Macroeconomic modelling of electric cars penetration in EU28

Scenario results

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1 Introduction

The contribution of CIRED to the EV-STEP research programme is centred on macroeconomic modelling through implementation of the IMACLIM-P model, in link with the bottom-up expertise developed by the TIMES PanEU model of the IER of the university of Stuttgart.

Had time allowed, this linking would have taken the form of an iterative implementation of both models with exchange of outputs, up to convergence on the TIMES energy system trends (outputs of TIMES, inputs of IMACLIM)\(^1\) and on GDP (output of IMACLIM, input of TIMES). The EV-STEP programme turned out to provide too-limited resources, many of which had to be devoted to time consuming, but inescapable, data issues (cf. Ghersi, 2014),\(^2\) to allow for this ‘first best’ modelling option. As a consequence we substantially modified our take on IMACLIM implementation to develop a ‘second best’ modelling option, which we describe in section 2 below. In section 3 we report and comment upon the consecutive modelling results, first for pessimistic industrial variants in which the European automobile industry barely dominates its own electric car (EC) market and does not succeed in accessing international markets; then for optimistic industrial variants in which European exports develop even beyond domestic demand. In section 4 we conclude.

2 A revised one-way IMACLIM-P / TIMES PanEU linkage

The development of SMASH’s contribution to EV-STEP suffered two major delays. The first delay concerned the calibration of IMACLIM-P on European Union data, and stemmed from the unanticipated necessity to reconstruct an input-output matrix with uses expressed at consumer prices rather than at basic prices—Section 2 of deliverable 3.2 reports on this and details the consecutive unexpected data treatment effort.

The second delay happened in the wake of the first output report received from TIMES PanEU. This report revealed that TIMES PanEU projections were built on demographic projections substantially below the latest available EUROSTAT forecasts (Figure 1). It was then decided to update TIMES PanEU projections to the latest forecasts, but the discrepancy between the former and latest demographic forecasts made developing updated TIMES projections a tedious task. As a consequence, the updated TIMES PanEU runs came very late in the project. It thus became urgent to develop a consistent IMACLIM/TIMES projection in much less time that initially planned. We consequently abandoned the initial plan of iterating modelling runs to convergence, or at the very least to iterate once and allow TIMES to work on a GDP trajectory traced by IMACLIM.

\(^1\) The trends imported in IMACLIM from TIMES PanEU are thoroughly reported in Annex 3 below.

\(^2\)
The challenge was then to maximise the consistency between the two models without the option of iterating between them—in other terms, to implement IMACLIM as an ex post tool computing the macroeconomic background to TIMES PanEU modelling of the EU energy system.

2.1 Aligning a central IMACLIM trajectory on the REF- trajectory of TIMES PanEU

We therefore decided to focus our linking effort on the REF- scenario developed by TIMES (Table 1), i.e. that scenario least ambitious in terms of greenhouse gases (GHG) abatement and electric mobility penetration, which we deemed more compatible with the ‘business-as-usual’ GDP forecasts used by TIMES.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>REF-</th>
<th>REF</th>
<th>EU-</th>
<th>EU</th>
</tr>
</thead>
<tbody>
<tr>
<td>GHG abatement target</td>
<td>EU-ETS emissions: -21% in 2020 compared to 2005 then -1.74% per annum</td>
<td>Total emissions -20% in 2020, -80% in 2050 compared to 2005</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Renewables</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electric mobility</td>
<td>No target</td>
<td>National targets</td>
<td>No target</td>
<td>National targets</td>
</tr>
<tr>
<td>Biofuels</td>
<td>No target</td>
<td>National targets</td>
<td>No target</td>
<td>National targets</td>
</tr>
</tbody>
</table>

Table 1 Overview of 4 scenarios explored by TIMES PanEU

Source: Markus Blesl, IER

The exogenous GDP growth trajectory used by TIMES proved far above the reach of our initial “Harrod” treatment of technical progress, which bases growth, beyond demographic drivers, on

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3 TIMES PanEU provided us with data by 5-year steps only; for this series as for all other TIMES PanEU series we report on henceforth, the interpolation is ours (at a constant variation rate within each 5-year period, as explained in Annex 3). The small 2014 break in EUROSTAT data marks the passage from the statistical series demo_pjan to the population forecast proj_13npms.
exogenous improvements of labour productivity only. More precisely, IMACLIM, under the assumption of Harrod-neutral technical progress, required extreme labour productivity improvements (up to 4% a year for some decades) to approach the growth scenario backing up TIMES PanEU projections; besides, such labour productivity improvements induced high unemployment rates along our trajectory (up to 24%).

To fall back on more plausible productivity growth and employment rates, we consequently decided to move to a Hicks representation of technical change, i.e. to extend to capital the exogenous productivity gains that benefited labour only. Note that we only made this decision reluctantly and under the pressure of time: the question of the productivity of physical capital is not easily settled, be it only because it is linked to that of the measurement of the capital stock—in Annex 1, section 3.1, we describe with what care we calibrated our 2007 capital stock, both for lack of convincing statistics and lest the unemployment trajectory resulting from an ill-calibrated stock fell out of control. From a strictly subjective point of view, we doubt that the productivity of physical capital stock has actually grown in any way in recent years, possibly not since the burst of the Internet bubble fifteen years ago; and we consider it overly optimistic to believe that capital productivity could register sustained growth over our prospective horizon—in the runs that follow we increase capital productivity apace with labour productivity, which means we apply a 1.37% annual growth rate beyond 2020 up to 2050.4

It turns out, however, that extending productivity gains to capital allows IMACLIM’s growth trajectory under constraint of the energy system trends derived from the REF- scenario to align quite well on TIMES PanEU’s growth trajectory (Figure 2)—which only tends to demonstrate that this trajectory indeed builds on what we deem overly optimistic assumptions regarding capital productivity. To improve the match of both trajectories we only ended up limiting the development of international trade (EU28 export markets) in further years, reducing our exogenous export markets growth trend from 3% to 2.5% in 2026, to 2% in 2031 then to 1.5% in 2036 and further down to 1.0% in 2041.

Note that the 3 “crisis factors” \( \Omega_L, \Omega_K \) and \( \Omega_X \) as well as the wage moderation factor \( \Theta \), are adjusted as planned (cf. section 3.3 of Annex 1) to align IMACLIM under REF- energy constraints on observed 2007 to 2013 growth, unemployment and trade performance. All 4 factors are then phased out at a constant rate from 2014 on to 2020. They are left untouched in all subsequently explored scenarios.

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4 The rate is the average annual growth rate of GDP per EU worker between 2000 and 2007 according to EUROSTAT.
2.2 Developing the REF, EU and EU- scenarios as departures from REF-

The decision to ‘calibrate’ IMACLIM on the REF- scenario of TIMES PanEU turned out to imply an imperfect treatment of the alternative REF, EU and EU- scenarios. We might have chosen to adjust productivity improvements and export growth to accommodate the 3 other scenarios, thus systematically aligning IMACLIM’s projected GDP on the same single GDP trajectory used by TIMES PanEU for all 4 scenarios. Obviously, this would have barred any possibility of comparing the GDP achievement of scenarios, which is one of the central expected results of our endeavour.\footnote{We still would have had unemployment variations from one scenario to the other; we also could have compared the 4 scenarios in terms of their required productivity and/or export growth gains, but the analysis would have been delicate to interpret.} We thus resolved to rather analyse the 3 remaining scenarios by forcing the energy system trends specific to each of them on the unchanged macroeconomic parameterisation of REF-, \textit{i.e.} with all macroeconomic drivers and especially productivity and autonomous growth of export markets following their REF- scenario trajectories.

Section 3 however reveals that the EU and EU- energy system trends at least differ enough from those of REF- to significantly impact growth. This is where our TIMES-IMACLIM linkage remains unfinished: for the REF, EU and EU- scenarios, we report on IMACLIM results under constraint of energy system trends that are projected by TIMES for a GDP trajectory significantly different from that computed by IMACLIM. The gap between the two trajectories is indeed the justification of our initial intent to iterate model runs. If IMACLIM computes a GDP trajectory below that on which TIMES builds, then the energy system trends drawn from TIMES reflect energy demands above those required by the ultimate level of economic activity—and above those induced, for households, by the corresponding income level. Conversely, re-implementing IMACLIM under the less constrained energy system trends computed by TIMES for the lower GDP trajectory initially projected by IMACLIM is bound to positively re-evaluate that trajectory. Ultimately, the GDP impact computed by IMACLIM for what amounts to the first step of an (unexplored) iterative spiral convergence is...
overestimated, whatever its sign. We shall keep this in mind when concluding upon our modelling results below.

2.3 Trade balance assumption

Contrary to what was intended at the time of writing Annex 1, we eventually shunned from exploring alternative assumptions on the closure of IMACLIM. Throughout scenarios and competitiveness variants we stick to the standard assumption of an exogenous trade balance, matching statistics up to 2013 then maintained at 2.8% of GDP up to our 2050 prospective horizon. This amounts to assuming that monetary authorities throughout EU28 (including the European Central Bank for the Eurozone) effectively adjust the exchange rate of EU28 currencies to EU28 trading partners with a view to maintaining the average competitiveness of the European economic productions at its 2013 level up to 2050. This is indeed a pertinent assumption over a long term, but compared to the alternate option of mimicking constant exchange rates it has the disadvantage of partially masking potential short term impacts on the trade balance. A full exploration of this alternate ‘polar’ option, together with more subtle blends of the two options, is however outside the scope of our research and can only be performed in future research.

3 Modelling results

As evoked in the introduction, and with a view to contrasting our macroeconomic assessments of the impact of electric car (EC) penetration in the European Union, we develop two alternative transcriptions of the 4 energy systems scenarios devised by TIMES PanEU. These two sets differ in their optimistic vs. pessimistic stance on the ability of the European Union automobile industry to produce internationally successful electric cars. In the first two subsections below we explore the macroeconomic results and public budget impacts of the first (pessimistic) set of scenarios. In the third subsection we more succinctly report on the changes brought about by an optimistic stance on the trade performance of the EU electric car industry.

3.1 Macroeconomic costs of EC penetration in differing mitigation contexts

Under our pessimistic assumptions on the competitiveness of the EU electric car (EC) industry, the impact of EC penetration on growth is almost systemically negative, but only slightly so: for all years both the REF and EU growth trajectories are below their REF- and EU- counterparts (cf. Table 1 p.6). This is an expected result considering the terms in which we chose to describe the 2007 EC sector (cf. section 1.1 of Annex 1): one importing half its domestic sales from abroad; consuming, for its domestic production, batteries that are for 14% of them imported (the average import rate of the electrical equipment sector); substituting, at a twice higher cost, to conventional vehicles that are only for 8% of them imported goods (the average import rate of the motor vehicles and trailers sector). These conditions evolve along the scenario trajectories as terms-of-trade change, and under the influence of our assumptions on battery costs for domestic vs. imported ECs (cf. section 1.1 of Annex 1). However, in the 4 scenarios and at all time-steps the market share of domestic EC production never
exceeds 63%. The substitution of ECs to non-electric cars, whose imported share remains close to its 2007 value of 8%, therefore logically comes at some macroeconomic cost.

The magnitude of the impact on growth and its independence from the carbon mitigation context (Figure 3) is a more interesting result. In the REF scenarios, where 2050 EC sales shift from 348 thousand to 4.7 million units i.e. to close to a fourth of total personal car sales,\(^6\) GDP does not abate by more than 0.17% along the entire time trajectory—the maximum loss of 0.17% is reached in 2030, a moderate cost at such distant horizon. In the EU scenarios, where 2050 sales shift from 16.0 million (EU- scenario) to 18.8 million (EU scenario) vehicles, an 18% increase, the maximum growth impact is barely higher at 0.22% in 2025, then recedes up to 2050 at which time it is only of 0.08%. Incidentally, in 2050 the most constrained of our 4 scenarios, EU, is 3.1% below our least constrained REF- scenario: we evaluate the GDP cost of shifting from a ca. -50% target or factor 2 cut (REF-scenario)\(^7\) to a factor 5 cut with high EC penetration (EU scenario) at around 3 GDP points in 2050.

An in-depth scrutiny of modelling results backed by some sensitivity analysis reveals that these assessments find their source not only in the extra cost of massively imported electric cars, but also in the impact of scenarios on the price of electricity.\(^8\) TIMES PanEU reports electricity price hikes between the REF- and EU- scenarios—which only differ in their 2050 mitigation ambitions, cf. Table 1 p.6—of up to 66% in 2050 (Figure 4). It also reports that the marginal effect on electricity prices of

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\(^6\) Annex 4 reports on IMACLIM’s EC penetration trajectories and compares them to those extrapolated from TIMES PanEU data on vehicle stocks.

\(^7\) The exact cut is communicated in the report commenting upon TIMES PanEU runs. We did not bother tracking CO\(_2\) emissions in IMACLIM-P EU28 (although it would be an easy development of the model).

\(^8\) Among other sensitivity tests we checked that the trajectory of an EU scenario variant implementing the REF- electricity capital intensity (rather than the much higher intensity required to match the electricity price trajectory computed by TIMES for the EU scenario) remains within 1% below the REF- trajectory until 2040 and is at most 1.8% below it in 2050, to be compared with the 3.3% gap of the full EU scenario.
increased EC penetration peaks at +1.4% in 2030 in the REF context\textsuperscript{9} and at +3.6% in 2025 in the EU context, both dates which match these of the maximum GDP gaps.

These price hikes directly impact the cost structure of all productions as well as the budget of households, with obvious growth consequences—the provision of an identical kWh requiring a larger share of national income. They also play through the indirect channel of the capital market: compared to both REF scenarios, the share of the total capital stock immobilised in electricity production significantly increases in both EU scenarios (Figure 5).

\textsuperscript{9} This is more precisely the peak increase from 2007 to 2046. From 2047 to 2050 the price gap picks up again and climbs to 3.1%.

\textsuperscript{10} The producer price is equal to the sum of all production costs only \textit{i.e.} does not include sales taxes or subsidies, nor trade and transport margins. The reported prices are expressed in constant 2007 currency \textit{i.e.} relative to (deflated by) the GDP price index, which is computed as a chained Fischer index along the trajectory.
Under our assumption of an exogenous rate of investment, the electricity sector crowds out other production sectors on the capital market. Note that this relative capital shortage is bound to impact growth all the more as capital is a scarce resource. In this particular regard our extension of productivity gains to capital, which numerically amounts to a yearly increase of capital endowment, induces a lower estimation of GDP costs.

The relative abundance of the capital factor induced by arguably optimistic capital productivity gains also impacts unemployment results: it prompts unemployment to plunge to its 4% floor value once the effect of the crisis has worn off in 2020 (Figure 6). This trend turns out to be strong enough to dominate any influence of the mitigation and EC penetration scenarios. From the REF- to the REF scenario, the penetration of ECs induces a maximum 0.03 point increase of the unemployment rate in 2015, which amounts to a mere 75 thousand job loss. In the EU factor 5 mitigation context, the maximum increase is contained at 0.06 points, which amounts to a 147 thousand job loss.

![Figure 6](image)

**Figure 6** Unemployment rate, 4 IMACLIM scenarios

### 3.2 Public budgets impacts

The resources dedicated to EV-STEP did not allow us extending our IMACLIM model of the European Union to the secondary distribution of income. Consequently, the model does not provide a comprehensive coverage of public budgets: as any standard CGE it rests on the assumption of a representative consumer that owns all primary factor endowments and receives all tax payments net of public expenses; but it does not model direct taxes on firms’ and households’ incomes, and it lacks a description of social transfers to households. As a matter of fact it does not either model payroll taxes, for the simple reason that the EUROSTAT tables on which it calibrates do not disaggregate such taxes from total labour costs. All in all, the EUROSTAT “other net taxes on production” and the “taxes less subsidies on products” that IMACLIM explicitly models amount to 12% of 2007 GDP, *i.e.* to about 30% of a fiscal charge reported at 40% of GDP by EUROSTAT for that year.

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11 Contrary to national versions of the model especially dedicated to distributional issues.
Notwithstanding, we devoted a specific data treatment effort to separating excise duties from the “taxes less subsidies on products” aggregates. This effort revealed significant excise duties on electricity consumptions, higher than half those on refined petroleum products for households, and indeed almost on par with them for firms (Table 2, repeated from Annex 1).

This could incite to optimism about the impact of EC penetration on tax income. Two caveats however apply. First, the efficiency of ECs is currently much higher than that of conventional vehicles, and probably remains so along our trajectories even if technical progress on non-motor dimensions of personal vehicles can erode this advantage. The excise payments per toe should thus be translated in per passenger-kilometre terms to provide a more accurate preconception of how the penetration of EVs affects direct energy tax income.

Secondly, the rates on refined petroleum products are average rates computed over the total physical consumption of such products. But this consumption includes domestic and industrial fuel consumptions, which are much less taxed than transportation fuels. Our country-by-country computation for households thus reveals average levies of 578 Euros per ton-of-oil equivalent (€/toe) for transportation fuels vs. €139/toe for residential fuels. We use these two quite distinct rates to compute corrected excise payment trajectories on the basis of the demand trends imported from TIMES PanEU.

Beside excise payments, energy consumptions, for their households’ part at least, are the basis of VAT payments. For lack of statistics on the VAT levied on electricity vs. domestic and transportation fuels, and considering the closely similar rates applying to the various energy carriers in all MSs, we resolved to assume identical VAT rates on electricity and petroleum products when calibrating 2007 product taxes (cf. section 1 of Annex 1)—the common rate comes out at 12.0%. Similar to excise payments, this does not mean that the aggregate VAT income should be insensitive to the switch from

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12 Cf. section 1 of Annex 1. The non-excise part of these ‘taxes less subsidies’ is modelled as the product of a uniform ad valorem tax on final consumptions (by households, public administrations, and for investment).

13 We lack precise TIMES data to confirm this assumption.


15 Because the TIMES trends are forced into IMACLIM regardless of relative prices, the ex-post computation (computation made on modelling results) of excise payments delivers a quite precise statistics. We miss however the feedback of the adjusted conventional fuels payments on household demand.

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<table>
<thead>
<tr>
<th>Excise payment, €/toe</th>
<th>Sector code</th>
<th>Households</th>
<th>Firms</th>
</tr>
</thead>
<tbody>
<tr>
<td>On coal products</td>
<td>COAL</td>
<td>3</td>
<td>-</td>
</tr>
<tr>
<td>On crude petroleum</td>
<td>OIL</td>
<td>-</td>
<td>7</td>
</tr>
<tr>
<td>On petroleum products,</td>
<td>PPBW</td>
<td>411</td>
<td>142</td>
</tr>
<tr>
<td>biomass and waste</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>On electricity</td>
<td>ELEC</td>
<td>224</td>
<td>121</td>
</tr>
<tr>
<td>On gas, heat, steam</td>
<td>GAS+</td>
<td>50</td>
<td>28</td>
</tr>
</tbody>
</table>

Table 2 Calibrated excise payments on energy consumptions
conventional to electric vehicles. The former caveat of a higher efficiency of EC energy consumption identically applies—it should translate in a lower VAT income from EC penetration.

A second specific caveat is on the contrasted fuels vs. electricity prices: contrary to excises, in the case of VAT it is energy payments rather than physical energy consumptions that matter. Indeed, the absolute comparison of electricity vs. fuel prices in 2007 matters, together with their compared evolution to 2050. Feebly sensitive to the 4 scenarios, the producer price of petroleum products climbs steadily from €546/toe in 2007 to about €1030/toe in 2020, then less rapidly to between €1325 and €1369/toe in 2050 (depending on scenarios). The producer price of electricity starts at a comparatively much higher €1332/toe in 2007 then follows the scenario-contrasted dynamics already commented upon (cf. Figure 4 p.11).

One last element of the direct impact of EC scenarios on public budgets is the public subsidy on vehicle sales, which we felt compelled to assume as a minimal policy tool to facilitate EC penetration (cf. section 1.1 of our Annex 1). We posit (i) that the 2007 public subsidy amounts to a 4\textsuperscript{th} of the purchase price of vehicles, i.e. to €6,125 for vehicle sales to firms and €6,802 for vehicle sales to households; (ii) that it linearly decreases to 0 in 2020, to acknowledge the progress made on battery costs, which drop to 25% their 2007 value by 2020.

In a REF policy context EC penetration is marginally decreasing fiscal income from electricity and fuel sales (Table 3): the cumulated 2007 to 2050 total of 9,686 billion Euro payments registers a 1.4% drop to 9,543 billion Euros, as the increased excise (+€50 billion) and VAT (+€44 billion) payments on electricity sales do not compensate the decreased excise (-€144 billion) and VAT (-€80 billion) income from conventional fuel sales. Note that the 3.0% increase of excise payments on electricity lower than the 4.3% increase of VAT payments on electricity sales indicates higher electricity prices in REF than in REF—it is hardly perceivable Figure 4 above but REF electricity prices are on average 1.0% above REF- electricity prices.

\[\text{With crude oil expenses amounting to 72\% of refined products cost structure in 2007 this profile mostly translates the exogenous international oil price trend imported from TIMES PanEU.}\]
In the factor 5 policy context of EU scenarios, further EC penetration similarly decreases the cumulated fiscal income from electricity and fuels sales by 1.0%, a €92 billion difference over 43 years. The 1.6% increase of excise payments on electricity betrays a limited impact of the further EC penetration on total electricity consumption. Comparing this increase to the 2.9% increase of VAT payments on electricity hints at a 1.3% average increase of electricity prices between EU- and EU, which means that the price of electricity appears to still increase at a pace lower than that of electricity demand in the EU context—a supply curve sloped below 45 degrees but still approximately twice as steep as that similarly computed in the REF context.

Let us note, incidentally, the relative stability of excise payments on fuels, which in the EU scenario only lose 7% over the REF- scenario. This betrays largely inflexible fuel consumptions that are not abated when moving from a moderate factor 2 to a stringent factor 5 mitigation objective by 2050.

To complement this long term analysis on the whole projection horizon, we also report cumulated fiscal income on fuel and electricity sales from 2007 to 2020 (Table 4). We have observed how scenarios diverge over time and we expect smaller differences on that shorter term. Indeed, REF and EU cumulate fiscal incomes on petroleum products and electricity only 0.3% and 0.1% below those of REF- and EU-. The 0.3% and 0.1% divergences of the two mitigation settings amount to cumulated €9 and €5 billion fiscal income differences, arguably negligible at the scale of the EU. This however means that at €5 billion the cumulated subsidy to EC sales of the REF and EU scenarios, which was dwarfed by the total fiscal income over 43 years (cf. Table 3 above), amounts to a large share of their gaps to the REF- and EU- scenarios over the shorter 2007 to 2020 term.

Table 3 Cumulated 2007 to 2050 fiscal income from electricity and petroleum products sales, 4 IMACLIM scenarios

<table>
<thead>
<tr>
<th>Billions 2007 Euros</th>
<th>IMACLIM REF-</th>
<th>IMACLIM REF</th>
<th>IMACLIM EU-</th>
<th>IMACLIM EU</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cumulated excise on pet. products</td>
<td>5 904</td>
<td>5 760</td>
<td>5 562</td>
<td>5 472</td>
</tr>
<tr>
<td>Cumulated VAT on pet. products</td>
<td>1 317</td>
<td>1 237</td>
<td>1 186</td>
<td>1 132</td>
</tr>
<tr>
<td>Total on petroleum products</td>
<td>7 221</td>
<td>6 998</td>
<td>6 748</td>
<td>6 604</td>
</tr>
<tr>
<td>Cumulated excise on electricity</td>
<td>1 682</td>
<td>1 732</td>
<td>1 761</td>
<td>1 789</td>
</tr>
<tr>
<td>Cumulated VAT on electricity</td>
<td>784</td>
<td>818</td>
<td>973</td>
<td>1 001</td>
</tr>
<tr>
<td>Total on electricity</td>
<td>2 466</td>
<td>2 550</td>
<td>2 734</td>
<td>2 790</td>
</tr>
<tr>
<td>Gross total</td>
<td>9 687</td>
<td>9 548</td>
<td>9 482</td>
<td>9 394</td>
</tr>
<tr>
<td>Cumulated EV subsidy</td>
<td>1.1</td>
<td>4.9</td>
<td>1.1</td>
<td>4.9</td>
</tr>
<tr>
<td>Net total</td>
<td>9 686</td>
<td>9 543</td>
<td>9 481</td>
<td>9 389</td>
</tr>
</tbody>
</table>

N.B.: all modelling outputs deflated by chained Fischer GDP price index. Excise payments on petroleum products encompass residential and transportation uses; they are corrected ex post to account for contrasted residential vs. transportation rates (cf. supra) For the sake of consistency VAT payments on petroleum products are adjusted to mirror this correction.
<table>
<thead>
<tr>
<th>Billion 2007 Euros</th>
<th>IMACLIM REF-</th>
<th>IMACLIM REF</th>
<th>IMACLIM EU-</th>
<th>IMACLIM EU</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cumulated excise on pet. products</td>
<td>2 045</td>
<td>2 040</td>
<td>2 039</td>
<td>2 037</td>
</tr>
<tr>
<td>Cumulated VAT on pet. products</td>
<td>426</td>
<td>423</td>
<td>425</td>
<td>423</td>
</tr>
<tr>
<td><strong>Total on petroleum products</strong></td>
<td>2 471</td>
<td>2 464</td>
<td>2 465</td>
<td>2 460</td>
</tr>
<tr>
<td>Cumulated excise on electricity</td>
<td>522</td>
<td>523</td>
<td>518</td>
<td>520</td>
</tr>
<tr>
<td>Cumulated VAT on electricity</td>
<td>233</td>
<td>235</td>
<td>242</td>
<td>243</td>
</tr>
<tr>
<td><strong>Total on electricity</strong></td>
<td>755</td>
<td>758</td>
<td>760</td>
<td>763</td>
</tr>
<tr>
<td>Gross total</td>
<td>3 227</td>
<td>3 221</td>
<td>3 224</td>
<td>3 223</td>
</tr>
<tr>
<td>Cumulated EC subsidy</td>
<td>1</td>
<td>5</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>Net total</td>
<td>3 226</td>
<td>3 217</td>
<td>3 223</td>
<td>3 218</td>
</tr>
</tbody>
</table>

Table 4  Cumulated 2007 to 2020 fiscal income from electricity and petroleum products sales, 4 IMACLIM scenarios

Let us lastly analyse the scenario impacts on the aggregate fiscal income of the output and product taxes modelled by IMACLIM-P (30% of total fiscal income, cf. *supra*), all productive sectors considered. At that more comprehensive scale, differences between scenarios fall back on those in their GDP performances (Figure 7): the further penetration of electric mobility, whether in a factor 2 or in a factor 5 mitigation context, has an impact on fiscal income below 0.25% across time (while in the long term factor 5 scenarios end up collecting ca. 3% fiscal income less than factor 2 scenarios). This alignment of the GDP and fiscal income impacts of EC penetration indicates that the economic weight of the car industry is not large enough, and its tax structure not differentiated enough from that of other economic activities (to which it partially substitutes), to significantly weigh on public budgets.

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**Figure 7**  Total fiscal income from output and product taxes, 4 IMACLIM scenarios
In the shorter 2007 to 2020 term, the cumulated fiscal income of output and product taxes is €14 billion lower in the REF scenario than in the REF- scenario but only €6 billion lower in the EU scenario than in its EU- counterpart. Thus, even from a more comprehensive public budget perspective, the €4 billion cumulated extra subsidies on EC sales induced by further EC penetration make up a significant share of the short term public budget impact of this further penetration.

3.3 Scenario variants under optimistic industrial assumptions

In this final result section we develop “v2” optimistic variants of the 3 scenarios with significant EC penetration, namely the REF, EU- and EU scenarios. We build these variants under the industrial ‘success story’ assumptions of combined low EC imports from and massive EC exports to non-EU trading partners. More precisely,

- We modify the 2007 share of imports in total EC resource (sum of imports and domestic production, in value): rather than the 50% share prevailing in what we can now call “v1” scenarios (cf. section 1.1 of Annex 1) we retain the 8.3% share reported by EUROSTAT for the aggregate ‘motor vehicle’ sector. From 2007 on this share is impacted by the evolution of terms-of-trade following the “Armington hypothesis”,17 but of course the starting point of this trajectory matters.

- We reject the pessimistic assumption of nil EC exports common to v1 scenarios (cf. section 1.1 of Annex 1) and force a trajectory of exports defined as a ratio to vehicle sales to households (in units). We start this ratio at 10% in 2008, then increase it at a constant rate up to 200% in 2020, after which date we maintain it throughout our projection horizon until 2050. Note that we totally disconnect this trajectory from the compared domestic vs. imported EC costs in 2007 (our own assumption indeed) or the evolution of terms-of-trade to 2050—endogenously determined by the model to guarantee a constant contribution of trade to GDP (cf. section 2.3 p. 9). Our assumption is that of a qualitative dominance of the EC industry over its international competitors, combined with that of an expanding market for ECs outside the EU, whatever the reason for this expansion.

As a direct consequence of both assumptions, EC productions in v2 scenarios strongly exceed EC productions in their v1 counterparts (Figure 8). The impact on GDP is of course not as straightforward as the multiplication of extra units produced by export price, because EC production competes for inputs with other sectors. One exception, however, is the model’s imperfect labour market where EC production can find unemployed resources to put to use, and this is one mechanism through which the v2 assumptions favourably impact growth—although the low unemployment levels of the v1 scenarios leave little unemployed labour (cf. Figure 6 p. 12). Another major mechanism is obviously through international trade: v2 assumptions guarantee substantial exports (and lesser imports) regardless of terms-of-trade competition;18 they thus lift some pressure off the trade balance, which allows EU prices appreciating vis-à-vis international prices and thus diminishing the brunt of imports.

17 Of a constant elasticity of substitution between the domestic and imported varieties of ECs, cf. Equations 13 and 14b of the updated model formulary of Annex 1.
18 To give an order of magnitude: 10 million vehicles at 25 thousand Euros amounts to €250 billion exports; the REF v2, EU- v2 and EU v2 scenarios respectively reach 7 million, 24 million and 28 million units exports. In the REF- v1 scenario, EU exports start from ca. €1,700 billion in 2007 and climb to €4,444 billion in 2050.
Modelling results expectedly indicate that the two mechanisms combine all the more efficiently as EC production is high. In 2050 the GDP of REF v2 ends up 0.2% above that of REF v1; that of EU- v2, 0.6% above EU- v1; and that of EU v2, 0.8% above EU v1 (Table 5). In the factor 2 framework of REF, the v2 variant indeed induces a GDP trajectory slightly above that of the REF- v1 scenario. Similarly, in the ambitious framework of a ‘factor 5’ mitigation objective, the costs of a moderately increased EC penetration (+18% car sales, cf. section 3.1 supra) turn out negative for v2 variants.19 This demonstrates that strong trade performances of the EU electric car industry can finance the increased electricity investment needs of further EC penetration both in a factor 2 and a factor 5 climate mitigation context. Incidentally, a strong trade performance of the EC industry also mitigates the 2050 costs of shifting from a factor 2 to a factor 5 objective—these are cut down by 20%, from ca. 3% to ca. 2.4% of REF- GDP in 2050.

<table>
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<th>2020</th>
<th>2030</th>
<th>2040</th>
<th>2050</th>
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<td></td>
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<td>+0.1%</td>
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<td>w.r.t. EU- v1</td>
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<tr>
<td></td>
<td>w.r.t. REF- v1</td>
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<td>+0.8%</td>
</tr>
<tr>
<td></td>
<td>w.r.t. REF- v1</td>
<td>-0.8%</td>
<td>-0.6%</td>
<td>-1.3%</td>
<td>-2.3%</td>
</tr>
</tbody>
</table>

Table 5  Relative GDP performance of v2 scenario variants

Unemployment impacts echo GDP impacts but in a toned down way (Table 6), a consequence of the low unemployment levels of v1 scenarios. In the short term of 2020, v2 assumptions allow containing the rate of unemployment of REF v2 at its REF- v1 value of 5.8%, erasing the 0.1-point cost of REF v1; EU- v2 and EU v2 similarly allow a 0.1-point decrease of the unemployment rate over their v1 variants, but rather in the long term when the exports of ECs have risen—in the short term the higher

19 Compare the GDP impacts of EU v2 and EU- v2 measured against REF- v1 (Table 5).
costs of energy transition (with TIMES taking account from the early years on of a stronger long term carbon constraint) counter any gains from boosted EC export markets. None of these unemployment variations exceed 150 thousand jobs though—the maximum gain from the shift of v1 to v2 variants is of 134 thousand jobs, for the EU scenario in 2025.²⁰

<table>
<thead>
<tr>
<th>Scenario</th>
<th>2020</th>
<th>2030</th>
<th>2040</th>
<th>2050</th>
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</thead>
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<tr>
<td>REF- v1</td>
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<td>4.9%</td>
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<td>4.3%</td>
</tr>
<tr>
<td>REF v1</td>
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<td>4.5%</td>
<td>4.3%</td>
</tr>
<tr>
<td>REF v2</td>
<td>5.8%</td>
<td>4.9%</td>
<td>4.5%</td>
<td>4.3%</td>
</tr>
<tr>
<td>EU- v1</td>
<td>6.1%</td>
<td>5.0%</td>
<td>4.6%</td>
<td>4.4%</td>
</tr>
<tr>
<td>EU- v2</td>
<td>6.1%</td>
<td>5.0%</td>
<td>4.5%</td>
<td>4.3%</td>
</tr>
<tr>
<td>EU v1</td>
<td>6.1%</td>
<td>5.0%</td>
<td>4.6%</td>
<td>4.4%</td>
</tr>
<tr>
<td>EU v2</td>
<td>6.1%</td>
<td>5.0%</td>
<td>4.5%</td>
<td>4.3%</td>
</tr>
</tbody>
</table>

Table 6  Unemployment rates of v1 and v2 scenarios

Concerning public budgets at last,²¹ the v2 assumptions induce tax collection that does not significantly differ from their v1 counterpart—which implies that it does not significantly diverge from our core REF- baseline (Figure 9). Detailed numerical results reveal a slight, unexpected negative impact: in 2050, REF v2 collects 0.02% less taxes than REF v1, although it induces a 0.2% higher GDP; EU- v2 collects 0.19% less taxes than EU- v1 from a 0.6% higher GDP; and EU v2 0.18% less taxes from a 0.8% higher GDP. This only reflects a modelling error: we should have indexed excise levies on the domestic GDP price rather than on international prices. The error is virtually without influence on v1 scenarios, which exhibit quite stable nominal exchange rates. It marginally impacts v2 scenarios, as reported above, where massive electric vehicles exports allow a slight appreciation of EU28 currencies (including the Euro), thereby mechanically deflating all excise levies. Time forced us to leave this minor mistake uncorrected.

²⁰ This gain is only the difference in total jobs counts of both scenarios. It should not be interpreted as job creations in the production of EC only.

²¹ For the sake of concision we focus our presentation of the impacts of v2 assumptions on growth, unemployment and public budgets, and do not report the consecutive changes in electricity prices and the capital stock mobilised in electricity production. The latter changes are anyway only marginal because the targeted increases of our proxies of BU electricity prices remain identical—the scenario variants only differ in their assumptions about the international competitiveness of the EU EC industry—and thus the core mechanism of electricity production investment crowding out other productive investment plays quite similarly as it does in the v1 scenarios.
4 Conclusion

We close this report on a set of conclusions emerging from the above scenario exploration—and on some caveats to avoid any over-interpretation of what remain preliminary modelling results.

One first conclusion is that the development of electric personal mobility has a small GDP impact, which could be compensated by a strong trade performance of the EU electric car industry. Under pessimistic trade performance of EU electric cars (nil exports, between 35 to 50% reliance on imports), in a factor 2 mitigation context, a penetration of electric cars up to a fourth of total car sales in 2050 comes at a moderate GDP cost peaking at 0.17%; in a factor 5 mitigation context, an increased penetration of ECs leading to an additional 2.8 million vehicle sales in 2050, induces GDP losses peaking at 0.22%. Contrastingly, under strongly optimistic trade performance of EU electric cars (exports twice as high as sales to households, reliance on imports similar to that of conventional vehicles i.e. below 10%), the same EC developments induce small GDP gains peaking at 0.15% in a factor 2 context and at 0.10% in a factor 5 context. Interestingly, under pessimistic trade performance the two peaks of GDP losses happen at years when EC penetration has a maximum impact on electricity prices, rather than at years when electric car sales peak in market share or sheer volume. This implies that the impact of EC penetration on electricity generation costs is one major driver of its economic costs.

One second conclusion is that EC penetration only marginally impacts tax collection. At the restricted level of fuel sales, the cuts in oil products sales imply losses of both excise and VAT income that are substantially compensated by the increase of the excise and VAT levied on electricity sales: under pessimistic EC trade assumptions, cumulated excise and VAT proceeds net of vehicle purchase

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22 After 2020 and across the 3 v2 variants the EU exports ca. 50% more units than it purchases domestically (purchases by firms must be added up to purchases by households, on which the assumption of exports twice as high as sales is computed, cf. opening of section 3.3). This is an extremely optimistic export ratio, to be compared to 2007 exports of the 8 manufactured goods aggregates of EUROSTAT national accounts, which are at most 39% below total domestic sales (in value).
subsidies only drop by 1.4% in a factor 2 context and 1.0% in a factor 5 one. At a comprehensive macroeconomic level, the corresponding tax savings fuel household consumption anyway, which in turn raises taxes that fuel public budgets; consequently, whether in a factor 2 or factor 5 context total (modelled) tax proceeds net of vehicle subsidies register a negative impact below 0.25% across time. Notwithstanding, in the short run up to 2020 our assumed vehicle sale subsidy makes up a significant share of the lost public income.

Turning to caveats, this is first the place to recall that the runs we present are unfinished. With the exception of REF- v1—and it is a debatable exception, because matching TIMES PanEU GDP assumptions required extending productivity improvements to capital, whereas our favoured option would be to limit them to labour—they unfold GDP trajectories that are below the single one on which TIMES PanEU constructed the energy system projections that constrain their own energy intensities, prices, and household consumptions. Providing TIMES PanEU with the lower GDP forecasts computed by IMACLIM would presumably induce it to compute, among other, lower trajectories of electricity prices, and we have underlined the negative impact of high electricity prices on growth. It is thus reasonable to think that the GDP deviations ultimately computed by IMACLIM after a convergence process with TIMES PanEU would be anywhere between the ‘first round’ impacts reported here and the original TIMES PanEU GDP trajectory.

A second important caveat regards our use of GDP as our main macroeconomic indicator, which implies it is a good approximation of aggregate welfare, the legitimate measure of economic performance. However, GDP certainly masks the welfare loss induced by the persisting 20% higher cost of electric vehicles over conventional alternatives in the long run. In the EU v1 scenario, e.g., electric cars remain €4,800 more expensive than conventional alternatives in 2050. At that year, households spend 0.5% of their total consumption budget on this extra cost, without any welfare benefit in first approximation (assuming that at that point electric cars render exactly the same service as conventional cars). Fuel costs at least should also enter this equation to refine the assessed economic loss, which should then be interpreted in welfare terms—the point however remains that GDP is not an accurate measure of economic performance.

A third important caveat regards our unemployment results, and prompted us indeed to shun concluding on them. As reported in section 2.1, we made a last-minute decision to extend to capital the substantive productivity improvements that were to benefit labour only, considering how well this move allowed matching our GDP trajectory under REF- energy systems with that indistinctly sustaining the 4 TIMES PanEU scenarios we build on. We highlighted at various points of our report the consequence that our growth trajectories envisage abundant capital endowment. This mechanically damps any unemployment variations induced by contrasted scenarios. In other words, less optimistic capital productivity gains would both induce higher unemployment levels in all scenarios, but also higher unemployment variations between scenarios. As a consequence GDP variations would also probably be magnified.

Beyond these three major items, there are many directions in which the proposed linking of IMACLIM and TIMES PanEU could be developed. Time and resources were too scarce, in the course of our EV-STEP project, to e.g. mirror in IMACLIM the development of biofuels envisioned by

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23 This is indeed the case of the preliminary results reported to the French ministry of Transport in July 2015.
TIMES; differentiate the energy intensity trends of the COMP vs. ELEQ, ICE and EC sectors of IMACLIM—or for that matter study the possibility of deriving from IMACLIM projections some trends of the relative prices of capital vs. operation and maintenance costs to be fed back to TIMES. The combination of top-down and bottom-up models of energy systems and the macro-economy is still a developing methodological field indeed. It remains, in our view, the necessary path to relevant prospective modelling of energy constraints and policies at country scales or beyond.

5 References

Annex 1
Addendium to CIRED WP 55

This annex amends and complements CIRED working paper 55 (Ghersi, 2014), hereafter WP55. It records the developments that occurred when it came to numerically implementing the IMACLIM-P model described in WP 55. Echoing the structure of this working paper, it details (i) a revised set of assumptions regarding electric vehicle production at IMACLIM’s 2007 base year, together with a late addition to the data collection and treatment sustaining the model, focusing on the question of energy excise taxes in the 28-country European Union (EU28); (ii) improvements to the version of IMACLIM-P eventually applied to numerical analysis, including much numerical detail on the results of the TIMES PanEU model of energy systems that IMACLIM-P uses; (iii) improvements of model implementation and particularly of the calibration on 2007 to 2013 observed statistics.

1 Further data mining and treatment

This section details data mining and treatment, either revised from, or supplementary to, the substantial data section of WP55. Because of aggregation difficulties and for lack of national accounting data,24 we eventually decided to focus the ‘electric vehicle’ sector of IMACLIM on the production of electric cars—and for the sake of clarity we will from now on systematically favour the more precise ‘car’ term over the ‘vehicle’ term we have used so far. This means that the economic impact of buses and trucks shifting to electric mobility depicted in TIMES scenarios will only be assessed by IMACLIM in its fuel implications (the substitution of electricity to standard road fuels) and not in terms of extra vehicle (battery) costs.

We also clarified with EV-STEP partners the scope of our ‘electric car’ product: we limit it to battery and plug-in hybrid electric cars, all other technologies excluded. As a consequence our ‘ICE’ remainder of the ‘motor vehicles, trailers and semi-trailers’ sector of EUROSTAT statistics encompasses more than the conventional internal combustion engine vehicles, particularly for later years—we nonetheless stick to the ‘ICE’ denomination.

1.1 Updated assumptions on electric car imports, production, sales and exports

In WP55 we detailed how our disaggregation of the electric vehicle production from the generic production of motor vehicles was initially based on exogenous information or assumptions on

- The number of electric vehicle (EV) units sold in EU28 in the year 2007,

24 On the one hand representing both the production of personal cars and of buses and trucks in one aggregate ‘motor vehicles’ sector (not mentioning two- and three-wheelers) is quite a modelling challenge. On the other hand the data necessary to split the motor vehicle sector of national accounts into trucks and buses vs. personal cars vs. other vehicles sub-sectors is missing—or its gathering and treatment at EU28 scale is beyond the reach of our EV-STEP contribution.
The average price, subvention included, of these vehicles—we now precise that this price is meant net-of-VAT,

The average subsidy (or the rate thereof), on vehicle purchase,\textsuperscript{25}

The detailed EV market, \textit{i.e.} to which economic agent the vehicles are sold,

The share of total EV sales imported from extra-EU producers,

For the EU production, the share of the battery cost in the total vehicle cost.

The matrix reported in Annex 1 of WP55 tentatively retained the following numerical assumptions: the sales of 25 thousand vehicle units at the subsidised price of 25k€, with the subsidy amounting to 33\% of the production cost for domestic production; a market structure identical to that of conventional motor vehicles barring sales to electric vehicle production itself (for the sake of clarity) and exports, but also (precisions omitted in WP55) to ICE production, to public administrations and as fixed capital formation; a 50\% share of imports in total sales; a 40\% cost share for the battery in domestic production.

With our focus on personal cars and the battery and plug-in hybrid technologies (and our further treatment of product taxes, \textit{cf. infra}) we update these assumptions to: the sale of 25 thousand electric cars (EC) units at the net-of-VAT subsidised price of 25k€, with the subsidy amounting to 25\% of the purchase price of vehicles, \textit{i.e.} to €6,125 for vehicle sales to firms and €6,805 for vehicle sales to households.

We do not modify our assumptions on the market structure of ECs, the 40\% share of domestic costs devoted to the battery or the 50\% share of vehicle resources (the sum of domestic production and imports) coming from abroad. On the latter point we however make the complementary assumption that the cost of the imported vehicles is the same as the cost of those domestically produced—which implies that an identical 50\% share of vehicle units are imported.

Regarding the EC market structure, we more precisely replicate the 2007 split of motor vehicle sales in value,\textsuperscript{26} although excluding from our computation (\textit{i}) sales to the conventional vehicle sector, whose consumption is in fact massively one of vehicle parts; (\textit{ii}) public consumption and investment, to fall back on the conventional national accounts treatment of both end-uses; (\textit{iii}) exports, reserving to optimistic scenario variants the exploration of massive electric car exports. As a result, electric car sales are attributed for 23.5\% of them to the composite (COMP) sector, for 2.2\% of them to the land transportation services (LDT) sector, and for 73.6\% of them to households. The remaining productive sectors share the residual 0.7\% sales between themselves.

Note that for lack of a better assumption we keep this market structure constant across scenarios and times, at least as a rule of thumb that we use to split the vehicle sales inferred from TIMES PanEU

\\textsuperscript{25}EC penetration as modelled by TIMES PanEU is by essence regulatory. The substantial price premiums between ECs and their conventional counterparts are however formidable political obstacles to the penetration rates envisioned in both EU scenarios of course but also in the REF scenario. This, together with an overview of the already existing support schemes across MSs, is what prompted us to consider some public support assumption.

\\textsuperscript{26}This is a crude approximation, because (\textit{i}) the ‘motor vehicle, trailers and semi-trailers’ sales we rely on encompass all sorts of vehicles other than passenger cars including trucks, buses, LDVs and motorcycles, and (\textit{ii}) because we apply the market structure of the ‘motor vehicle’ sales in value (million Euros) to the market structure of electric cars in volume (vehicle units).
between sales to households, whose trend we directly implement, and sales to firms, which we relate to the GDP trajectory underlying TIMES to construct a trend indifferently applying to the EC intensities of all productions (cf. Annex 3). From a GDP perspective the basic assumption of a maintained households vs. firms split of sales only marginally matters, to the extent that the average cost structure of firms differs from the budget shares of households.

Beyond 2007, besides making assumptions on the market structure of ECs, we posit:

- That battery costs steadily decrease to 25% their 2007 value by 2020 (cf. Annex 3).
- That, as direct consequence (considering globally consistent battery markets), the import price of ECs regularly decreases to 70% its 2007 value in 2020.
- That (as yet another consequence) the public subsidies to vehicle sales linearly decrease to 0 in 2020, to acknowledge the progress made on battery costs.

1.2 Accounting for energy taxes

One of the research questions linked to a large-scale penetration of electric vehicles is the impact of such penetration on public budgets through the erosion of the consumption of fossil vehicle fuels, a significant fiscal basis of all Member States (MS) (Stamatova and Steurer, 2013). The taxes levied on fossil fuel consumption mainly take the form of excise taxes, i.e. taxes proportional to the volume of consumption. They are to be opposed to ad valorem taxes, which are proportional to monetary expenses—first and foremost of these is the value-added tax (VAT) raised on all household expenses including, as a matter-of-fact, energy expenses. An analysis of the dynamics of energy taxes thus requires an explicit distinction of the two fiscal products: the fiscal income of excise taxes should evolve as physical consumption, whereas that of ad valorem taxes should evolve as monetary expenses.

In the hybrid EU28 matrix annexed to WP55 (p. 30), consumption taxes appear as an aggregate “Taxes less subsidies on products” resource to sectors. This resource thus mixes ad valorem and excise levies, which does not allow a differentiated calibration of the ad valorem \( t_{AI}, A \in \{IC, H, G, I, X\} \) vs. excise \( t_{AI}, A \in \{IC, H, G, I, X\} \) components of product taxation that are detailed in the consumer price equations 27 to 31 (p. 25 and 26 of WP55). Further data collection and treatment was required to disaggregate the two resources.

EUROSTAT data was used to that purpose. Regretfully, the database does not directly provide the required disaggregation of energy tax income per energy carrier. It does, however, provide the total fiscal income from energy taxes (env_ac_tax series),\(^{27}\) which amounts to 220 billion euros in our 2007 calibration year. It also provides

- Statistics on the net-of-VAT and net-of-all-taxes household prices of electricity and natural gas.\(^{28}\) These are given for various levels of consumption. For electricity the difference between the two prices does not vary much, from 216 to 233 euros per ton-of-oil-equivalent (€/toe)


\(^{28}\) We more precisely use the nrg_pc_202 and nrg_pc_20 series for semester S2.
depending on consumption volumes; we therefore retain the average €224/toe difference as the average excise on households’ electricity consumption. For natural gas, it is rather the observed share of the all-taxes-included price that is paid as excise that appears somewhat stable across the various levels of consumption (from 11.3% to 12.8%); we thus use the average share, 12.1%, to deduce total excise revenues from total expenses. Divided by the total volume of consumption these define an average €50/toe excise on households’ natural gas consumption.

- Extensive MS statistics about the excise taxes on liquid fuels in 2007, distinguishing between various uses.\textsuperscript{29} We had to collect these levies (arbitrarily selecting one of several reported rates when required) and cross them with detailed EUROSTAT data on oil products and coal products statistics to produce an estimate of households excise payments on such products. The total household excise on oil products thus computed reaches 101.874 billion, which translates into an average €411/toe levy. The household excise payment on coal products is a much lower 27 million euros, barely amounting to an average €3/toe levy.

Turning to the excise payments of firms, we shun from constructing similar ‘bottom-up’ estimations, the wide disparities of fiscal regimes forbidding, in our view, the fixation of any sensible average levy. We circumvent this difficulty by (i) deducing, from the EUROSTAT statistics on total payments and our own computation of household payments, the total amount of firms energy excise payments—€96 billion of the €220 billion total (ii) for the sake of simplicity, assuming nil excise payments on coal consumptions,\textsuperscript{30} and conversely transferring the total “Taxes less subsidies on products” €5-billion resource for crude oil to excise payments on firm consumptions;\textsuperscript{31} (iii) distributing the remaining €91-billion excise payments between oil products, electricity and gas, under the constraint that their average VAT rates should be equal—an assumption that is sustained by the VAT rate statistics provided by EUROSTAT (cf. footnote 29).

\textsuperscript{29} Cf. https://circabc.europa.eu/sd/a/a13b1143-40d4-4a6b-b298-2f65d3de7a0a/EDT%202007%20July%20REF%2020125%20Energy%20Rev1.pdf, accessed February 4\textsuperscript{th}, 2015.

\textsuperscript{30} Additional reasons to this simplification are that EUROSTAT does not report excise payments on coal and coal products consumption for non-heating purposes, and that it induces a plausible 14% VAT rate on coal products (when treating all non-excise taxes less subsidies on products as VAT payments).

\textsuperscript{31} Final consumption of crude oil is nil. This implies nil VAT payments under our simplifying modelling of VAT as a sales tax.
<table>
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<th>Firms</th>
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<tr>
<td>On crude petroleum consumptions</td>
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<td>28</td>
</tr>
</tbody>
</table>

Table 7 Calibrated excise payments on energy consumptions

For reference purposes, Table 1 synthesises the excise rates to which these computations lead.

2 Improvements to the IMACLIM-P model

Compared to the version we detailed in WP55, our IMACLIM-P model of EU28 improved on several aspects linked to the model’s dynamics. To avoid too many references to WP55 we reiterate parts of it, which we modify where necessary.

2.1 Articulation with the TIMES PanEU model

At the core of the articulation of IMACLIM to TIMES PanEU, both the former model’s producers’ trade-offs between primary factors and energy and its consumer’s trade-off between energy and other consumptions are imported from the latter model, for the most part.\(^{32}\) For both agents, the competition between energy vectors, or energy mix, is also taken from TIMES PanEU. To be more specific, for each prospective run of IMACLIM-P the energy intensities of most productions and the household consumptions of all energy vectors follow exogenous trajectories drawn from TIMES PanEU (Annex 3).

A second major import from TIMES PanEU to IMACLIM-P is the vector of import prices of the model’s 5 energy aggregates (Annex 3). These are forced into IMACLIM-P, keeping other import prices constant. This implies that the probable hike in energy prices of prospective runs is measured against non-energy imports, which therefore collectively define the numéraire of the model.\(^{33}\)

A third major import from TIMES PanEU to IMACLIM-P regards the cost structure of domestic (EU) electricity production. Beyond the drivers of international primary energy prices, TIMES PanEU elaborately settles the competition between alternative techniques to produce electricity; it also presumably tracks quite relevant information on the investment requirements on networks, which age

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\(^{32}\) Annex 3 details the extent of information imported from TIMES PanEU—some lesser energy intensities were left aside when articulating the models.

\(^{33}\) Price homogeneity holds in IMACLIM-P as in any standard CGE model. Keeping constant non-energy import prices amounts to (i) selecting one of the import goods, e.g. the composite aggregate, as numéraire, and (ii) assuming that the prices of non-energy imports relative to the price of this numéraire are constant.
and expand differently in the various Member States. This information is aggregated to be passed on to the capital intensity of the electricity production of IMACLIM-P according to an original methodology detailed in Annex 3.

A fourth import from TIMES Pan-EU to IMACLIM regards the volume output of the oil, gas and coal sectors, together with the export volumes of such products (cf. Annex 3)—although these are inferred from TIMES Pan-EU projected net imports of each fuel. Forcing output and exports guarantees that imports are the source of any increase of final demand, and priced accordingly.

A fifth set of imports from TIMES Pan-EU to IMACLIM-P regards transportation. It entails the number of electric and conventional passenger vehicles sold both to the various producers and to households, and indexes of variations of the consumption of the 3 transportation services by the composite sector and by households (cf. Annex 3).

2.2 Updated IMACLIM-P formulary

This updated IMACLIM-P formulary departs from that which formed WP55 in a few aspects, regarding mostly:

- An explicit introduction of the dynamic drivers that affect labour endowment, capital and labour productivity or exports;
- An explicit introduction of 4 ‘crisis factors’ that are calibrated to allow the model to fit the 2007 to 2013 trajectories or real GDP, unemployment and terms-of-trade (cf. section 3.3 below);
- Some changes in the closure rule of the model, which now explicitly entails a set of alternative assumptions on the dynamics of the trade balance.

Rather than reporting the modified equations only we develop again the entire model, for the sake of clarity. As a consequence a good part of what follows is a repetition of WP55, although we cut short some of the introductory explanations to the formulary. Suffice it to recall that, as in WP55, any variable name indexed with a ‘0’ designates the specific value taken by the variable in the 2007 equilibrium (i.e. the value calibrated on the 2007 hybrid IOT); it thus indicates a parameter of the equation system. Also, when necessary, goods are individualised as:

<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>COAL</td>
<td>Coal and coal products.</td>
</tr>
<tr>
<td>OIL</td>
<td>Crude oil.</td>
</tr>
<tr>
<td>GAS+</td>
<td>Gas, heat and steam.</td>
</tr>
<tr>
<td>PPBW</td>
<td>Petroleum products, biomass and waste.</td>
</tr>
<tr>
<td>ELEC</td>
<td>Electricity.</td>
</tr>
<tr>
<td>ICE</td>
<td>All vehicles except electric cars as defined below.</td>
</tr>
<tr>
<td>EV</td>
<td>Electric cars limited to the battery and plug-in types.</td>
</tr>
<tr>
<td>ELEQ</td>
<td>Electrical equipment, including the batteries of electric vehicles.</td>
</tr>
<tr>
<td>AIRT</td>
<td>Air transport services.</td>
</tr>
</tbody>
</table>
LDT   Land transport services.
WTT   Water transport services.
COMP  A composite remainder of all other economic products and services.

In some instances the energy goods COAL, GAS, OIL, PPBW, ELEC are for short indexed by a general E. Similarly, the Leontief aggregate of non-energy goods is indexed with C.

2.2.1 Production

At the bottom of the production tree, capital and labour trade off with a constant $\sigma_{KL}$ elasticity of substitution (cf. Annex 2 of WP55) to form a $KL$ aggregate. The mobilised quantity of labour $L$ and capital $K$ are augmented by a productivity factor $\Phi$, and also adjusted by specific ‘crisis’ factors $\Omega$ that are specifically calibrated to reproduce the observed 2007 to 2013 macroeconomic trajectory (cf. section 3.3). Facing prices $p_K$ and $p_L$, cost minimisation canonically induces

\[
L_i = \frac{1}{\Omega_L \Phi} \left( \frac{\Omega_L \Phi \beta_{KLi}}{p_{Li}} \right)^{\sigma_{Li}} \left( \alpha_{KLi} \sigma_{Li} \left( \frac{p_{Ki}}{\Omega \Phi} \right)^{1-\sigma_{Li}} + \beta_{KLi} \sigma_{Li} \left( \frac{p_{Li}}{\Omega \Phi} \right)^{1-\sigma_{Li}} \right)^{-\frac{1}{\sigma_{Li}}} \left( KL_i \right), \quad (1b)^{34}
\]

\[
K_i = \frac{1}{\Omega_K \Phi} \left( \frac{\Omega_K \alpha_{KLi}}{p_{Ki}} \right)^{\sigma_{Li}} \left( \alpha_{KLi} \sigma_{Li} \left( \frac{p_{Ki}}{\Omega \Phi} \right)^{1-\sigma_{Li}} + \beta_{KLi} \sigma_{Li} \left( \frac{p_{Li}}{\Omega \Phi} \right)^{1-\sigma_{Li}} \right)^{-\frac{1}{\sigma_{Li}}} \left( KL_i \right). \quad (2b)
\]

On the tier immediately above, with the energy consumption $\alpha_{Ei}$ exogenous (a sum of the energy intensities inferred from TIMES PanEU results) the cost-minimisation programme is truncated. $KLE_i$ is still assumed to be a CES production of $KL_i$ and $\alpha_{Ei} Y_i$ though, following

\[
KLE_i = \left( \alpha_{KLEi} KL_i^{\rho_{KL}} + \beta_{KLEi} (\alpha_{Ei} Y_i)^{\rho_{KL}} \right)^{-\frac{1}{\rho_{KL}}}, \quad (3)
\]

where for convenience $\rho_{KL} = \frac{\sigma_{KLE} - 1}{\sigma_{KLE}}$ (cf. Annex 2 of WP55 for the sectoral values of $\sigma_{KLE}$).

Still higher on the production tree, the $KLE_i$ aggregate and ‘materials’ input $\alpha_{Ci} Y_i$ are traded off with a constant $\sigma_{yi}$ elasticity of substitution (cf. Annex 2 of WP55) to form domestic production $Y_i$. Facing prices $p_{KLE}$ and $p_{Ci}$, cost minimisation induces

\[
KLE_i = \left( \frac{\alpha_{yi} \sigma_{yi} p_{KLE}^{1-\sigma_{yi}} + \beta_{yi} \sigma_{yi} p_{Ci}^{1-\sigma_{yi}}}{p_{KLE}} \right)^{-\frac{1}{\sigma_{yi}}} \left( Yang_i \right). \quad (4)
\]

\[
\alpha_{Ci} Y_i = \left( \frac{\beta_{yi} \sigma_{yi} p_{KLE}^{1-\sigma_{yi}} + \beta_{yi} \sigma_{yi} p_{Ci}^{1-\sigma_{yi}}}{p_{Ci}} \right)^{-\frac{1}{\sigma_{yi}}} \left( Yang_i \right). \quad (5)
\]

The ‘materials’ input $\alpha_{Ci} Y_i$ is an aggregate of non-energy goods based on a Leontief constant-intensity assumption, with a few exceptions where TIMES PanEU data is used as described in Annex 3.

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34 For reference purposes equations are ordered identically to those of WP55; they are indexed with $b$ whenever modified.
2.2.2 Final consumption and investment

Equation (6) of WP55 was flawed, because it did not encompass the sum of specific margins $\tau_{MS}$, which is nil only at the calibration equilibrium. When properly posed it is anyway redundant with the price formation equations and the goods market balances. It is thus dropped in favour of an explicit closure on international trade, cf. below. As a consequence the sum of tax revenues is not required anymore, and equation (7) of WP55 is also dropped. For reference purposes we skip the corresponding equation numbers—to keep equation numbering in line with the total number of equations we however use them for supplementary equations cf. below.

Household consumptions of energy $C_{COAL}$, $C_{OIL}$, $C_{GAS}$, $C_{PPBW}$, $C_{ELEC}$ follow exogenous trends imported from TIMES PanEU, cf. Annex 3. Household consumptions of air, water and (public) land transport ($C_{ART}$, $C_{WTT}$, $C_{LDT}$) are similarly indexed on the billion passenger-kilometres projected by TIMES PanEU. Household consumptions of electric cars and other motor vehicles ($C_{EC}$, $C_{ICE}$) are indexed on the vehicle sales reported by TIMES PanEU. Electrical equipment ($C_{ELEQ}$) are devoted a constant budget share. The remaining budget, spent on the composite good ($C_{COMP}$) derives from the saturation of the budget constraint:

$$\sum_{i=1}^{n} p_{Hi} C_i = R \quad (8)$$

Public spending $G_i$ is a constant share $s_{Gi} G_i$ of GDP (traditionally nil for energy goods)

$$p_{Gi} G_i = s_{Gi} GDP \quad (9)$$

with GDP defined on the expenditure side as

$$GDP = \sum_{i=1}^{n} p_{Hi} C_i + \sum_{i=1}^{n} p_{Gi} G_i + \sum_{i=1}^{n} p_{Hi} I_i + \sum_{i=1}^{n} p_{Hi} X_i - \sum_{i=1}^{n} p_{Hi} M_i \quad (10)$$

Investment has an exogenous ratio $s_i$ to consumed income (this amounts to an exogenous savings rate; of course immobilisation in energy goods is nil)

$$\sum_{i=1}^{n} p_{Hi} I_i = s_i R \quad (11)$$

The good-structure of investment is supposed constant through time

$$\forall i, j \quad \frac{I_i}{I_{i0}} = \frac{I_j}{I_{j0}} \quad (12)$$

2.2.3 International trade

International trade specifications are quite changed from what they were in WP55. As far as imports are concerned, goods part in 2 categories: those following an Armington specification (Armington, 1969) and those whose imports simply balance the domestic (EU28) production $Y$, either exogenous or
imported from TIMES PanEU, in total resource \( Q \). The first category, that of Armington goods, extends to all non-primary energy goods. For such goods domestic production \( Y \) and imports \( M \) are

\[
\forall i \neq OIL, COAL, GAS + Y_i = \left( \frac{\alpha_Q}{p_{Yi}} \right)^{\sigma_{yi}} \left( \alpha_{Qy} \sigma_{yi} p_{yi}^{1-\sigma_{yi}} + \beta_{Qy} \sigma_{yi} p_{Mi}^{1-\sigma_{yi}} \right)^{\sigma_{yi}} Q_i, \tag{13}
\]

\[
\forall i \neq OIL, COAL, GAS + M_i = \frac{1}{\Omega_X} \left( \frac{\beta_Q}{p_{Mi}} \right)^{\sigma_{yi}} \left( \alpha_{Qy} \sigma_{yi} p_{yi}^{1-\sigma_{yi}} + \beta_{Qy} \sigma_{yi} p_{Mi}^{1-\sigma_{yi}} \right)^{\sigma_{yi}} Q_i, \tag{14b}
\]

with imports inversely impacted by \( \Omega_X \), a ‘crisis factor’ on exports that allows calibration on the 2007 to 2013 trade balance trajectory (cf. section 3.3). The second category embraces the coal, oil and gas goods, whose production \( Y \) is imported from TIMES PanEU. These goods acknowledge commensurability of the domestic and imported resource:

\[
\forall i \in OIL, COAL, GAS + \quad M_i + Y_i = Q_i, \tag{16}
\]

Exports also follow either one of two specifications. Those of energy goods are exogenous, extrapolated from TIMES PanEU results (cf. Annex 3); exports of electric cars are an exogenous assumption defining variants to the 4 scenarios explored by TIMES PanEU (cf. section 1.1 above). All other goods have exports elastic to terms-of-trade around an exogenous trend defined by an autonomous growth of export markets \( \delta_X \), and subject to a ‘crisis factor’ \( \Omega_X \) calibrated to fit the model on observed 2007 to 2013 trade balance trajectory (cf. section 3.3):

\[
\forall i \neq E, EV \quad X_i = \Omega_X (1 + \delta_X) X_{i0} \left( \frac{P_{Wi}}{P_{Mi}} \right)^{\sigma_{wi}}, \tag{17b}
\]

As was mentioned when commenting upon dropping out equation (6) of WP55, and because of the probable importance of trade effects in the macroeconomic impact of electromobility penetration, we decided to change the closure rule of the model with a view to focus on explicit assumptions regarding trade. We eventually settled for two alternative variants of the model. The first variant resorts to the standard assumption of an exogenous trade balance, or more precisely an exogenous contribution of the trade balance to GDP:

\[
\frac{\sum p_{Xi} X_i - p_{Mi} M_i}{GDP} = B, \tag{6b}
\]

which amounts to a flexible exchange rate regime allowing an adjustment of the ratio of the vector of domestic prices to that of international prices to influence export and import volumes through equations (14b), (15) and (17b). The second variant explores the opposite assumption of an exogenous exchange rate regime. To do so, it constrains the evolution of terms-of-trade by the equivalent of a ‘wage curve’ linking the purchasing power of domestic wage \( w \) in the imported composite good, to unemployment:

\[
\frac{w/ p_{MCOMP}}{w_0/ p_{MCOMP0}} = \Phi \Theta \left( \frac{1}{u/u_0} \right)^{\sigma_{wm}}, \tag{6c}
\]

with \( \Phi \) the labour productivity multiplicator, which should benefit to real wage if factors were remunerated at their marginal productivity; \( \Delta \) an exogenous exchange rate factor; \( \Theta \) a ‘wage moderation’ factor that is calibrated by the process of fitting the 2007 to 2013 simulated trajectory on
observed GDP, unemployment and terms-of-trade statistics (cf. section 3.3). With this equation, the purchasing power of the domestic wage in international goods is only allowed to vary following explicit exchange rates variations (Δ), labour productivity improvements (Φ) and wage moderation (Θ).

2.2.4 Market clearings

Market balance for each good \( i \) is
\[
Q_i = \sum_{j=1}^{n} \alpha_{ij} Y_j + C_i + G_i + I_i + X_i
\]  
(18)

Concerning the labour market, the model of WP55 is extended by endogenising unemployment through the implementation of a domestic ‘wage curve’ that acknowledges the elasticity of real wage to unemployment \( u \) above some unemployment floor \( u \) corresponding to frictional unemployment, which is set at 4% across time and scenarios. The real wage attached to constant unemployment \( (u = u_0) \) is defined as the 2007 real wage multiplied by labour productivity increase \( \Phi \) and a wage moderation factor \( \Theta \). Then the purchasing power of the real wage is isoelastic to unemployment, with elasticity \( \sigma_{wu} \) set at 0.2.
\[
\frac{w/\text{CPI}}{w_0} = \Phi \Theta \left( \frac{1}{(u-u)/(u_0-u)} \right)^{\sigma_{wu}}
\]  
(7b)

with the consumer price index CPI computed as a chained Fisher index.

Labour demand by the 12 productions balances labour endowment \( L \) net of unemployment \( u \)—contrary to WP55 \( L \) exogenously grows at a rate reflecting active population projections but not labour productivity, which is accounted for at the level of labour contents, equation (1b):
\[
\sum_{i=1}^{n} L_i = (1-u)L = (1-u)(1 + \delta_N)L_0.
\]  
(19b)

Similarly capital markets clear (through the adjustment of \( p_K \)) modulo a capacity utilisation rate \( (1-\omega) \), but the trajectory of the capital stock follows the traditional accumulation rule—for this unique dynamic equation we add \( t \) subscripts to variables to mark time periods.
\[
\sum_{i=1}^{n} K_{i,t} = (1-\omega)K_t = (1-\omega)(1-\delta_K)K_{t-1} + I_{t-1}
\]  
(20b)

2.2.5 Producer and Consumer Prices

At the bottom of the nested production structure, labour costs in sector \( i \) are equal to net wage \( w \) plus payroll taxes that are levied at a constant rate \( \tau_{CSI;} \)
\[
p_{li} = \left(1 + \tau_{CSI} \right) w
\]  
(21)

\[35\] In WP55 wage \( w \) had mistakenly been indexed with \( i \) as sector-specific.
$w$ adjusts to clear the labour market (cf. above). Similarly, $p_K$ the price of capital rental common to all sectors adjusts to clear the capital market.

One tier higher in the production structure, $p_{KLi}$ is the price of the KL aggregate in sector $i$, a canonical function (considering that KL is a CES product of $K$ and $L$) of prices $p_K$ and $p_L$ and of the elasticity of substitution of the two inputs $\sigma_{KL}$

$$p_{KLi} = \left( \alpha_{KL}^{\sigma_{KL}} p_K^{1-\sigma_{KL}} + \beta_{KL}^{\sigma_{KL}} p_L^{1-\sigma_{KL}} \right)^{1/(1-\sigma_{KL})} \tag{22}$$

Still one tier higher, contrary to $p_{KLi}$, $p_{KLi}$ the price of the KL aggregate in sector $i$ cannot be defined as a function of prices $p_{KLi}$ and $p_{Ei}$ and of the elasticity of substitution of the two inputs $\sigma_{KLEi}$, because exogenously setting $E$ in the KLE aggregate (importing it from TIMES PanEU) truncates the underlying cost-minimisation programme. Consequently, $p_{KLi}$ is rather inferred from the simple accounting equation$^{36}$

$$p_{KLi} = p_{KLi} KL_i + p_{Ei} \alpha_{Ei} Y_i \tag{23}$$

At the tier of domestic production $Y$, $p_{Yi}$ the producer price of good $i$ is again the canonical CES price of the KLE aggregate and the composite input to production $\alpha_{Ci} Y_i$, to which a constant ad valorem output tax is added:

$$p_{Yi} = \left( \alpha_{Yi}^{\sigma_{Yi}} p_{KLi}^{1-\sigma_{Yi}} + \beta_{Yi}^{\sigma_{Yi}} p_{Ki}^{1-\sigma_{Yi}} \right)^{1/(1-\sigma_{Yi})} + \tau_{Yi} p_{Yi} \tag{24}$$

Then $p_{Mi}$ the price of imported good $i$ is good-specific: the international composite good is the numéraire of the model; its price is consequently assumed constant. The prices of imported non-energy goods (electrical equipment, conventional and electric vehicles, transport services) are assumed constant relative to the price of the international composite good. Then the prices of imported energy goods relative to the price of the international composite good are directly imported from TIMES PanEU—if the calibration of year 2007 produces perfect matches they can be imported as such; if it does not their growth is replicated.

Because of the difference in aggregation of $Y$ and $M$ into total resource $Q$ (CES vs. simple sum), $p_{Qi}$ the price of the resource of good $i$ is good-specific. For the non-energy goods it is the Armington price of the imported and domestic varieties:

$$p_{QC} = \left( \alpha_{QC}^{\sigma_{QC}} p_{KLi}^{1-\sigma_{QC}} + \beta_{QC}^{\sigma_{QC}} p_{MC}^{1-\sigma_{QC}} \right)^{1/(1-\sigma_{QC})} \tag{25}$$

For the energy good, considering that the Armington specification is dropped lest a specific quantity index is introduced, the price of the resource is simply inferred from

$$p_{QE} Q_E = p_{YE} Y_E + p_{ME} M_E \tag{26}$$

Turning to purchasers’ prices, the price of good $i$ consumed in the production of good $j$ $p_{ij}$ is equal to the resource price of good $i$ plus a constant-through-time agent-specific margin (allowing the price

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$^{36}$For the sake of simplicity this accounting equation is substituted to the canonical price definition for $p_{KLEC}$ too, although the canonical CES price definition could have been retained. When the CES optimisation is respected the 2 equations can be substituted freely.
differentiation of energy goods, cf. the matrix of energy prices, Annex 2 of WP55) and an aggregate of other excise taxes; this is all multiplied by an *ad valorem* sales tax.

\[ p_{ij} = \left[ p_{Qj} \left( 1 + \tau_{MSij} \right) + I_{Ki} \right] \left( 1 + \tau_{Ki} \right) \]  

(27)

The consumer price of good \( i \) for households \( (p_{Hi}) \), public administrations \( (p_{Gi}) \) and investment \( (p_{Ki}) \), and the export price of goods \( i \) \( (p_{Xi}) \), are constructed similarly.

\[ p_{Hi} = \left[ p_{QHi} \left( 1 + \tau_{MSHi} \right) + I_{Hi} \right] \left( 1 + \tau_{Hi} \right) \]  

(28)

\[ p_{Gi} = \left[ p_{QGi} \left( 1 + \tau_{MSGi} \right) + I_{Gi} \right] \left( 1 + \tau_{Gi} \right) \]  

(29)

\[ p_{Ki} = \left[ p_{Qi} \left( 1 + \tau_{MSKi} \right) + I_{Ki} \right] \left( 1 + \tau_{Ki} \right) \]  

(30)

\[ p_{Xi} = \left[ p_{Qi} \left( 1 + \tau_{MSXi} \right) + I_{Xi} \right] \left( 1 + \tau_{Xi} \right) \]  

(31)

### 3 Model implementation

The IMACLIM-P model is implemented in Microsoft Excel leaning on Excel’s built-in solver, which adequately addresses non-linear equation systems.

#### 3.1 Static calibration on 2007 accounts

The static calibration of the model on 2007 accounts (EUROSTAT accounts preliminary hybridised with energy data) is quite standard and does not require exposition, with the exception of two specific features.

First, the production and import prices of the energy goods and the electric car sector, together with the specific pricing margins on the energy consumptions of the different productions, of households and for exports, are computed by numerically solving a specific set of equations guaranteeing the energy balances and the selected electric car production and import volumes.

The second specific feature of our 2007 calibration regards capital stock \( K_0 \): our imperfect labour market demands carefully setting \( K_0 \) lest the unemployment rate \( u \) grow out of control along our trajectory—reaching either extremely high or low values depending on whether \( K_0 \) is respectively over-estimated or under-estimated.\(^{37}\) The challenge is thus to define a rule-of-thumb that produces plausible unemployment trajectories for the wide variety of economies and scenarios modelled and considering the uncertainty about how observed 2007 to 2013 data relate to any hypothetical stabilised growth trajectory in the canonical sense. After having tested different rules we settled on:

\[ K_0 = I_0 \frac{A}{\delta_K + g_{av}}, \]  

(25)

---

\(^{37}\) An over-estimated \( K_0 \) dwarfs 2007 investment \( I_0 \), which does not allow an increase of the capital stock in pace with growth, which in turn impacts on activity and hence employment. Conversely, an under-estimated \( K_0 \) allows the capital stock to grow faster than GDP, thereby reducing capital costs at the benefit of activity and employment.
which ultimately recognises $I_0$ as a fraction of $K_0$, with:

- $A$ the ratio of the investment rate $s_I$ to its 2007 value $s_{I0}$, averaged over the 2014 to 2050 simulation period (cf. section 3.2 for our assumptions on investment rate variations beyond statistical years). It multiplies $I_0$ to reflect possible misalignment of the specific 2007 investment volume with its average level over the later years of the projection. We focus on 2014 to 2050 investment rates to increase our control over the unemployment at these later years, considering that it is constrained by dynamic calibration in earlier years.

- $\delta_K$ the depreciation rate, which divides $I_0$ to acknowledge that $I_0$ is supposed to entail the replacement of $\delta_K K_0$ the capital stock scraped at the end of period 0.

- $g_{av}$ the average annual 2007 to 2050 potential growth rate (the product of exogenous productivity and active population increases), which similarly divides $I_0$ to acknowledge that $I_0$ is also supposed to provide the growth of the capital stock necessary to activity growth, under the simplified assumption of a maintained capital intensity of production.

### 3.2 Main drivers of the 2014 to 2050 macroeconomic trajectory

The dynamics of the model develop stepwise, year by year, under the influence of the following set of dynamic assumptions.\(^{38}\)

**Labour endowment** $L$ adjusts following active population growth $\delta_N$. We draw $\delta_N$ from direct EUROSTAT data from 2007 to 2013; from 2014 to 2020 we compute it by making the 2013 ratio of active to total population evolve as the same ratio forecasted by the EAPEP exercise of the International Labour Office;\(^{39}\) from 2021 on we force it to evolve as the ratio of the 18 to 64 population over the total population as forecasted by EUROSTAT (proj_13npms series).

The **labour and capital productivity** factor $\Phi$ we calibrate on EUROSTAT data. From 2007 to 2013, it evolves as the observed evolution of the ratio of real GDP to the active working population; beyond 2014 it grows at a constant rate defined by the average annual growth rate of the same ratio between 2000 and 2007 (crisis years deliberately left out). Contrary to what was announced in WP55 and considering our focus on scenario variants we do not report any sensitivity analysis on this assumption.

**Capital endowment** $K$ follows the standard accumulation rule of equation (20). The rate of capital depreciation $\delta_K$ remains constant through time at 2.5% (contrary to what was announced in WP55 it is not adjusted to minimise discrepancy with observed growth up to 2013).

**Non-energy export markets** $X_i$ vary around an exogenous growth trend $\delta_X$ (cf. Equation 17b). The rate of growth of the volumes exported outside variations of the terms of trade is set at a constant 2% annual increase.

\(^{38}\) For the sake of clarity and concision we do not stress the various modifications induced in this section by the enhancement of the model since WP55.

The savings rate \( s_I \) determines the gross fixed capital formation ratio to GDP. We match the rate with EUROSTAT statistics (ne.gdi.ftot.zs series) until 2013. Then we assume that the difference between the observed 2013 rate and the average rate between 1995 and 2007 phases out at constant speed by 2020. From 2020 on the rate remains constant at its average 1995 to 2007 value.

The capacity utilisation rate of the capital stock \((1-\omega)\) (cf. Equation 20), for lack of data availability,\(^{40}\) (i) is fixed at 1 in 2007 (a normative assumption without numerical consequence); (ii) from 2008 to 2013, is defined as the ratio of the statistical variation of real GDP over that of the capital stock endogenously computed by IMACLIM-P—which, considering dynamic calibration of the model on the same observed variation of real GDP, amounts to adjusting capital endowment to real growth for the dynamic calibration years; (iii) from 2014 to 2020, similar to \( s_I \), is assumed to converge back to 1 at a constant rate (iv) is kept equal to 1 beyond 2020 up to 2050.

The exchange rate \( \Delta \) is targeted to vary as the World Bank data on the official exchange rate of Euro to US dollar for the 2007 to 2013 years of availability of that statistics, for lack of a weighted average of exchange rates to trading partners. It is anyway kept constant at its 2013 value until 2050.

Note that with the exception of capital accumulation, which is by definition recursive, the entire set of dynamic changes is exogenous to IMACLIM-P’s trajectory (not impacted by it). After a first run there is no guarantee that the GDP variations computed by IMACLIM-P match the exogenous GDP trajectory underlying TIMES PanEU’s projection—although the Solow-based representation of growth and the use of internationally recognised datasets are features probably common to IMACLIM-P and whatever model is at the source of TIMES PanEU growth estimates. A natural way of improving the consistency of the IMACLIM-P and TIMES PanEU trajectories would be by iterating exchanges of GDP and other growth drivers versus energy sector details between IMACLIM and TIMES PanEU, each time re-running the models to compute revised trajectories. IMACLIM’s experience with other energy sector models is that convergence (stable GDP and energy sector trajectories) is obtained after a few iterations.

### 3.3 Fitting the 2007 to 2013 macroeconomic trajectory

We perform a dynamic calibration of IMACLIM-P on 2007 to 2013 statistically observed real GDP,\(^{41}\) unemployment and terms-of-trade (exchange rate), by adjusting the ‘crisis factors’ \( \Omega_L \), \( \Omega_K \) and \( \Omega_X \) (which impacts both exports and imports reversely) together with the wage moderation factor \( \Theta \). More precisely, to match the selected indicators of the 2007 to 2013 trajectory the model is expanded with 3 equations expressing the real GDP growth, unemployment and purchasing power of domestic wage in the imported composite good (following Equation 6c imposed simultaneously with Equation 6b targeting statistically observed contributions of trade to GDP), and 4 variables: the \( \Omega_L \), \( \Omega_K \), \( \Omega_X \), and \( \Theta \) factors (that are fixed as parameters after the calibration process is completed). By definition, the addition of a larger number of variables than of equations means that the expanded model is under-

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\(^{40}\) Statistics are hard to come by and are limited to industrial sectors (do not cover the entire economy).

\(^{41}\) The GDP deflator used to compute real GDP in IMACLIM-P, a Fischer price index, is chained \( i.e. \) computed each year with respect to previous year data.
determined. This allows retaining one solution by minimising the sum of square deviations of $\Omega_{L}$, $\Omega_{K}$, $\Omega_{X}$, and $\Theta$ from 1.

To synthesise, calibration on 2007 to 2013 observed macroeconomic trajectories is implemented as a set of minimised shocks on factor productivities, international trade and the wage expectations of the labour force. Beyond 2013 the 4 perturbations are assumed to phase out at a constant rate to reach 1 in 2020 then remain equal to 1 up to 2050.

Note that imposing a wage moderation factor $\Theta$ of 1 in 2020 forces the alignment of wage expectations for the particular rate of unemployment of 2007 on the wage of 2007 augmented by labour productivity gains. This has obvious consequences on unemployment and growth from 2014 to 2020 and onward. Similar, if less portent remarks apply to the 3 $\Omega$ shocks.

4 Annex 1 references


### Annex 2  Updated hybrid EU28 input-output matrix, year 2007

<table>
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<th></th>
<th>COMP</th>
<th>COAL</th>
<th>OIL</th>
<th>RPBW</th>
<th>ELEC</th>
<th>GAS+</th>
<th>31</th>
<th>34a</th>
<th>34b</th>
<th>60</th>
<th>61</th>
<th>62</th>
<th>TOTAL</th>
<th>C</th>
<th>G</th>
<th>I</th>
<th>X</th>
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<td>products</td>
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<td>52 565</td>
<td>24 525</td>
<td>177</td>
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<td>23 813</td>
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<td>2 531 718</td>
<td>2 635 819</td>
<td>1 734 994</td>
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</tbody>
</table>

| Compensation of employees | L  | 5 516 391 | 10 314 | 2 060 | 10 595 | 45 719 | 21 241 | 58 055 | 99 117 | 23 | 151 422 | 11 444 | 22 969  | 5 949 349 |                      |
| Consumption of fixed capital | K1 | 1 510 927 | 2 889 | 2 861 | 9 035 | 44 972 | 20 894 | 12 136 | 29 559 | 7  | 50 881 | 7 795  | 7 520  | 1 699 476 |                      |
| Operating surplus, net | K2  | 2 913 136 | 1 016 | 18 694 | 17 664 | 66 224 | 30 767 | 19 837 | 29 164 | 7  | 52 912 | 16 767 | 4 434  | 3 170 622 |                      |
| Other net taxes on production | T1 | 148 141 | -5 699 | -1 396 | -1 872 | 14 235 | 6 613 | 284 | -4 088 | -1 | 32 126 | 2 262 | -10 973 | 179 632 |                      |
| Domestic output | Y | 20 658 603 | 26 949 | 28 854 | 369 404 | 328 994 | 141 441 | 276 794 | 697 876 | 331 | 565 857 | 122 652 | 126 877 | 23 344 631 |                      |
| Imports | M  | 1 193 767 | 15 857 | 228 790 | 52 208 | 3 303 | 35 432 | 46 699 | 62 628 | 331 | 7 305 | 5 196 | 15 477 | 1 667 024 |                      |
| Taxes less subsidies on products | T2 | 1 032 125 | 342 | 4 800 | 191 831 | 51 345 | 23 854 | 6 544 | 61 892 | -103 | -23 714 | -298 | 5 891 | 1 354 508 |                      |
| Trade and transport margins | TTM | -135 617 | 6 777 | 11 448 | 68 317 | -8 330 | -3 870 | 48 282 | 152 698 | 104 | -134 637 | -4 214 | -958 | -0 |                      |
| RESOURCES               |      | 22 748 908 | 49 924 | 273 892 | 681 759 | 375 312 | 196 858 | 378 318 | 975 094 | 663 | 414 811 | 123 336 | 147 288 | 26 366 163 |                      |
Annex 3
Data imports from the TIMES PanEU model

Despite the care taken to ground IMACLIM-P on hybrid economy/energy accounts (cf. sections 2.2 and 2.3 of WP55), the data imports from the TIMES PanEU model into the IMACLIM-P model systematically take the form of trends developing from 2007 on, to be applied to IMACLIM variables, rather than of absolute values. The main reason for this is that TIMES PanEU is calibrated on 2005 data, and thus does not match the statistics of further years, including the 2007 data on which IMACLIM-P is calibrated. Another reason is that some non-energy variables, as vehicle sales or transport activities, are not described in IMACLIM with the same level of detail as they are in TIMES. A last reason is that we lacked time, in the limited course of our EV-STEP programme, to scan the extensive data content of TIMES PanEU for more disaggregated i.e. more ‘to-the-point’ information, which might have been used in a more direct way in IMACLIM. There is thus no question that a more thorough exploration of TIMES PanEU nomenclature could have allowed us a better articulation of IMACLIM on its results. We postpone this improved research agenda to future joint projects.

In what follows we successively report on the 2007 to 2050 yearly trends we extrapolate from 2005 to 2050 TIMES PanEU data or output by 5-year step,\(^{42}\) for the 4 scenarios jointly explored with that model.

International energy prices

TIMES PanEU relies on exogenous trajectories of primary energy prices. These trajectories are constant in all 4 scenarios explored (Figure 10).\(^{43}\) As regards refined petroleum products and electricity, TIMES considers exogenous net import trajectories and hence does not settle on import prices. For lack of a better assumption we use the domestic EU prices reported by TIMES as import prices for the 2 commodities. This means we force constant terms-of-trades for the 2 goods, i.e., considering Equation 14b p. 31, constant shares of imports in total domestic resources (demands) at their 2007 levels.

\(^{42}\) To interpolate between the 5-year steps of TIMES we systematically assume constant-rate variations.

\(^{43}\) Considering the contrasted import volumes of the 4 scenarios (esp. the two EU vs. two REF scenarios) and the weight of EU28 in global energy trade, even if it is bound to decrease over the horizon, the underlying assumption of a small economy (one without impact on international prices) is one shortcoming of our modelling approach.
Figure 10  Trends of international primary energy prices common to 4 TIMES PanEU scenarios

Figure 11  Trends of imported refined petroleum products (left panel) and electricity (right panel) prices

Fossil energy productions

The volumes of domestic (EU28) coal, oil and gas productions all but vanish at the 2050 horizon (Figure 12 to Figure 14). TIMES foresees particularly sharp decreases for oil and gas productions before 2020.
Figure 12  Trends of EU coal production, 4 TIMES PanEU scenarios

Figure 13  Trends of EU oil production, 4 TIMES PanEU scenarios
TIMES PanEU only reports trajectories of net imports \textit{i.e.} of import minus export volumes. To estimate gross exports and imports, (i) we applied to the net imports computed from the 2007 IEA statistics underpinning our EU28 hybrid matrix (cf. section 2.2 of WP55) the trajectories of net imports of TIMES PanEU runs; (ii) we assumed that, along the net import trajectories thus computed, exports evolve as the inverse of imports. From the consecutive exports and imports trajectories we only force the export ones in IMACLIM, to allow the model’s demands, which do not exactly match these of TIMES PanEU, to require increasing imports following Equations 14b and 16 p. 31.

For the sake of concision we only report here the export trajectories of refined petroleum products (PPBW) and crude oil (OIL) (Figure 15), the exports of all other energy commodities being negligible.\footnote{Across time and scenarios: below 6 Mtoe for coal products, 5 Mtoe for electricity and indeed below .2 Mtoe for gas exports.}
Energy intensities of producing sectors

As regards energy intensities we focused our data exchange efforts on the larger energy consumptions of electricity production (ELEC)—*i.e.* the electric mix—, transport services (LDT, WTT, ATT) and the composite sector (COMP). We synthesise this data exchange by reporting on the dynamics of $\alpha$ coefficients, which we index first by the commodity, then by the consuming sector—*i.e.* $a_{ij}$ is the consumption of commodity $i$ by sector $j$.

For the electricity sector we directly used TIMES results on coal, oil products and gas inputs to electricity production, which we related to final electricity demand corrected of net imports—this is indeed the relevant statistics from IMACLIM’s national accounts perspective.

![Figure 16 Trends of coal, gas and refined products intensities of EU electricity production derived from 4 TIMES PanEU scenarios](image)

For the composite sector we had to rely on ratios of TIMES consumption to TIMES GDP (Figure 17)—taking account, for electricity consumptions, of the share of electric car consumptions attributed to firms.
Using total real GDP as a common proxy of sectoral outputs is unsatisfactory, notwithstanding GDP composition problems, because aggregate GDP does not necessarily strictly evolve as total output does. This is however the most relevant data we could get from TIMES.

For the energy intensities of transport services we turned to more accurate activity data. We based our land transport fuel intensity trajectory on that of the ratio of non-passenger car fuel consumptions for transportation purposes to total ton-kilometre freight by land (Figure 18). We similarly based our land transport electricity intensity trajectory on that of the ratio of non-passenger car electricity consumptions for transportation purposes to total public passenger-kilometre by land. For our water transportation fuel intensity we simply related water transport fuel consumptions to ton-kilometre freight by water. For our air transportation fuel intensity, we retained the evolution of the air transport fuel consumption to passenger-kilometre by air ratio—assuming that efficiency gains in freight are identical to those in passenger transport.

**Figure 17**  Trends of coal (upper left panel), refined products (upper right panel), gas (lower left panel) and electricity (lower right panel) intensities of EU composite production derived from 4 TIMES PanEU scenarios
One of the challenges of linking the energy and macroeconomic trajectories of TIMES and IMACLIM lies in harmonising both models’ trajectories of electricity production costs. In TIMES these costs disaggregate in investment costs, operation & maintenance (O&M) costs and primary energy costs, for multiple technologies and in the 28 countries of the European Union. In all countries and across time, all these costs, including those of the primary energies, are exogenous. The evolution of the average cost of electricity production thus simply reflects the evolution of the portfolio of the production units that contribute to electricity production, which differ in their investment, O&M and primary energy ‘intensities’.

Contrastingly, in IMACLIM electricity is the product of one aggregate sector, which adjusts its input intensities facing input prices that are endogenous to the model—exceptions being of course its intensities in primary energies and the import prices of such primary energies, which are directly taken from TIMES (cf. supra). Forcing the quite reduced energy intensities of TIMES in IMACLIM induces a higher intensity of value-added in IMACLIM’s electricity production, following Equation (3) of section 2.2.1 above. There is however no reason why the 0.256 KL/E elasticity of substitution that governs this increase of value-added (cf. Annex 2 to WP55) could be compatible with the explicit investment and O&M shifts modelled by TIMES.

To measure if it is, we build a proxy of a BU price of electricity by combining, at each year of our projection, base year (2007) input prices and current year input intensities for the K, L and M inputs, to which we add current-year energy costs. We compare this proxy to the trajectory of electricity costs obtained by applying to our 2007 electricity cost the trend of average electricity cost of TIMES. At any given year, this proxy being below the TIMES trajectory indicates that the value-added and materials contents computed by IMACLIM are below that implicit in TIMES’ cost trajectory. We lack information on the split between the underlying costs, but the decarbonisation of TIMES’ scenarios is likely to impact significantly more on the capital content of electricity than on its labour or materials intensity—in other terms, carbon-free electricity generation is more a matter of investment than of operation and maintenance costs. We consequently translate the cost gap into adjusted capital intensity based on current year capital costs.
From this computation we derive a trajectory of exogenous adjustments to the capital intensity of electricity production in IMACLIM. We force this adjustment trajectory into the model (in the same way in which we force labour productivity variations, but targeting ELEC production only) and re-run it. Using the same proxy of BU price again, we derive an updated trajectory of exogenous adjustments to the capital intensity of electricity production... and iterate to convergence, i.e. to the point when the gap between the proxy trajectory and the TIMES average cost trajectory are tolerable matches. It turns out that after 4 iterations the maximum discrepancy (at one of the 42 years of the simulated trajectory) falls below 1‰, which we deem sufficient convergence.

To give a notion of the importance of thus acknowledging TIMES’ dynamics of electricity production costs, we report the ‘converged’ gap between IMACLIM’s (unadjusted) capital intensity and that compatible with our proxy of BU costs, for the 4 scenarios explored by TIMES PanEU (Figure 19). These scenarios are explored in the core of the WP above; suffice it to say here that their electricity production costs are expectedly ordered according to the stringency of the carbon mitigation pathways they envision—and that the stronger electric mobility developments of the REF and EU scenarios also marginally show.

![Figure 19](image)

**Figure 19** Ratio of TIMES-derived to initial IMACLIM capital intensity of electricity production, 4 scenarios

Non-energy input intensities (inc. treatment of battery cost)

To maximise the consistency of TIMES and IMACLIM simulations we draw from TIMES a set of proxies of non-energy input intensities. Considering the focus of our research these primarily concern the sales of electric vs. other vehicles, but also range to transport services and to the electrical equipment (ELEQ) of EC production.

Concerning electric car sales, to disaggregate TIMES data we assume a constant split between sales to firms and to households, i.e. we maintain the 2007 split first introduced section 2.3 of WP55 and revised section 1.1 of Annex 1 above: firms account for ca. 26% of electric car sales across time and
scenarios. This percentage applied to the total electric car sales extrapolated from TIMES data on stocks (cf. *infra*) yields sales to firms. For lack of a better activity indicator we relate these sales to TIMES’ GDP assumption. We apply the corresponding trajectory (Figure 20) to the EC intensity of all production sectors of IMACLIM. In Annex 4 we report on the aggregate sales trajectories computed by IMACLIM on the basis of these assumptions, and compare them to TIMES PanEU sales.

We also force exogenous trajectories of land transport (LDT) and water transport (WTT) intensities of the composite production—which again amounts to 92% of total 2007 output. We draw these from relating total ton-kilometres of freight transport via road or water to GDP. It turns out that the ratios are constant across scenarios, which indicates that freight transportation demand is function of total GDP and not prices in TIMES.
Last but not least, based on communication by TIMES PanEU modeller Markus Blesl, we force a decrease of the electrical equipment (ELEQ) intensity of the electric car (EC) to echo the hypothesis of a battery cost reduced by $3/4$ between 2007 and 2020. The transition from 100% to 25% of the 2007 intensity between 2007 and 2020 is made at a constant rate. In our contribution to D4.3 we report on the battery price trajectories thus induced.

Households consumptions

Households' consumptions (in volume) of 9 out of the 12 goods disaggregated by IMACLIM follow trends imported from TIMES PanEU: the 5 energy goods of course (Figure 22), the two vehicle consumptions (Figure 23) and land and air transport services (Figure 24).

Concerning energy goods, for coal products (COAL) we import the trend of residential coal products consumption as projected by TIMES—for crude oil (OIL) household consumption is nil and remains so. For the refined petroleum products and biofuels (RPBW) of IMACLIM we build an index on TIMES results by summing up residential petroleum products consumptions, and a share of road fuel consumptions, which we maintain over the entire time horizon at our estimated 2007 split of households vs. firms transportation fuel consumption, namely at 2/3. For the GAS+ good of IMACLIM we only replicate the trend of residential natural gas consumptions, although we should add up heat consumptions—the impact of this simplification is minored by the high relative weight of gas consumption in the total (85% at our 2007 base year in IEA statistics). For the electricity (ELEC) consumption of households, similarly to refined products we add to residential consumption the specific consumption of electric cars. To draw the latter data from TIMES we however need an assumption on the share of TIMES’ reported EC power consumptions that are theirs. For lack of statistics we settle close to our estimated 2007 split of households vs. firms transportation fuels consumption by attributing to households 2/3 of the electric consumptions of electric cars—we comment immediately below on the consequence of combining this assumption with that we make on vehicle sales.
Turning to the purchases of electric cars (EC) and of other vehicles (ICE) we regretfully had to extrapolate from on-road stocks provided by TIMES, to compute trends, which we imported as such (Figure 23). We reported in section 1.1 of Annex 1 how we distributed electric car sales among economic agents including households, which end up accounting for 74% of electric car sales across time and scenarios. Considering the 2/3 share of electric car electricity consumption we attribute them, we thus indirectly assume that the electric cars owned by firms consume 40% more electricity—i.e. circulate 40% more, all other things equal—than those owned by households.\(^{45}\)

As regards ICE sales to households, these encompass all sorts of motor vehicles and not only passenger cars, although we apply to them our extrapolated trend of non-electric personal car sales in TIMES. To minimise the economic impact of such an approximation, we deliberately set the 2007 production price of ICE goods at half the 26.4-thousand-Euro production cost of electric cars. In this manner we guarantee some plausible order of magnitude to the substitution of one good to the other—while acknowledging that the penetration of ECs will be based on non-market regulations rather than on economic trade-offs.

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\(^{45}\) Comparing 1/3 divided by (1-74%) to 2/3 divided by 74%.
For households’ consumption of land and air transport services we use the trends of public land transport and air transport passenger-kilometres of TIMES PanEU (Figure 24). These trends are constant across the 4 scenarios of TIMES PanEU—presumably because they are linked to GDP per capita evolution; it is only if the simulations of IMACLIM and TIMES PanEU are iterated to convergence that the trends become scenario dependant.
Annex 4
Detailed modelling results

We gather in this annex the few modelling results that are only alluded to in the main text. For the sake of concision we only report on v2 results when these significantly depart from v1 results.

Electric car (EC) sales

The comparison between TIMES PanEU-derived sales trajectories and the corresponding IMACLIM trajectories comforts our methodology of importing EC intensity trajectories into all productive sectors (cf. Annex 3): in the REF scenarios, where the GDP trajectory of IMACLIM is close from that of TIMES (indeed forced to be so in the case of REF), the trajectories almost match—if anything IMACLIM sales are slightly below TIMES PanEU ones in the REF scenario, which is consistent with a slight GDP lag. In the EU scenarios, compared to TIMES PanEU, IMACLIM’s more significantly lower GDPs induce more significantly lower EC sales.

Electric car production costs and battery prices

Electric car production costs are mainly driven by the assumption of significant battery prices reductions by 2020. Because we implement these reductions by targeting the ‘electrical equipment’ intensity of EC production (in volume), which we force to decrease to one fourth its 2007 value by 2020, the battery cost decrease trajectory reflects price variations and is consequently not totally smooth. Beyond 2020 the battery prices and the vehicle costs evolve quite similarly to the GDP price index.

Figure 25 Extrapolated TIMES PanEU vs. IMACLIM electric car sales, REF scenarios (left panel) and EU scenarios (right panel)

46 The costs and prices reported here are relative to the GDP price index according to footnote 10 p.11.
Electric car exports

To complement the levels of EC production induced by the v2 variants we more directly report on EC exports—EC exports are nil in the v1 scenario variants. The exported units are really exogenous assumptions forced into IMACLIM, as they are proportionate to sales to households that are directly imported from TIMES PanEU (cf. Annex 3).