The aggregate effects of energy transition policies in the French power system in the long run

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Introduction

Motivation

- France is committed to an ambitious energy transition that aims for carbon neutrality by 2050
- **Mass electrification** = the big chunk of the low-carbon transition policies
- The **interplay between the power system and the economic system will be stronger in the future**

→ the interaction between electricity and fuel and their respective prices – a relevant issue when analyzing low-carbon energy transitions

Research question

- **Main macroeconomic transmission channels of low-carbon transition policies in the power system** under two scenarios of the evolution of the power system qnd three paths for oil prices
- **Describe the interaction between economic and technical systems**

… how policies can influence the evolution of technologies and the evolution of agents' preferences

- **Effect of macroeconomic feedbacks on long-run electricity consumption and generation**

… energy policies based on bottom-up models without any consideration of the rest of the economy

Literature

- Transmission channels of the oil price to the economy - Pindyck and Rotemberg (1984), Kim and Loungani (1992), Finn (2000), and Kilian (2008)
- Long-run aggregate economic effects of energy and environmental policies – Dhawan et Jeske (2008), Böhringer and Rutherford (2013), Golosov et al. (2014), Annicchiarico et Di Dio (2015), Argentiero et al. (2018), Metcalf and Stock (2020)
- Others study the economy-wide effects of supply- or demand-side policies in the power system - Lutz et al. (2015), Mayer et al. (2019), Sievers et al. (2019), Bachner et al. (2020), Ulrich and Lehr (2020), Agurto et al. (2021), Blagrave and Furceri (2021), and Schreiner and Madlener (2021)

Conceptual framework

A hybrid electricity-economy model calibrated on French data

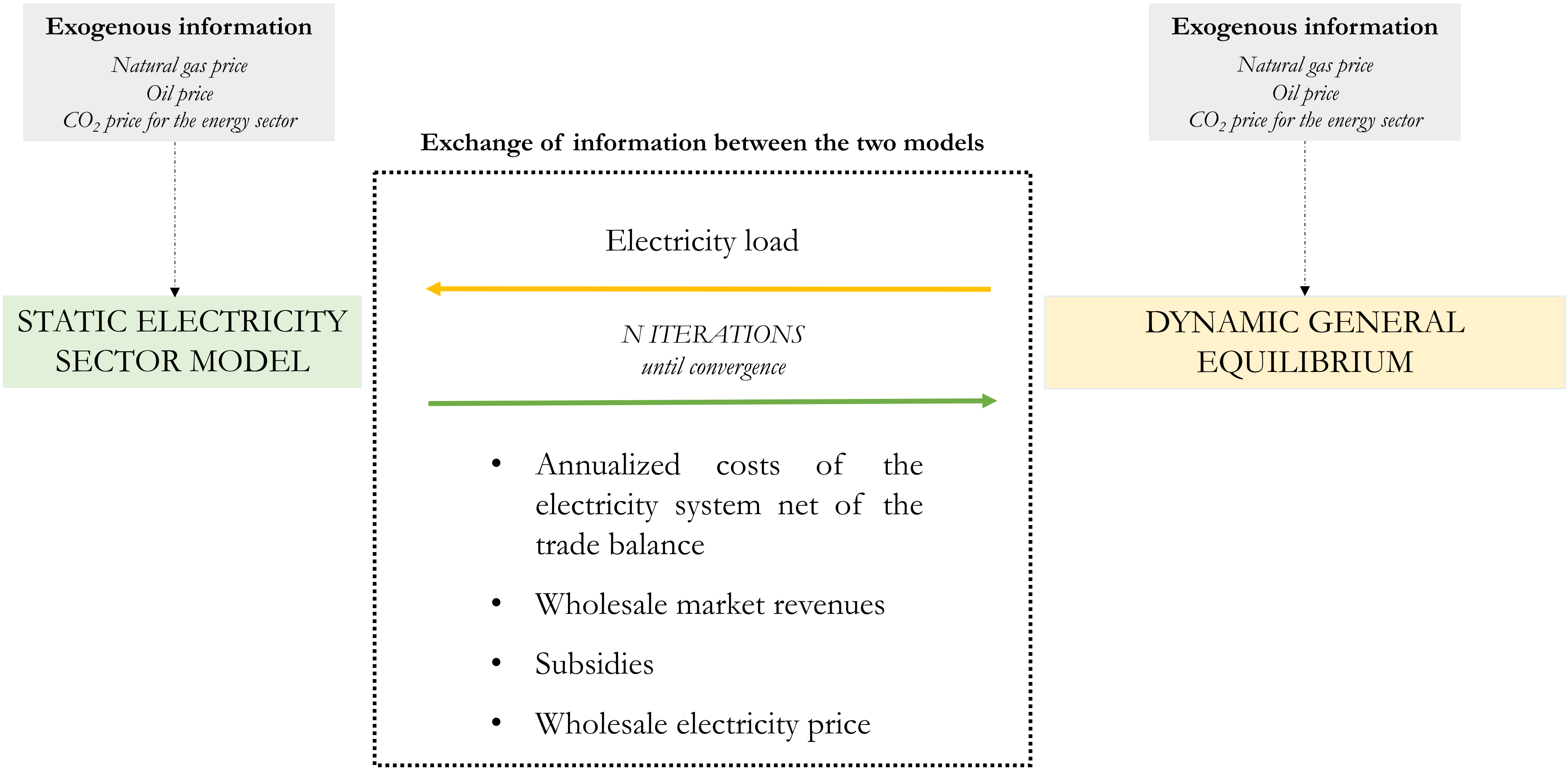

Figure 1. Interactions between the top-down and the bottom-up models

Modelling properties of the dynamic GE (toy) model

- General equilibrium models they allow macroeconomic feedbacks loops when forecasting energy demand
- **Characteristics of the calibrated GE model**
  1. Four agents – final good firm, public authority, two heterogeneous households
  2. Energy services produced from durable/capital goods and efficient energy use
  3. Two types of energy-saving technical progress
  4. Energy and environmental taxes
  5. Redistribution mechanism towards households
  6. Estimation of energy-related substitution elasticities for households and the final good firm

A technology-rich model of the electricity market at the European scale

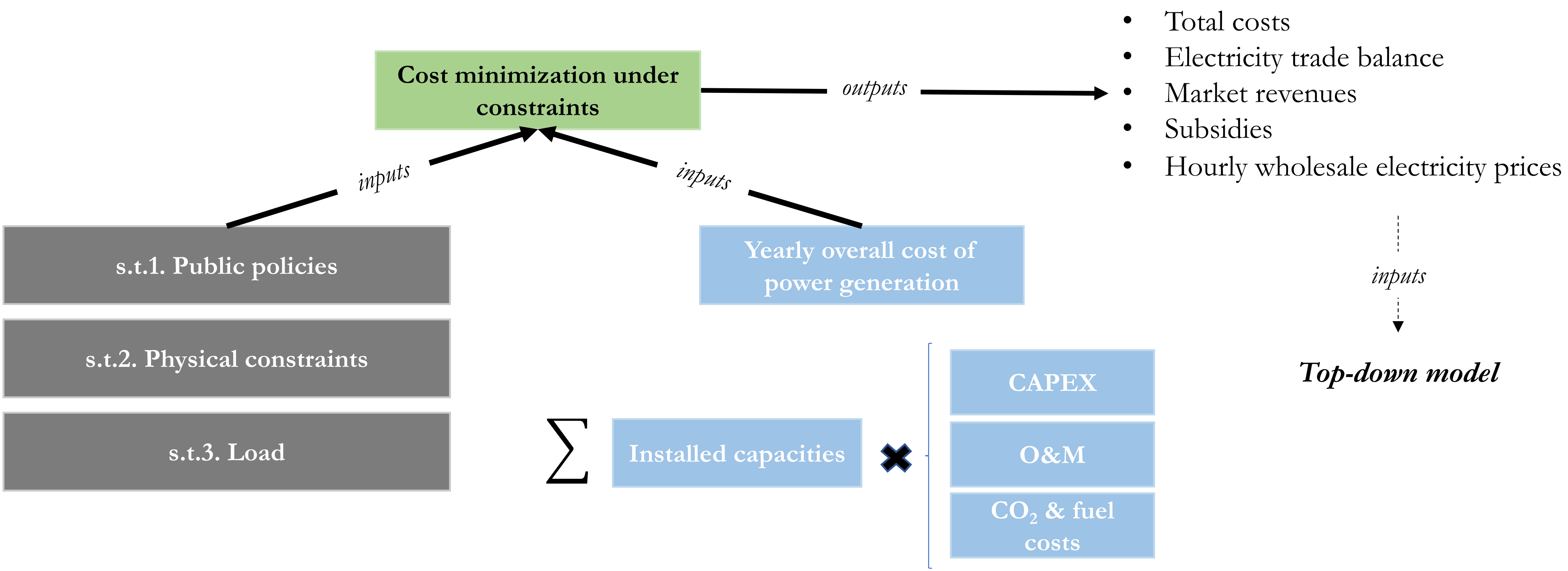

Figure 2. A simplified representation of model MICaDO – Camu (2016)

Scenarios

Two scenarios of the energy transition in the French power system

	1 AMPÈRE	2 VOLT
Mix by 2035	• Nuclear at 46% of the power generation mix *(50%)* • 0 extra thermal-fired power plants • Coal-fired power plants phase-out	• Nuclear at 56% and RE at 40% of the power generation mix • 0 extra thermal-fired power plants • Coal-fired power plants phase-out
Demand by 2035	• EVs fleet ~ 16 millions • Higher transfer of uses ~ +87 TWh • Higher energy demand control (refurbishment ~ 700K/year) ~ -161 TWh	• EVs fleet ~ 8 millions • Transfer of uses ~ +46 TWh • Energy demand control (refurbishment ~ 500K/year) ~ -123 TWh

Hydrocarbon and CO_2 prices, and carbon tax by 2035

Sustainable Development (IEA) → Medium

Stated Policies (IEA) → High

Saudi Aramco + Sustainable Development (IEA) → Low

	High	Medium	Low
Oil price	80 €2018/barrel	52 €2018/barrel	34 €2018/barrel
Natural gas price	24 €2018/MWh	22 €2018/MWh	22 €2018/MWh
CO_2 price on the ETS market for energy industries	32 €2018/ton	100 €2018/ton	100 €2018/ton
Carbon tax	180 €2018/ton	180 €2018/ton	180 €2018/ton

Table 1. Energy and CO_2 price in 2035 – Source: IEA and Saudi Aramco

Results

Electricity consumption scenarios are sensitive to macroeconomic feedbacks in the context of mass electrification

- Impacts of substitution mechanisms and temporal trade-off on electricity consumption is significant

… electricity consumption without macroeconomic feedbacks ~ 2-12% margin of error

	w/o macro feedbacks	**w/ macro feedbacks**		
		High oil price	Medium oil price	Low oil price
AMPERE *Renewable Energies ++* *Energy Efficiency and Transfer of Uses ++*	+ 0,12 TWh	+ 1,55 TWh	+ 0,60 TWh	+ 0,69 TWh
VOLT *Nuclear ++* *Energy Efficiency and Transfer of Uses --*	- 2,12 TWh	+ 1,03 TWh	- 0,12 TWh	- 0,02 TWh

Table 2. Compound annual growth rate of electricity consumption

Higher energy prices, increasing energy efficiency and subsidies towards the electricity sector are prompting decisions to decarbonize the economy …

		2035
Households	High oil price	-0,201%
	Medium oil price	0,044%
	Low oil price	0,217%
Firm	High oil price	-0,216%
	Medium oil price	-0,142%
	Low oil price	-0,103%

Table 3. Evolution of the relative fuel consumption *per efficient unit of labor* compared to 2018 – *Ampère scenario*

However, current policies may not be enough to reach the target of the French national low-carbon strategy

- **15% decrease in 2030 compared to 2012 ≠ 2030 national target of 40% to reach carbon neutrality by 2050**
- **<u>Policy recommendations</u>**

  … *floating carbon tax system*

  … *amplify energy efficiency and transfer of uses policies*

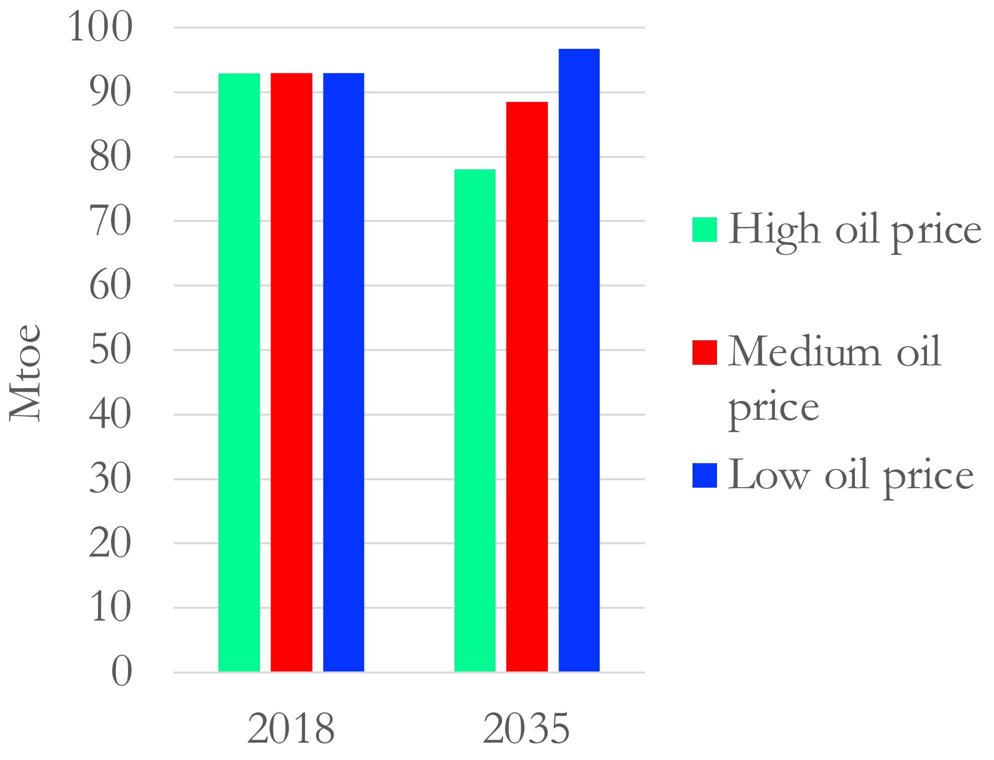

Figure 3. Fossil fuel consumption growth effects included – *Ampère scenario*

The potential growth effects of energy transition may be rather small (1/2)

- **Negative impact of ~ - 0.02 p.p./year on long-run growth**

1. electricity sector investments ~ 1.3% of GDP in France
2. new power generation technologies and low-carbon uses have no effect on labor productivity
3. carbon tax redistribution mechanism and substitution possibilities on the household side
4. *at the aggregate level*, energy costs ~ 3% of total production costs

	Non-durables consumption	Durables Investments	Capital Investments
High oil price	0,047%	-0,062%	-0,020%
Medium oil price	0,099%	-0,138%	-0,030%
Low oil price	0,137%	-0,217%	-0,040%

Table 4. Compound annual growth rate of variables (without growth effects) – ***Ampère scenario***

Households' economic well-being may improve in the long run thanks to substitution possibilities and carbon tax revenues redistribution

- **The peak in energy prices absorbed in part by**

… trade-off between durable and capital goods

… substitution towards non-durable goods

- The redistribution mechanism may reduce the regressive nature of the carbon tax on household consumption

	High	**Medium**	**Low**
Non-liquidity-constrained	0,0017%	0,0056%	0,0085 %
Liquidity-constrained	0,0004%	0,0042%	0,0069 %

Table 5. Household economic utility gains by 2035 compared to 2018 – *Ampère scenario*. *Utility gains are approximated by computing the steady-state consumption equivalent changes between two dates*

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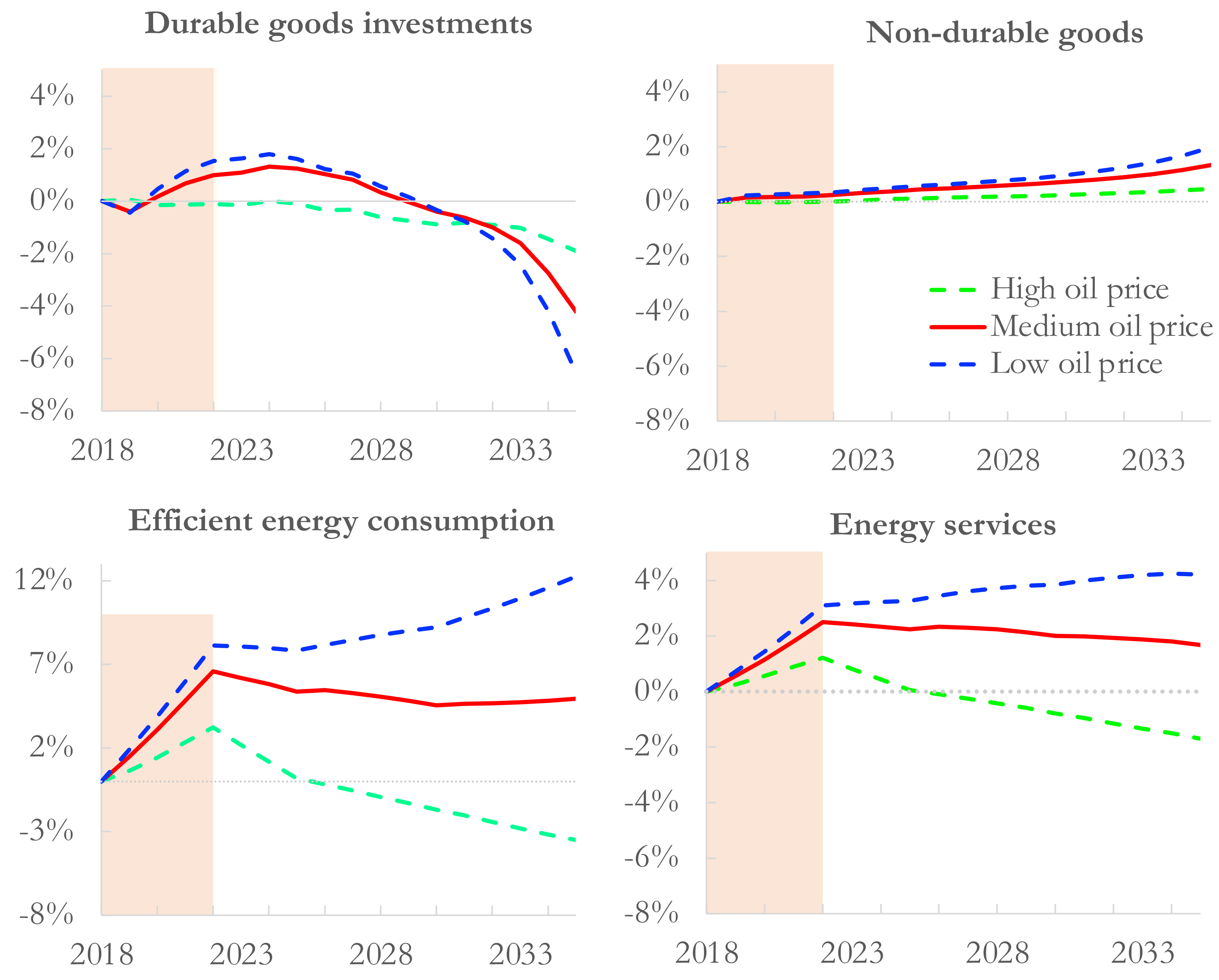

Figure 5. Dynamic response of variables per efficient unit of labor compared to 2018 – *Ampère scenario*

NON CONSTRAINED

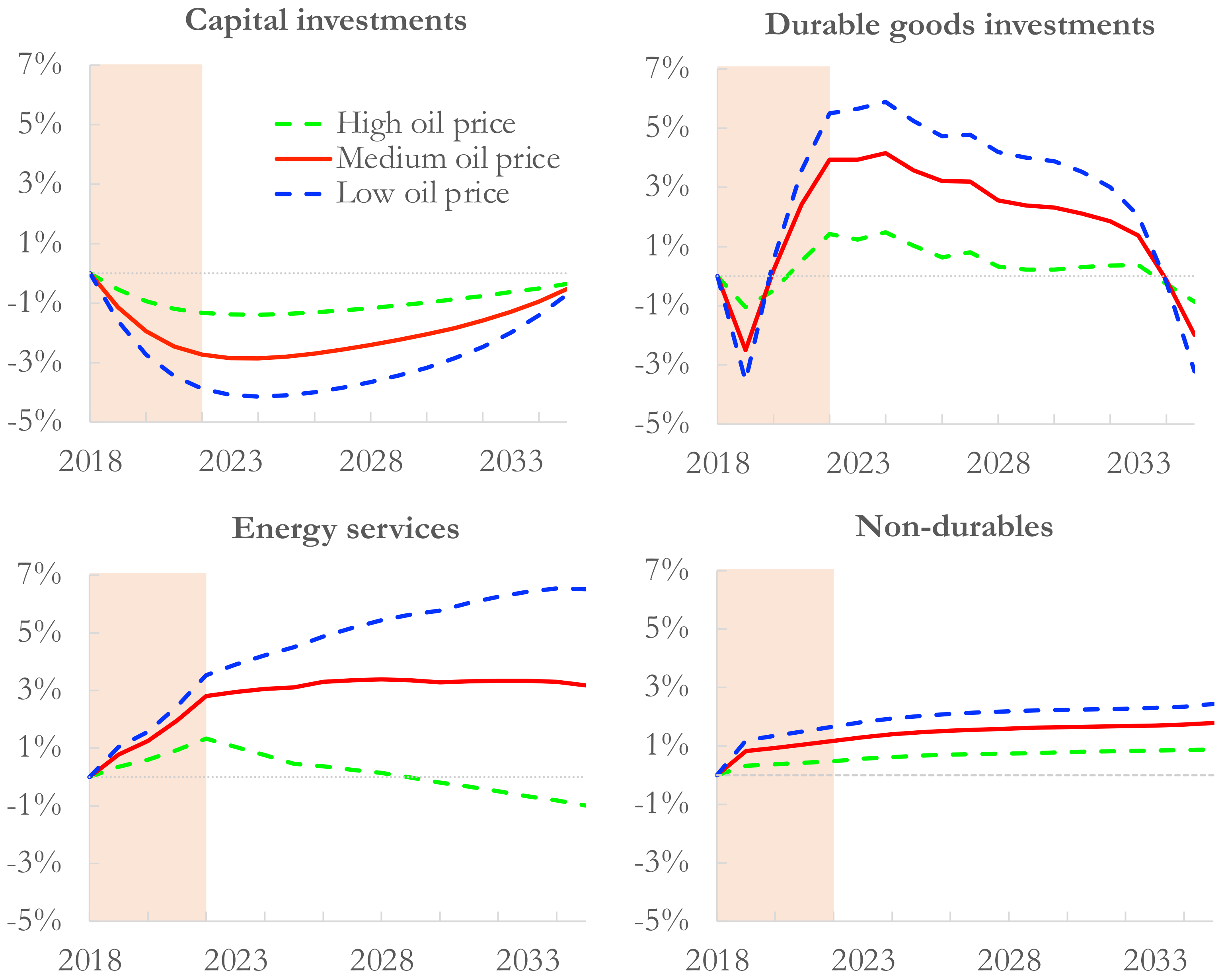

Figure 4. Dynamic response of variables per efficient unit of labor compared to 2018 – *Ampère scenario*

Despite an erosion of the taxable base of petroleum products, the switch to all-electric may not result to a loss of revenues for government

Fiscal revenues	Oil price	2025	2030	2035
Electricity	High	-8,93%	-12,93%	-16,65%
	Low	-9,51%	-18,19%	-21,29%
Fuels	High	11,04%	23,82%	33,20%
	Low	24,66%	47,66%	68,06%
V.A.T.	High	0,55%	0,60%	0,63%
	Low	1,81%	1,89%	1,61%
Capital	High	0,19%	0,51%	0,77%
	Low	0,35%	0,89%	1,20%

Electricity taxation freezing ← Electricity

Fuels → Carbon tax increase

Substitution in favour of non-durable goods ← V.A.T.

Capital → Higher electricity market revenues

Table 6. Fiscal revenues per efficient unit of labor compared to 2018 – Ampère scenario.

Positive impact on public finances [+0.05 p.p./year, +0.11 p.p./year]

Conclusion

- The interplays between investments in **durable and capital goods**, and between **relative energy prices** and relative energy efficiency are key transmission channels of low-carbon transition policies

  … With the right policies; the decarbonization of the economy and growth can be driven by technical progress and substitution mechanisms

- Importance of wholesale electricity prices and **detailed representation of electricity markets** when assessing the impact of low-carbon transition policies

- **Macroeconomic feedbacks** may have significant impacts on electricity outlooks

Appendix

Appendix 1. Electricity demand mechanisms

		Housing	Industry	Tertiary	Agriculture & Energy	Transport	
						Resid.	Non-resid.
AMPERE	*Control for energy demand*	-70,5	-22,2	-60,4	-2,5	-	-5
	New electricity uses	+20,5	+6,6	+22,4	+0,02	+25,7	+12,1
VOLT	*Control for energy demand*	-53,4	-18	-45,9	-2,3	-	-3,5
	New electricity uses	+8,3	+6,2	+11	+0,02	+13,5	+6,8

Table 7. Effect of demand mechanisms on electricity consumption in 2035 compared to 2016 (in TWh) – Data : Réseau Transport d'Électricité (RTE)

Appendix 2. Estimation of inter-energy substitution elasticities (1/2)

- Estimation from a single regression equation poor compared to a **simultaneous regression of a system of normalized non-linear equations**
- **Pros of the approach**

    1. inter-equation parameter constraints

    2. allows for the consideration of technical progress biased towards a factor

Appendix 2. Estimation of inter-energy substitution elasticities (2/2)

$$\begin{cases} log\left(\frac{p_t^{nel}.Nel_t}{p_t^e.E_t}\right) = log(1-\varpi_{el}) + \frac{1-\sigma_e}{\sigma_e}.\left[log\left(\frac{E_t}{\bar{E}}\right) - log\left(\frac{Nel_t}{\overline{Nel}}\right) - U - log(\vartheta)\right] + g_t \\ log\left(\frac{p_t^{el}.El_t}{p_t^e.E_t}\right) = log(\varpi_{el}) + \frac{1-\sigma_e}{\sigma_e}.\left[log\left(\frac{E_t}{\bar{E}}\right) - log\left(\frac{El_t}{\overline{El}}\right) - Z - log(\vartheta)\right] + h_t \\ log\left(\frac{E_t}{\bar{E}}\right) = log(\vartheta) + \frac{\sigma_e}{\sigma_e - 1}.log\left(\varpi_{el}.\left(exp^Z.\frac{El_t}{\overline{El}}\right)^{\frac{\sigma_e-1}{\sigma_e}} + (1-\varpi_{el}).\left(exp^U.\frac{Nel_t}{\overline{Nel}}\right)^{\frac{\sigma_e-1}{\sigma_e}}\right) + i_t \end{cases}$$

Where,

ϖ_{el} : distribution parameter

σ_e : substitution elasticity

(U, Z): fuel and electricity efficiency respectively approximated from Fourier series or Box-Cox transformation

ϑ : normalization constant

$(\overline{Nel}, \overline{El}, \bar{E})$: normalization points of fuel, electricity and the efficient energy composite

Appendix 3. Wholesale electricity prices

	2025			2030			2035		
Fuel costs	High	Medium	Low	High	Medium	Low	High	Medium	Low
AMPERE (RE ++)	56,38	56,28	56,57	57,24	63,82	63,82	57,72	62,94	62,89
VOLT (Nuclear ++)	56,82	56,55	56,84	58,40	66,04	66,02	61,09	67,85	67,72

Table 8. Weighted average wholesale electricity prices for each hydrocarbon price path – Own simulations from MICadO

Appendix 4. The evolution of the relative fuel price

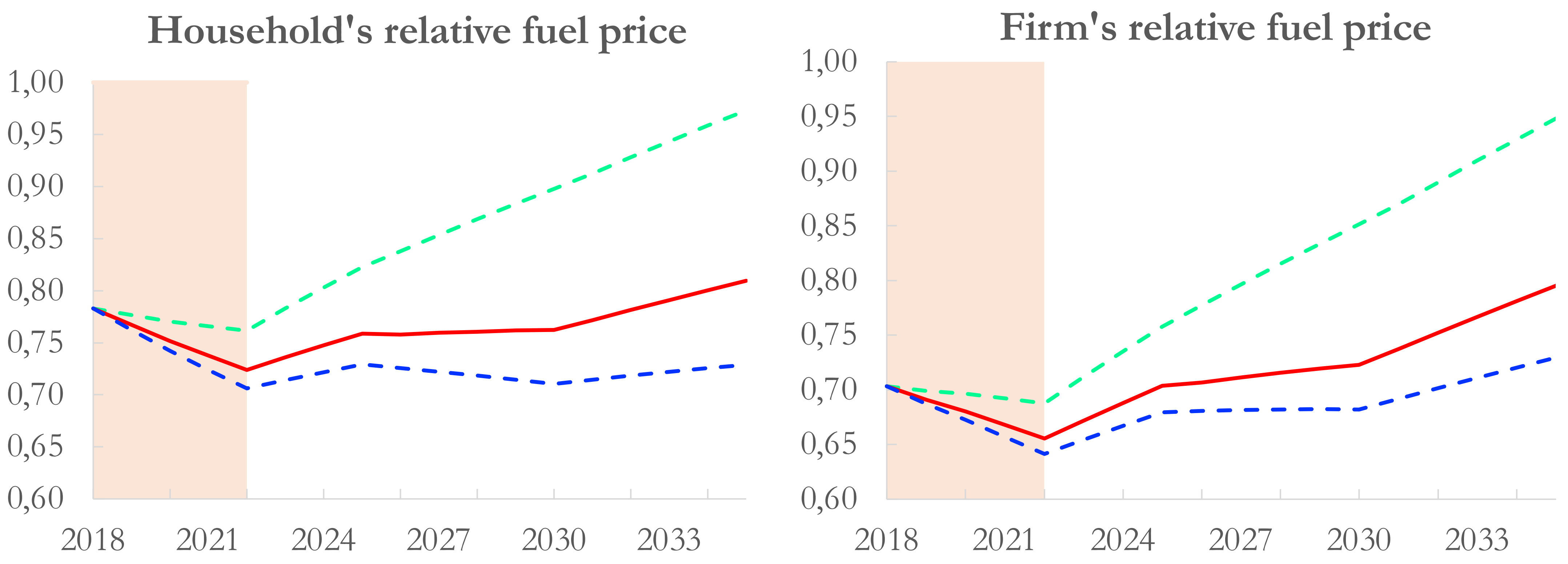

Figure 5. Evolution of the relative fuel price all taxes included – *Ampère scenario*

Appendix 5. French electricity sector investment costs in generation capacities and interconnections

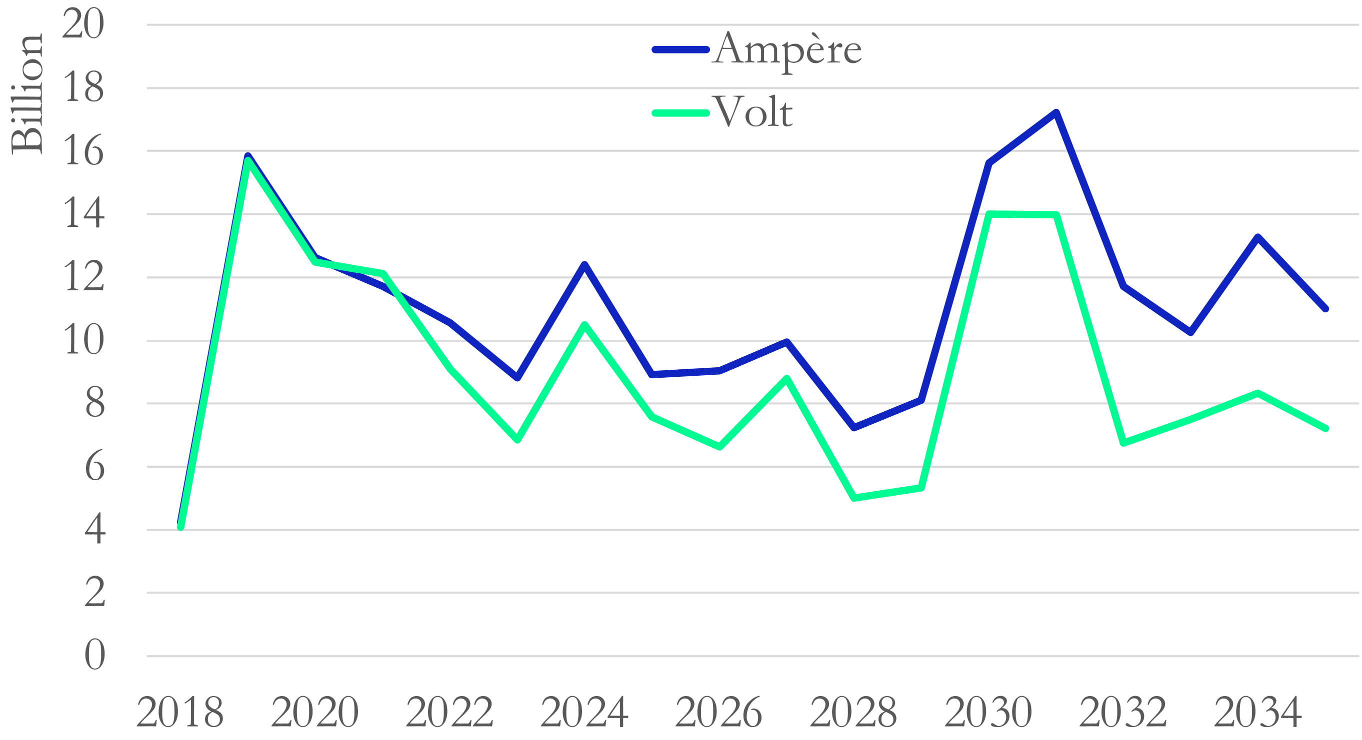

Figure 6. Evolution of investments into power generation installed capacities and interconnections – ***Source : Réseau Transport d'Électricité (RTE)***

Appendix 6. Robustness check

- Changing the value of substitution elasticities **does not change the dynamics of the model**

	Benchmark	**New value**
Household's inter-energy substitution elasticity	1.456	0.750
Firm's inter-energy substitution elasticity	0.513	1.250
Substitution elasticity between durable goods and efficient energy	0.750	0.450
Substitution elasticity between the capital-labor composite and efficient energy	1.006	0.400

Table 9. Substitution elasticities values for the robustness check

Appendix 7. Calibration of electricity efficiency based on RTE data

- The evolution of the electricity consumption depends on three effects: a growth effect, a "new electrified uses" effect and a "control for energy demand" effect.

- The growth rate is computed as follows:

$$g_t^{ael} = \frac{EL_{t-1}}{EL_t} - 1 \rightarrow \ EL_t = \frac{EL_{t-1}}{1 + g_t^{ael}}$$

- The computed electricity efficiency growth rate reproduces the electricity consumption trajectories of Ampère and Volt, excluding the growth effect, in the absence of a substitution effect between electricity and fuel due to macroeconomic feedback effects

Appendix 8. Calibration of fuel efficiency

- The annual fuel efficiency growth rate corresponds to the arithmetic average of energy efficiency growth rates (excluding electricity and growth effects) on French data from 1985 to 2018:

$$g_t^{anel} = \left(1 + g^l + g^n + g^l . g^n\right) . \frac{Nel_{t-1}}{Nel_t} - 1$$

- For the sectors of activity, the arithmetic average is 2.05%, and for households it is 2.09%. The paper retains a common rate of 2.07%

- Henriet, Maggiar and Schubert (2014) estimate, on French data from 1959 to 2010, an energy efficiency rate of 1.6%/year for households and 2.4%/year for companies

Appendix 9. The evolution of supply-side variables per efficient unit of labor