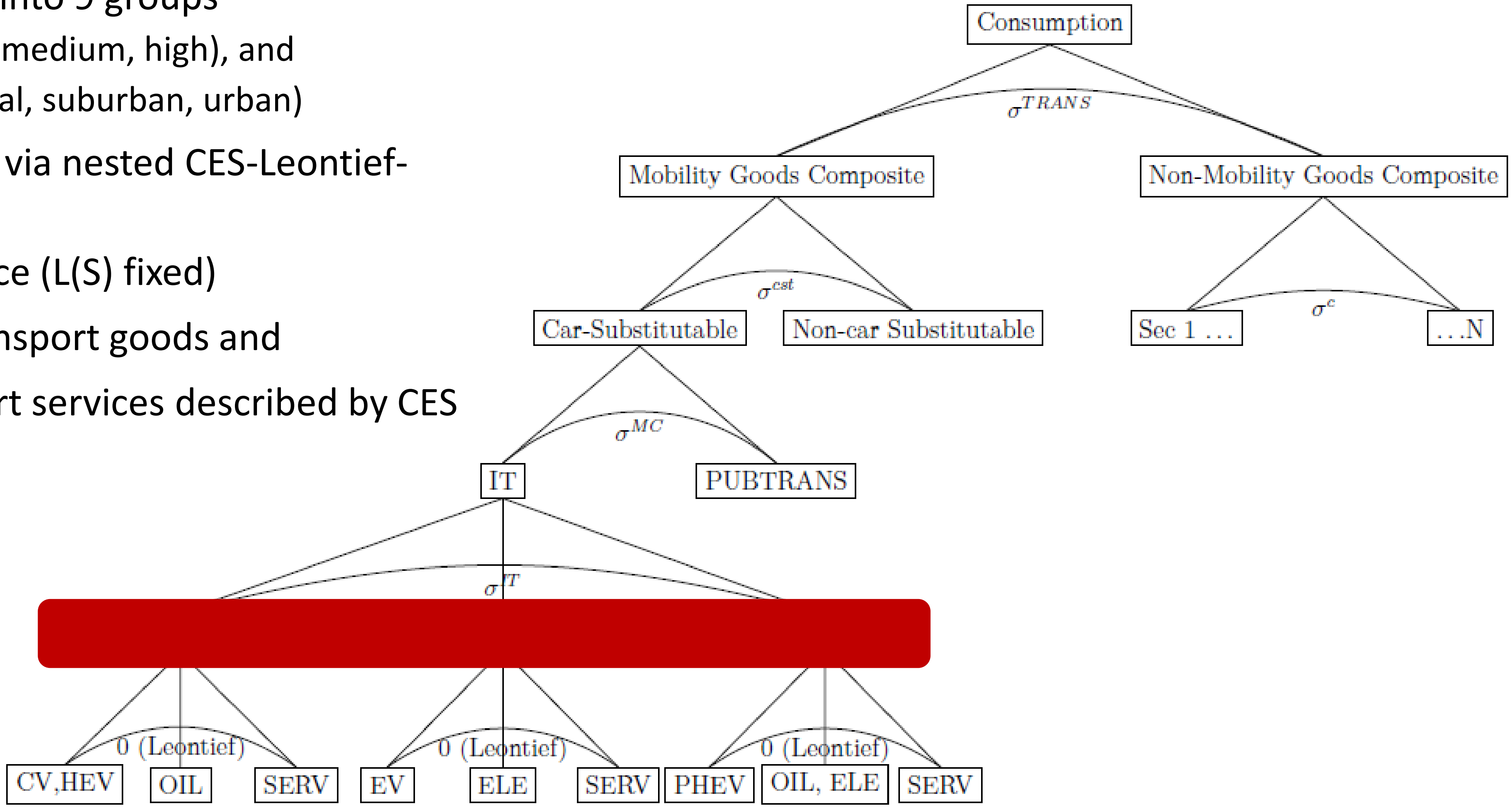
Nesting structure of energy production



- Imports of fossil fuels play a major role

Nesting CES consumption structure

- Households divided into 9 groups
  - 3 skill levels (low, medium, high), and
  - 3 living-areas (rural, suburban, urban)
- Utility maximization via nested CES-Leontief-Logit
- Labour/Leisure choice (L(S) fixed)
- demand for non-transport goods and
- demand for transport services described by CES



Vehicle Discrete Choice Model

- **Consumers preferences** over four vehicle technologies elicited through the discrete choice experiments (Bahamonde-Birke and Hanappi 2016 for Austria)

- **Utility parameters** estimated by CL for 3 location-specific groups *plus* adding interaction terms by ASC and education level
  - for calibration process, CL estimated with limited number of attribute variables (purchase price, fuel+O&M costs, driving range) absorbing the rest in the ASC's (Truong and Henscher, 2012)
  - **probability to choose j** derived from utility parameter estimates

- Hard-link: since the choice probabilities represent the aggregate level of the nine agents in the CGE model, they can be interpreted as **endogenous market shares** of purchases of car *i* in total car purchases of household *h* (see Truong and Henscher 2012)

Vehicle Stock-flow Model

- The resulting numbers of car purchases (i.e. yearly **new registrations**) of each vehicle type feed into the built up of vehicle stocks.
- standard **accumulation and depreciation process**, assuming 12 years lifetime

$$st_i(t) = st_i(t-1) + nr_i(t-1) - dc_i(t-1) \qquad \forall i, \forall t.$$

where CV depreciates with a constant rate

and AFVs do not depreciate for first 12 years $\quad dc_i(t) = st_{CV}(t) \cdot \delta_{CV} \quad for\ t \leq 12.$

- **Hard-link** to the CGE model
  - Car use: demand for **fuel**, and **service and maintenance** are determined according to the development of the stock of each technology over time. Stocks of BEVs and PHEVs demand **electricity** (ELE_INF) supplied by ELE.
  - **Car production** (CAR, ENG, CAR_SERV)
  - both disaggregated by 9 household agents

Electricity sector

- Multiple electricity generating technologies:
  - Coal, natural gas, oil, nuclear, hydro, wind, solar, biomass and other (LPG)
  - Aggregated generation of electricity (here) meets aggregated demand entered from the CGE
  - Unique market price for ELE given by production costs of the most expensive source
  - We solve a linear programming problem as in Böhringer and Rutherford (2009) simultaneously for the electricity sector and the whole economy
- Hard-link → electricity supply from the bottom-up enters via **ELE sector** to the top-down

Environmental benefit assessment

- **Damage factors** derived from the ExternE's Impact Pathway Approach for air quality and GHG emissions
  - Fuel use by cars (TREMOVE by vehicle type)
  - Electricity generation (CASES database per electricity generating technology)
  - Domestic economy (CREEA's EXIOBASE v2)
  - Footprints embodied in imports (modelled by EE MR IOT using EXIOBASE)
- Health impacts, effect on ecosystem, materials, and climate change

- <u>Soft-link</u>> (FUEL, ELE, production) and (ExternE's damage factors)

Data

- Social Accounting Matrix – extended national I/O tables
- Vehicle Registers – new registrations and stock
- Households
  - SILC, CES
  - DCE surveys - 1,449 Austrian respondents (Hannappi & Mayr, 2013; Bahamonde-Birke & Hanappi, 2016)
- Energy statistics, EXIOBASE CREEA database

Setting the Scenarios

- Counterfactual scenario setting:
  - Business As Usual (**BAU**) scenario: expected development of the economy
  - Modest adoption of electricity driven vehicles (**MODEST**)
  - Electromobility Plus (**EM+**)

BAU

- **Energy technology capacities** grow as forecasted by UBA
- Realistic development of **fuel costs** and **car purchase prices**
- Already **introduced policies**:
  - new registration tax for vehicles (NOVA) with a reduction for AFVs
  - an increase in mineral oil tax (occured in 2011)

➢ Result: a very small shift-in of AFVs, basic preferences of households are not changed, fuel and price effects have minimal influence

MODEST assumptions
… diverges from the BAU in two ways

MODEST A

- **Mild private investments into charging station infrastructure**
  - 1.25 charging stations per electric vehicle

MODEST

- MODEST A
- **Shift-in of household preferences** towards AFVs

EM+ assumptions

…diverges from the BAU even more…

EM+ A

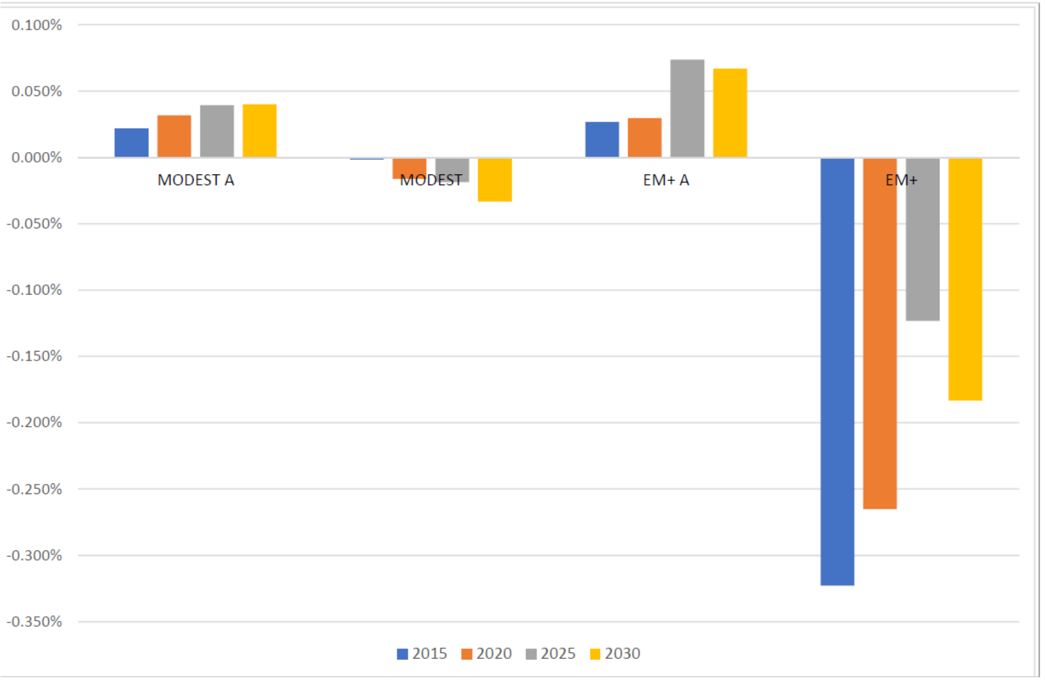
- Larger expansion of **charging infrastructure**
  - 1.5 charging stations per electric vehicle
  - Available in public space, P+R, shopping centers, working places, garages

EM+

- EM+ A
- **Rise in mineral oil tax** by 5 cents in 2015 and again in 2019 → **fuel cost** +3% by 2015-2019, +7% 2020-2030
- **NOVA** – 105 g/km from 2015 and 95 g/km from 2020 → **purchase price** favouring the AFVs: CV +9% , HEV -3%, PHEV -7%, BEV -2%

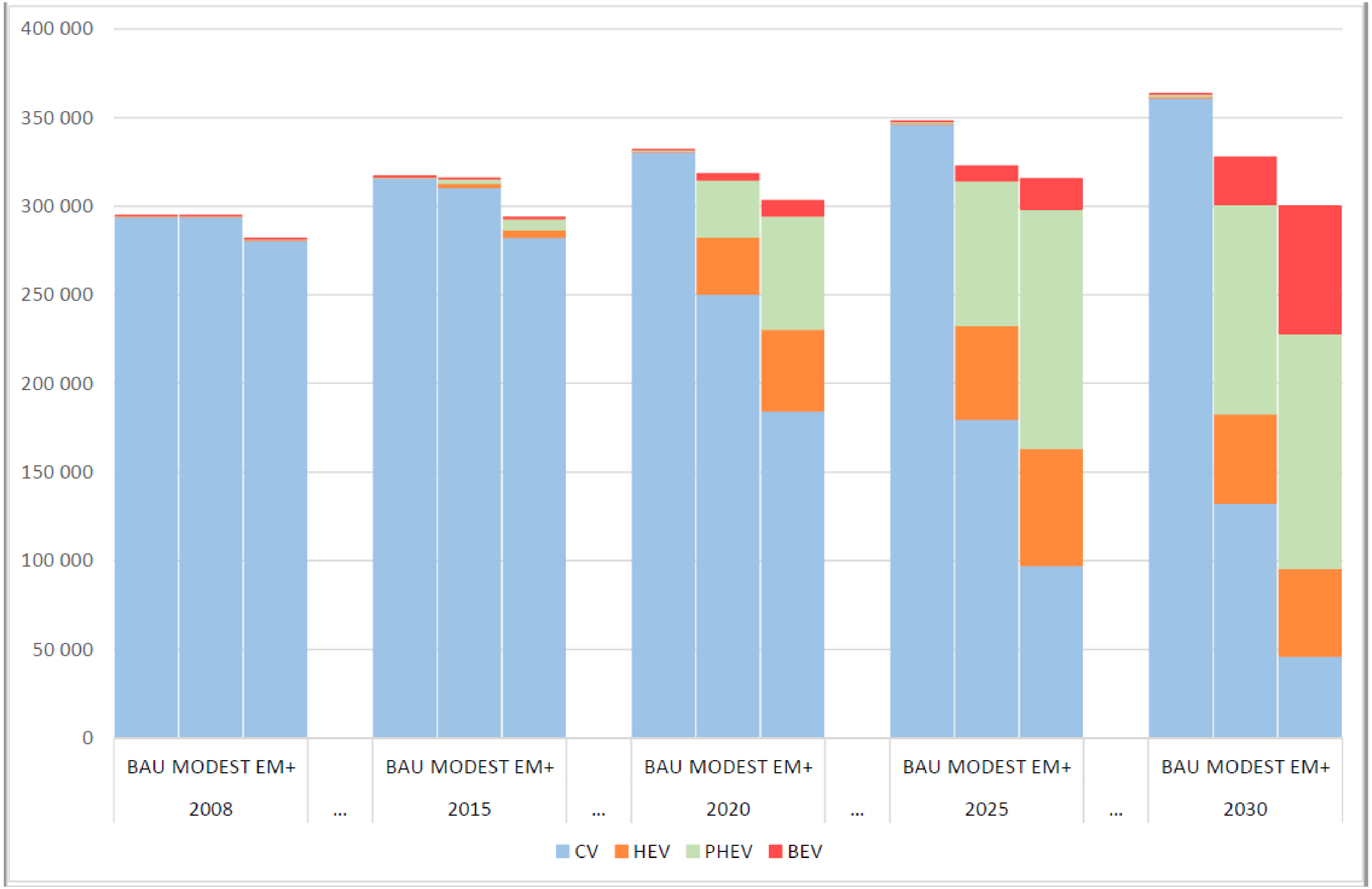
Output and GDP impact, deviations from BAU

Year	2010		2015		2020		2025		2030	
Scenario	MOD	EM+	MOD	EM+	MOD	EM+	MOD	EM+	MOD	EM+
Sector impact										
PT	0.00%	-0.05%	0.00%	-0.02%	0.02%	-0.04%	0.05%	-0.01%	0.07%	-0.04%
CAR-SERV	0.00%	-0.29%	-0.04%	-1.93%	-0.51%	-4.01%	-0.92%	-4.05%	-0.35%	-2.46%



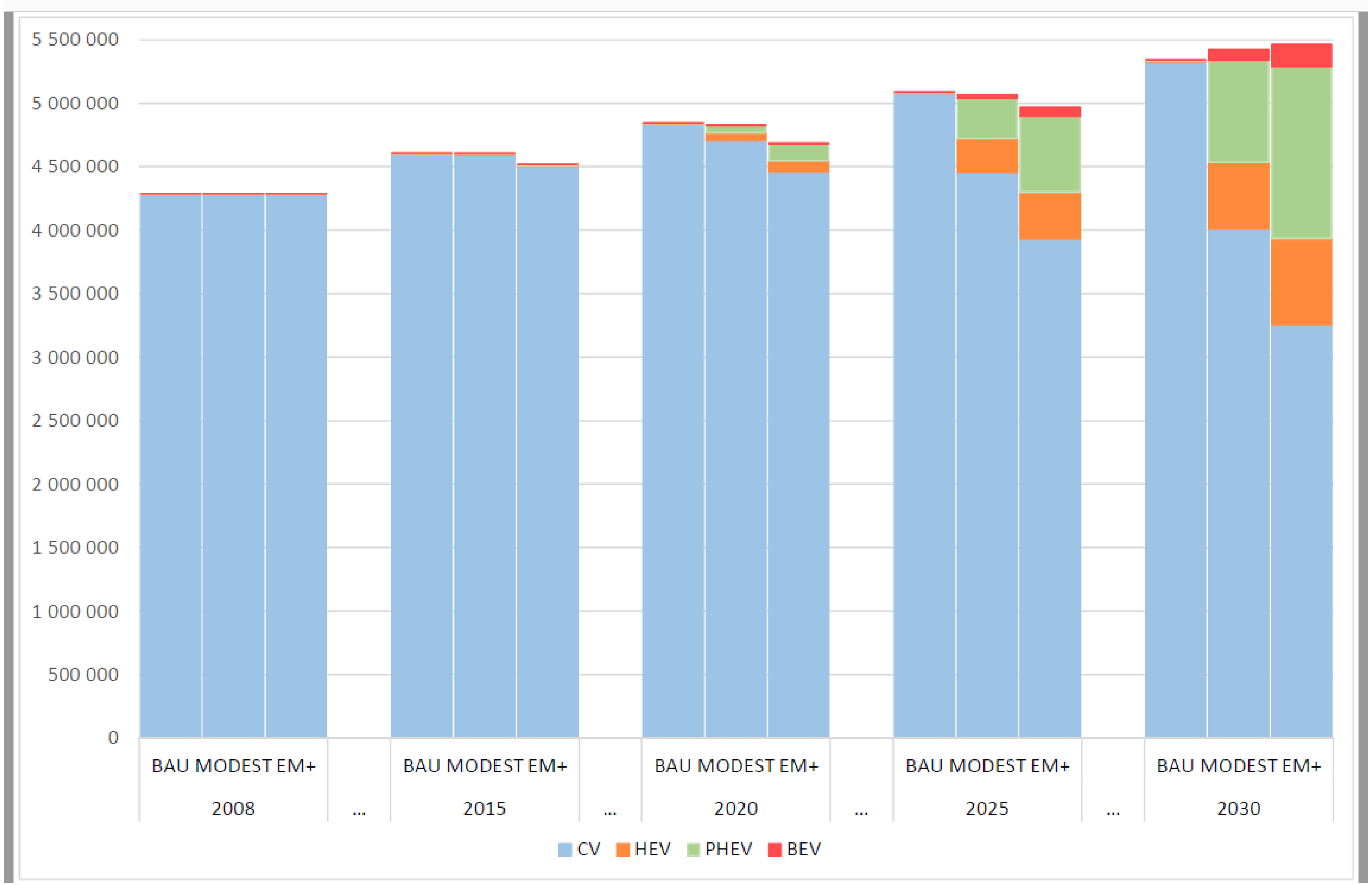
- **recharging infrastructure** = ↑ GDP +0.02 % in MODEST and +0.1 % in EM+.
- **household preferences** = ↓ GDP 0.03 %
- ↑**taxes** = ↓ GDP 0.2 % in 2030.
- ↓ household **income**, and consequently welfare (EV)

Number of **new vehicle registration** by technology, 2008-2030 in BAU, MODEST, and EM+



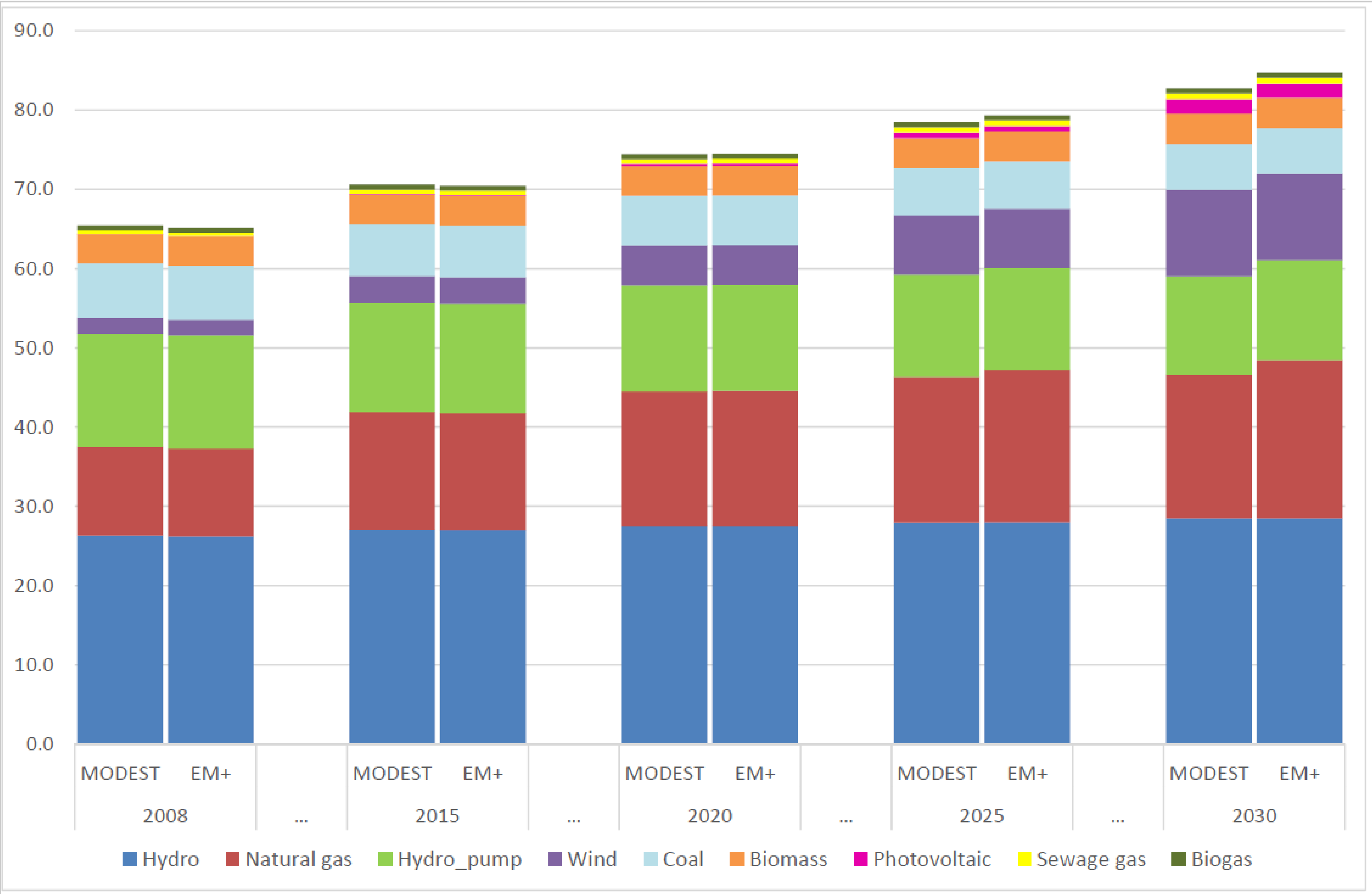
- EM+: rising share of **EV registrations**, **68 %** in **2030**.
- the **number of newly registered cars declines** over w.r.t BAU due to a **shift** in consumer preferences **away from IT to PPT,** as an effect of the increased **price** of the IT bundle.

Number of vehicles in the vehicle **stock** by technology, 2008-2030 in BAU, MODEST, and EM+



- **EVs 28 % in 2030, CVs** less than **60 %.**

Electricity generation technology mix in MODEST and EM+



Ele demand is increasing between 2008-2030 (**27%** in MODEST, and by **29%** in EM+)

2.3% of ele for **recharging batteries** in EM+ in 2030

High share of **RES** even in 2008 (72.5%) stay in 2030 (70%).

Gas is dominated fossil fuel (18%-24%).

Environmental benefits quantification – EM+

	GDP loss [mil. €]	EB Domestic sectors [mil. €]	Env Ben FUEL [mil. €]	EnvBen ELE [mil. €]	EnvBen Imports [mil. €]	TOTAL Envi Benefits [mil. €]	Damage as % of GDP loss	ΔCO2 (ths. t)	Ancillary benefits – Domestic *[€ per t CO2 abated]*	Ancillary benefits – Total *[€ per t CO2 abated]*
[redacted]										
2015	-1008	21	41	4	37	103	-7	816	153	106
[redacted]										
2025	-424	22	79	-18	14	98	-20	520	248	167
[redacted]										

Fuel use, emissions, and related environmental benefits

- The **increase** in the **fuel use** accompanying a larger vehicle stock is **offset** by the consumers' **shift** in preferences **towards EVs** resulting in a decline of fuel used in IT by 5.4 % and an **overall reduction** of fuel demand by 10.7 % in 2030 in EM+ in comparison to BAU.
- EM+ helps to **reduce** all considered domestic air quality **emissions** with the **avoided damage** amounting to 0.5 % compared to BAU. This benefit helps to reduce the GDP loss by about 10 %.
- The monetary value of the **fuel use reduction exceeds** the higher **damage** induced by an increased demand for **electricity** to charge vehicle batteries and together with the other abatement channels create **positive net environmental benefits**.

Conclusions

- The relatively **small magnitude** of impacts is due to two effects:
  - Austrian power sector has been **already** relying on **RES**
  - although the new registrations of BEVs and PHEVs are increasing, this increase is becoming especially **prominent after 2022-25**, which has only a limited effect on the vehicle stock until the end of the observed period in 2030.
- Our modelling approach was able to capture these small effects nonetheless, and as such, it can be applied to **other** national **economies** with different energy systems relying more on non-renewable resources.
- The model simulations show that the vehicle market depicted in the model can react flexibly to a shift in preferences by consumers towards electromobility.
- Extending this framework could provide insight on to what extent the net social costs of a shift-in of electric vehicles **differ between countries**, different **energy systems** and sets of **policy measures**.

DEFINE

Development of an Evaluation Framework for the Introduction of Electromobility

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