A macro-micro outlook on fuel poverty in 2035 France

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Abstract

The national strategy on energy transition underway in France identifies fuel poverty as one of the major constraints weighing on France's energy future. To contribute to this reflection, we develop a first prospective analysis of fuel povertyin the 2035 Franceoutlined by 4 influential macroeconomic scenarios. This analysis mobilises a 'macro-micro' approach that articulates computable general equilibrium modelling and extensive household survey data. At the core of this approach, a systemic modelling of household energy demand innovatively draws on urban economics research. Our modelling results show that both the number and share in total household count of fuel-poor households should increasein France between our 2006 reference year and our 2035 horizon, under our 4 macroeconomic scenarios and according to the two distinct operational measures of the phenomenon. This increase is furthermore concentrated on the poorer first income quintile, which shifts from concentrating half to three quarters of the domestic energy expenses of fuel-poor households. However, the moderate extent of these expenses when measured against French GDP allows envisaging some socialisation of them, even under the double constraint of contained public deficits and a constant fiscal pressure.

Keywords

Fuel poverty, energy demand, computable general equilibrium, micro-accounting with reweighting.

1 Introduction

Under the crossfire of a persisting economic crisis, increasing financial constraints on public social expenditures and a sustained rise of domestic energy prices, fuel poverty has been growing in France, thus attracting increasing attention from policymakers. The phenomenon is commonly defined as the difficulty in maintaining housing at an adequate warmthlevel for a reasonable cost (Boardman, 1991). In France,fuel-poor people are defined by law as anyone who encountersparticular difficulties in obtaining the energy required to meet their basic energy needs at home due to insufficient resources or bad housing conditions ("Grenelle 2" law number 2010-788, 2010).More practically, the indicator retained by French authorities to measure fuel poverty is the 10% 'need-to-spend threshold' (NST) of the 2001 United Kingdom Fuel Poverty Strategy:fuel-poor householdsare thosewho need or would need to spend more than 10% of their income on domestic fuel expenses to keep their homes tolerably comfortable. Following that measure, 3.8 million households were estimated in fuel poverty in France in 2006 (Devalière *et al*., 2011; RAPPEL, 2012).[1]

The literature identifies three main factors of fuel poverty: energy-inefficient housing, high fuel prices, and low income (IEA, 2011; RAPPEL, 2011; Palmer *et al*., 2008). Low energy performance of dwelling is indeed a determining factor of fuel poverty in France (Tyszler*et al.*, 2013):according to the French National Housing Agency (ANAH, 2008), 77% of allFrench homesare in the lower D to G categories of the French Energy Performance Certificate, mainly because these were built before the first thermal regulation in 1974. Moreover, the price of domestic fuels has increased over the past few decades and the trend has accelerated since 2010.[2]As regards correlation with income poverty, nearly 70% of the fuel-poor households in France are among the lowest income (1st quartile of the population), as indeed the average need-to-spend ratio strongly decreases with income levels—from 9.3% for the first income quartile to 2.7% for the 4th income quartile (Devalière *et al.*, 2011).

The 10% NST was first used in the 1990s by Brenda Boardman (Boardman, 1991). Her observations showed that the poorest 30% of British households spent on average 10% of their income on domestic fuel. This enabled a first targeting of the fuel-poor for policy action, together with the monitoring of fuel poverty over time. The indicator has however a number of limitations, some of them related to its intrinsic ratio form, some others to the specific relevance of the 10% figure (Hills, 2011). First, the systematic use of a ratio does not allow discriminating high-income households, who have obviously less difficulty affording necessary energy expenses than people on lower incomes forced to trade them off with other essential expenditures. Hills (2011) or Moore (2012) indeed underline a significant number of high-income households categorised as fuelpoor under the 10% NST measure. Furthermore, as fuel prices change, the distribution of fuel expenses moves in relation to the fixed threshold, and the numbers counted as fuel poor can change very rapidly. Finally, the10% threshold isin fact quite specific to the late 1980s' UK: it was computed as twice the median domestic fuel expenditure of the 1988 United Kingdom Family Budget Survey. But it has not been revised since, or adjusted to the particulars of other countries where it has been applied, including France.To overcome these limitations, in an influential report commissioned by the British government Hills (2012) recommends adopting a new indicator focusing on the overlap of high fuel costs and low income, the "Low Income-High Costs"(LIHC) indicator. Hills proposes to set (*i*) the income threshold at 60% of national median income in equivalised terms (accounting for household composition), in accordance with the official definition of income poverty, and (*ii*) the fuel cost threshold at the national median of households' fuel expenses. Using this new measure, fuelpoverty in France is re-estimated at 2.7 million households (10.3% of total population) in 2006, *i.e.* 29% lower than with the arguably too-inclusive 10% NST measure (ONPE, 2014).

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[1] The corresponding fuel poverty rate is estimated at 14.4%.

[2] Since the last months of 2014 oil prices have substantially dropped. There is however widespread agreement among experts that low prices should not last, because of concerns about the sustainability of the shale oil & gas boom in the United States, and of doubts about the ability of Saudi Arabia to keep on barring production decreases by OPEC countries.

Our objective in this paper is to develop a first prospective analysis of fuel poverty in the 2035 France outlined by 4 macroeconomic scenarios of the *Centre d'Analyse Stratégique* (CAS), a prominent advisory body to the French government (CAS, 2011). We build our outlook on a 'macro-micro' modelling of the French economy, which simultaneously mobilises a prospective macroeconomic model, IMACLIM-P, and the database of an extensive French households' survey, the *Budget de Famille*(BdF) enquiry. While building up on past improvements over the standard computable general equilibrium architecture (calibration on hybrid energy/economy matrixes and bottom-up expertise; tracking of the secondary distribution of income between public administrations, firms and household income quintiles), we implement a version of IMACLIM-P purposely extended to model households' energy demand in a systemic approach, with a view to take stock of urban economics research on the housing/transportation nexus and the energy demands it induces. We use it to project a 2006 calibration on the French economy to 2035, based on exogenous growth assumptions drawn from the CAS complemented by other authoritative French public bodies and international organisations. We further break down the resulting income and expenditures variations across quintiles among 10,240 household types derived from the *Budget de Famille* household survey, after proper adjustment of their resources and expenditures. This allows us to assess the extent of fuel poverty with both the standard 10% NSTand the latest LIHC measures.

The paper develops as follows. A first section synthesises the macroeconomics of our prospective methodology, *i.e.* the IMACLIM-P 3.4 model, insisting on our innovative treatment of households' trade-offs. A second section details the assumptions that form the driving forces of our projections of the French economy, and the resulting macroeconomic contexts fleshing out the synthetic macroeconomic scenarios of the CAS. A third section introduces our method of disaggregation of the 2035 macroeconomic projections of IMACLIM-P, then presents and discusses the estimates of fuel povertythat it produces.

2 The prospective general equilibrium model IMACLIM-P

Our projections of the French economy mobilise the 3.4 version of the IMACLIM-P model, a static computable general equilibrium model of the IMACLIM modelling family (of which recent applications comprise Ghersi *etal.*, 2013,Waisman *et al.*, 2012 or Hourcade and Ghersi, 2010): IMACLIM-P simultaneously represents the balance of supply and demand on all markets of consumption goods & services and production factors, through a set of equations, whose parameters can be changed to simulate economic mutations.

IMACLIM-P is implemented in a Harrod-type exogenous growth framework, on central assumptions regarding demographic shifts and the growth of labour productivity.The model describes second best economic conditions, in the sense that it models (*i*) myopic foresight for both the producers and the consumers: the 2035 trade-offs (which synthesise adaptation to implicit 2006 to 2035 relative price trajectories) are influenced by the 2035 relative prices only—no dynamic assumption is made whatsoever; notably, savings and investment rates are exogenously maintained at their 2006 values; (*ii*) mark-up pricing, *i.e.*constant average margins on production costs, while marginal pricing (synonymous of competitive markets) is guaranteed by the product-specific calibration of decreasing returns, which are modelled as an iso-elasticity of costs to real output.

Besides, IMACLIM-P is specifically built to allow calibration on bottom-up expertise of the energy systems, with a view to acknowledge the complex multiple technical constraints that frame the evolutions of energy systems. Among others this translates into calibration on ‘hybrid’ matrices, recomposed through the cross-exploitation of national accounting and energy balance statistics.The latter matrices notably acknowledge agent-specific net-of-tax pricesimplemented through the calibration of agent-specific margins.

At last, rather than considering one single agent endowed with all production factors, IMACLIM-P represents both the primary income distribution among 5 household living-standard quintiles, firms, public administrations and foreign economies (the ‘rest-of-the-world’ of its small, open economy setting), and the secondary income distribution—transfers of varying nature—between these different agents. This is the *sine qua non* condition to exploring distributive issues.

Beyond a series of accounting equations that guarantee the simultaneous equilibrium of all markets in money-metric and volume terms, IMACLIM-Prests on a set of behavioural equations that govern the responses of economic agents to the changes in relative prices registered over the term considered. In the following we concentrate on the description of households’ trade-offs, which are at the core of our forecasting of energy poverty and form the central methodological contribution of our research. Ghersi (2014) provides an exhaustive description of the rest of the model.

Because of their historical focus on the description of energy supply technologies, most prominent CGE models applied to energy forecasting still resort to nested CES functions to represent consumer demand—cf. the DART (Klepper *et al.*, 2003), the EPPA (Paltsev *et al.*, 2005), the PACE (Böhringer, 2002) or the PHOENIX model (Sue Wing *et al.*, 2011). These functions commonly isolate one aggregate energy bundle from all other consumptionsand level off both the substitution possibilities among energy goods on one side,and those between the energy bundle and the bundle of all non-energy goods on the other side.[3]In this way they substantially abstract from the actual complexity of the technical systems and behaviours that govern households’ energy consumption.This is probably acceptable for small deviations of the relative prices over a short term, all the more so as it backs up analyses focusing on the supply side of economies.It is however quite debatable for the large deviations of the relative prices that the oncoming energy and climate conundrum seems bound to impose,

[3] In the version referenced the PACE model bundles fossil fuels only; electricity is aggregated to non-energy consumptions through a Cobb-Douglas specification. The EPPA model gives automotive fuels a specific, explicit treatment, in line indeed with our recommendations; however it fails to connect housing and transportation expenses.

especially if the research question is concerned with how consumers fare. As we demonstrated in a former paper researching production functions (Ghersi and Hourcade, 2006), a proper modelling of energy consumptions flexibilities requires hybridising top-down CGE assessments with some bottom-up expertise on the underlying technical systems. This is precisely the spirit in which we develop our first attempt at an innovative modelling of household energy demand, focusing on the dynamic constraints embedded into spatial systems.

This modelling distinguishes 8household consumption goods: housing, housing maintenance and renovation (to record renovation expenses), public transports, automotive fuels, electricity, natural gas, domestic fuels and a composite good remainder.[4] Public transports and automotive fuels are further disaggregated in 'constrained' *vs.* 'leisure' varieties; similarly, electricity is broken down between specific and non-specific (*i.e.* substitutable) uses. All goods enter an extended utility function, which centrally exploits the conclusions of urban economics on the long term choices regarding housing, and the transportation activities induced by such choices. Fujita (1989), who synthesises developments dating back to the 1960's, sets a milestone to this research. Bertaud and Malpezzi (2003) provide an extensive survey of its robustness, by applying it to 48 megalopolises around the globe.

We thus stretch the interpretation of the urban economics model by applying it to an aggregate country (France), rather than to some geographically consistent urban unit. In a nutshell, our specification boils down to (*i*) impose a constant budget share to housing expenses—*i.e.* assume a Cobb-Douglas utility of housing *vs.* other expenses; (*ii*) derive constrained transportation demand as a function of the housing surface, based on the assumption of nil transportation requirements for a minimum housing surface exogenously set at 9 square metres *per* consumption unit (Box 1).[5]

Regarding energy consumptions for heating purposes, (a little over 80% of domestic energy consumptions outside specific electricity in 2006 France), we exploit results of the model developed by Giraudet (2011) on the dynamics of the French residential building stock disaggregated in energy performance classes, for the 3 main substitutable energy carriers (fuel oil, natural gas and electricity).[6] This model notably innovates by explicitly considering the gap between the theoretical energy efficiency improvements induced by renovations, and the effective improvements when 'rebound effects' are accounted for—*i.e.* the observed tendency to partiallytradeoff, after housing renovation, lower energy bills and higher comfort standards.

[4] The 9th good disaggregated by the model is an aggregate of crude oil and coal—the two goods are not distinguished because of the current quite low level of coal consumption in France, and the little prospect of any pick up considering the role of nuclear energy in electricity production. Households do not consume crude oil, and their residual coal consumption still appearing in 2006 statistics disappears from 2007 on. We consequently assume nil household consumption in 2035.

[5] The 9 square-metre minimum surface is translated into aggregate constraints on household classes thanks to household survey data.It echoes a French regulation (*loi 2000-1208*) that bans renting any lodging below such surface.

[6] Giraudet's analyses sustain a report by the *Commissariat général au développement durable* (Giraudet *et al.*, 2011).A hard link of its RES-IRF model with IMACLIM-R, an extended version of IMACLIM-P, is used in (Giraudet *et al.*, 2011), and performed sensitivity analysis upon in (Branger*et al.*, 2014).

Let U be the utility of some household enjoying LOG square metres of housing surface, and an aggregate of Z other consumptions, following a Cobb-Douglas specification:

$$U = LOG^a Z^b \quad (1)$$

with a and b strictly positive coefficients such as $a + b = 1$. If R_{CONS} is the consumed income of this household, p_{LOG} the price of a square metre of housing (assumed to decrease with LOG), $p_{TCONT}T_{CONT}$ the daily transport expenses induced by the choice of housing surface LOG; using Z as *numéraire* with a price normalised to 1, the budget constraint of the household reads

$$R_{CONS} = p_{LOG}\, LOG + Z + p_{TCONT}\, T_{CONT} \quad (2)$$

Injectingthe expression of Z drawn from equation (2) in U allows computing the optimal housing surface LOG^*:

$$LOG^* = \frac{a\,(R_{CONS} - p_{TCONT}\, T_{CONT})}{p_{LOG}} \quad (3)$$

Injecting this surface and the same expression of Z in U yields maximum utility U^*:

$$U^* = a^a\, b^b\, \frac{R_{CONS} - p_{TCONT}\, T_{CONT}}{p_{LOG}^a} \quad (4)$$

The urban economics model synthesised by Fujita (1989) hangs on the assumption that this utility, at the equilibrium, is equal whatever the choice of localisation. Besides, it assumes that the transport requirements T_{CONT0} induced by the smallest possible housing surface LOG_0 is nil. Equating U_0 the utility of housing choice LOG_0 to U, that of any other housing choice, both of them expressed following equation (4), allows defining p_{LOG0} the price of LOG_0 as a function of p_{LOG}, R_{CONS}, $p_{TCONT}T_{CONT}$ and a; injecting this definition in the expression of LOG_0 from equation (3) allows in turn defining p_{LOG} as a function of LOG_0, R_{CONS}, $p_{TCONT}T_{CONT}$ and a; injecting at last this expression of p_{LOG} in LOG defined following equation (3) yields:

$$LOG = LOG_0 \left(\frac{R_{CONS}}{R_{CONS} - p_{TCONT}\, T_{CONT}} \right)^{\frac{1}{a}} \quad (5)$$

This relationship is easily inverted to define the daily transport services requirementsattached to any housing surface LOG:

$$T_{CONT} = \frac{R_{CONS}}{p_{TCONT}} \left(1 - \left(\frac{LOG}{LOG_0} \right)^{-a} \right) \quad (6)$$

Box 1 **Daily transport requirements induced by housing choices in the urban economy model**
Notations are these of the IMACLIM-P formulary (Ghersi, 2014)

These two central features of household energy behaviour are completed by assumptions on the energy consumptions induced by cooking and water heating requirements, and specific electricity demand. Following Cayla (2011), the two first consumptions are supposed strictly proportional to total population, under the assumption that any energy efficiency gains are crudely compensated by increased *per capita* services. Aggregate specific electricity demand dynamics are exogenously taken from an influential prospective scenario by the French powergrid authority, the *Réseaude transport d'électricité*(RTE, 2011). Their distribution among household quintiles is further discussed below.

3 Prospective assumptions and macroeconomic modelling results

3.1 Prospective assumptions

In the exogenous technical change framework of IMACLIM-P, growth conventionally results from the combination of demographic changes and productivity improvements. As regards demographics, the total, active and retired French population register variations of +12.8%, -1.0% and +53.8%, following projections by the French national statistics institute INSEE[7] and the *Conseil d'orientation des retraites* (COR, 2010). Population counts are disaggregated among the 5 household classes according to their 2006 compositions in each of the three population groups (active, retired and other populations).[8]

Turning to productivity, IMACLIM-P models improvements following a Harrod-neutral assumption oflabour productivity gains homogeneously impactingall productions.These gainsendogenously adjustto target the GDP growths envisioned in a set of 4contrasted prospective scenarios produced by a central advisory body to the French government, the*Centre d'Analyse Stratégique* (CAS, 2011): a worst case scenario (hereafter WCS), an unsustainable growth scenario (UGS), a sustainable growth scenario (SGS) and a variant of the latter with improved labour market efficiency (SGS+).The unemployment rates of these CAS scenarios are exogenously forced in the projections, with a direct impact on the employed workforce counts (Table 1).

	Worst case scenario	**Unsustainable growth sc.**	**Sustainable growth sc.**	**…& efficient labour market**
2006 to 2035 GDP growth (per annum *rate)*	47.7% *(1.35% p.a.)*	57.6% *(1.58% p.a.)*	75.1% *(1.95% p.a.)*	79.6% *(2.04% p.a.)*
2035 unemployment rate	8.5%	7.5%	6.5%	4.5%

Table 1 **Effective growth and unemployment rates of 4 CAS scenarios**
Source: CAS (2011) completed by national statistics for 2006 to 2009 growth.

A third major growth driver is an assumption that must be made, in the open economy framework of IMACLIM-P, on the development of export markets independently from terms-of-trade changes (changes in the prices of French exports relative to prices of French imports). The French economy is indeed inserted in a global context marked by high economic growth, which should impact on French exports even if relative prices remained unchanged. A scalar is thus applied to exports as an upward trend that is then corrected by relative prices changes following conventional price elasticities. This scalar is computed by assuming an average2% yearly growth of export markets, resulting in a +78% trend over the 29 years of projection.

A fourth set of determinant prospective assumptions regards 2035 public policies. Considering its focus on distributive issues, IMACLIM-P indeed distinguishes public administrations, including social security institutions, from firms and households. It tracks the evolution of their resources by representing a dozen aggregate fiscal levies, assumed constant in their 2006 effective rates and fiscal bases across our 4 projections;[9] the two sustainable growth scenarios complete this set of taxes with a substantial €127 *per* ton of CO_2 (/tCO_2)

[7] Population projections to 2060, cf.http://www.insee.fr/fr/themes/document.asp?ref_id=ip1320 (accessed November 2015).

[8] Considering the slight demographic composition differences of living-standard quintiles in 2006, this means that the size of each quintile does not evolve identically—the 2035 household classes are not quintiles anymore strictly speaking;however they remain close enough to it for us to keep on labelling them that way, for the sake of clarity and concision.

[9] The substantial excises on fuel consumption are maintained in real terms, *i.e.* deflated by the consumer price index.

carbon tax, following the recommendation of a previous CAS report on the normative value of carbon (CAS, 2008). Besides, public administrations capture part of the gross operating surplus of firms, based on a share that, for lack of a better hypothesis, is also maintained at its 2006 level. On the expenditure side, public consumption and public investment are assumed to grow at the same pace as GDP.[10] Under these two sets of assumptions, the indexation of social transfers crucially determines the evolution of the public debt. To avoid an unsustainable increase of this debt under the pressure of dramatically higher pension payments (the threat is obviated by the comparison between the increase of the retired population, +54%, *vs.* that of the active population, -1%), all 3 modelled categories of *per capita* transfers (pensions, unemployment benefits and one aggregate social income remainder) are equally adjusted to maintain the public debt at its 2006 level of 63 GDP points. In a context where wages strongly benefit from the productivity gains that drive growth, this implies a substantial increase in inequality between the active occupied households and all other households. Current responses to the persisting economic crisis suggest plausibility of this assumption of a much reduced social security system.

A final set of assumptions regards the energy field. International prices of oil and gas are drawn either from the 'Current policies' (for the WCS and UGS scenarios) or the 'New policies' (for the SGS and SGS+ scenarios) scenarios of the IEA (IEA, 2011). Assumptions then have to be made on the prices of imported refined petroleum products and electricity. For lack of better hypotheses these are indexed on national prices, *i.e.* the competitiveness of the French refining industry and electricity production is supposed unchanged at the projected horizon.Concerning energy demand, at last, an assumption on the development of specific electricity consumption is directly derived from RTE (2011). Contrary to other forced trends the RTE projection is supposed inelastic to relative prices.It is translated into one uniform*per capita*yearly consumption equally forced on all household classes, to reflect convergence of behaviours regarding,particularly,ICTs uses. Another important assumption is required on the energy efficiency of residential buildings heating. The penetration of an updated 2005 building code is bound to increase the average efficiency of the building stock, at a cost that is, by definition, already integrated in the 2006 calibration data on investment. This is a typical case where the relative price-centred modelling approach is helpless in representing an expected trend, which, consequently, must be forced into the model. Based again on RTE (2011), the efficiency of post-2006 buildings is supposed 47% (WCS, UGS) to 70% (SGS, SGS+) higher than the average efficiency of the 2006 stock. However this only applies to a limited share of the 2035 stock, as a conservative 0.35% yearly destruction rate is imposed (following Giraudet, 2011), *i.e.* a massive 90.3% of the 2006 building stock remains in use in 2035. The forced trend is, as the majority of other such assumptions, an *ex ante* trend that is *ex post* corrected by relative-price induced renovations—calibrated on Giraudet (2011) as well, cf. section on households' trade-offs above and Ghersi (2014).

For reference purposes Table 2 synthesises the main assumptions backing our scenario projections.

[10] In money-metric terms. Because the prices of these expenditures and investments do not exactly match the GDP deflator real variations ultimately differ, cf. *infra*.

Variations from 2006 to 2035	Worst case scenario	Unsustainable growth sc.	Sustainable growth sc.	…& efficient labour market
Population, total	+13%	+13%	+13%	+13%
Population, retired	+54%	+54%	+54%	+54%
Population, active	-1%	-1%	-1%	-1%
GDP	+48%	+58%	+75%	+80%
Unemployment rate	-0.3 pts.	-1.3 pts.	-2.3 pts.	-4.3 pts.
Export markets (volume, trend)	+78%	+78%	+78%	+78%
Ratio of public debt to GDP	id.	id.	id.	id.
World oil prices	+109%	+109%	+80%	+80%
World gas prices	+47%	+47%	+37%	+37%
Carbon tax, ^{2006}€/tCO_2	id.	id.	+127	+127
Effective energy efficiency of post- *vs.* pre-2006 buildings	+47%	+47%	+70%	+70%
Specific electricity consumption (volume)	+29%	+29%	+29%	+29%

Table 2 **Main assumptions backing the 4 prospective scenarios**
*Sources: INSEE, COR, CAS, IEA, RTE (*cf. *text)*

3.2 Macro-economic modelling results

The targeted GDP increases turn out to distribute in a contrasted manner between the aggregate GDP components from an expenditure point of view (Table 3). Real consumptionlags behind other GDP components, because the exposure to international competition drastically limits the ability of real wages increases to reflect labour productivity gainsin a context where increasing energy import prices hamper the competitiveness of French products—degraded terms-of-trade explain, conversely, the gap between labour productivity gains and GDP growth.[11]Public expenses, although a constant share of GDP in money-metric terms, increase slightly beyond it in real terms for the simple reason that their deflator does not encompass energy prices.[12]Exports develop massively, in line with the 78% forced trend but all the more above it as scenarios envision higher growth and lower unemployment. However the contribution of trade balances to growth remains small (below 2%), as imports grow substantially as well and the 2006 trade balance only amounts to 1.3% of GDP.

Although incidental to our focus on households, results on the energy and CO_2 intensity of GDP are of interest. Simple calculation on Table 3 results reveals that the two unsustainable scenarios register 24%and27% drops in the energy intensity of GDP, *vs.* 38% and 39% for the two sustainable scenarios, where a substantial carbon tax adds up to slightly less increased energy import prices. However these efficiency gains are systematically compensated by demand growth and the volume of energy consumptions increases from 9% to 14% across scenarios. Fuel substitutions allow further CO_2 intensity decreases, from 31% and 34% for the unsustainable scenarios, up to 46% for both sustainable scenarios. However, the 5% decrease in total emissions attained by the best performing SGS is hardly in line with expected French commitments around 2035. Our rejection of any "autonomous energy efficiency improvements", together with our crude assumptions on the many technical asymptotes to input decreases are main keys tothese results. To the best of our knowledge, none of these

[11] The disindexation of wages relative to prices is an observed trend in France as in other economies (INSEE, 2009).

[12] National accounts treat public expenses as the exclusive consumption of a public sector good, which in our aggregation is part of the composite remainder.

assumptions could be lightly rejected as too pessimistic. The only potentially major source of decarbonisation that we do not give justice to is the possible massive penetration of electrified personal transports.Its impact on energy poverty, the focus of our research, is however arguably negligible.

	Variations from 2006 to 2035	Worst case scenario	Unsustainable growth sc.	Sustainable growth sc.	…& efficient labour market
National aggregates	GDP (forced)	+48%	+58%	+75%	+80%
	Consumption	*+32%*	*+37%*	*+47%*	*+49%*
	Public expenditures	*+51%*	*+59%*	*+77%*	*+80%*
	Investments	*+55%*	*+66%*	*+87%*	*+92%*
	Exports	*+76%*	*+87%*	*+102%*	*+107%*
	Imports	*+51%*	*+51%*	*+54%*	*+54%*
	Labour productivity	+63%	+75%	+99%	+102%
	Average real wage	+42%	+45%	+49%	+48%
	Fiscal pressure	-1.0 pts.	-1.1 pts.	-0.2 pts.	-0.2 pts.
	Energy consumption	+12%	+14%	+9%	+10%
	CO_2 emissions	+2%	+4%	-5%	-4%
Relative prices	Real and imputed rents	+26%	+30%	+38%	+40%
	Housing M&R	+2%	+1%	-1%	-1%
	Public transports	+15%	+14%	+22%	+22%
	Vehicle fuels	+43%	+49%	+87%	+90%
	Electricity	+9%	+9%	+23%	+23%
	Domestic fuels	+78%	+88%	+149%	+153%
	Natural gas	+30%	+38%	+95%	+98%
Households' consumptions (volumes)	Composite good	+42%	+48%	+63%	+66%
	Housing surface	+12%	+14%	+18%	+19%
	Public transports	+11%	+14%	+8%	+9%
	Constrained	+13%	+16%	+11%	+13%
	Leisure	+10%	+12%	+6%	+7%
	Vehicle fuels	+10%	+12%	+4%	+5%
	Constrained	+12%	+14%	+7%	+8%
	Leisure	+8%	+10%	+2%	+3%
	Housing M&R	+57%	+69%	+134%	+139%
	Electricity	+34%	+37%	+41%	+42%
	Specific	+29%	+29%	+29%	+29%
	Non specific	+38%	+46%	+53%	+55%
	Domestic fuels	-36%	-38%	-49%	-49%
	Natural gas	+5%	+0%	-26%	-27%
	Residential energy	+4%	+3%	-10%	-10%
	Total energy	+6%	+6%	-5%	-5%
	Hh CO_2 emissions	-2%	-2%	-15%	-15%

Table 3 **Main aggregate scenario results**
Source: IMACLIM-P modelling.

Relative prices of the consumer goods are quite distorted by the projected increases in international oil and gas prices and by the carbon tax in the sustainable scenarios (Table 3). Unsurprisingly, domestic fuels show the highest increases, while vehicle fuels, although similarly based on crude oil, increase substantially less because of their constant excise tax component. Electricity prices register relative increases of 9% to 23%, in line with currently circulating estimates among French experts. Gas prices increase substantially more, reflecting IEA's projections on international markets and the €127/tCO_2 carbon tax in the sustainable scenarios. Public transports, at last, are expectedly much less sensitive to the price increases of both their vehicle fuels and electricity inputs. Outside the energy field, housing costs register substantial 26% to 40% increases, induced by the projected 12% to 19% increases in housing surfaces.[13] Housing maintenance and renovation costs do not diverge significantly from the composite good prices.

Driven by those relative prices variations, composite consumption increases more than any other consumption, with the exception of housing maintenance and renovation—but this is merely a computational artefact stemming from aggregating renovation investments to the 'small repairs and maintenance of dwelling' consumption (a handy way to model the substitution possibilities between renovation and heating expenses). Our 'urban economics' specification performs satisfactorily: under the Cobb-Douglas assumption on housing expenses a quite higher average income would tend to project a substantial urban sprawl, but this is checked by the high decreasing returns of housing services production (cf. footnote 13); transports follow and indeed exceed the housing surface development, with some limited substitution between the public and private modes.[14]

On the residential energy front, investment in insulation or equipment to cut down heating expenses shows in the strong increase of housing maintenance and renovation services consumption and in the gap between housing surface increases and residential energy consumption variations. The carbon tax exacerbates this investment, allowing residential consumptions to drop by 10% in the sustainable scenarios, whereas they increase by 3% to 4% in the unsustainable scenarios. Reflecting relative prices variations, the energy mix of substitutable domestic energy consumptions shifts towards electricity at the expense of natural gas and domestic fuels, especially in the SGS and SGS+ where the carbon tax strongly impacts relative prices. This allows the residential energy consumption variations to translate into a 2% drop of the direct CO_2 emissions of households for the unsustainable scenarios, and a 15% drop for the sustainable scenarios.

Note at last that the value-added of our innovative methodology shows at a glimpse in the comparison of households' aggregate vehicle fuels and natural gas consumptions: in all scenarios and especially in the two with a carbon tax, although vehicle fuels prices rise significantly more than natural gas prices, vehicle fuels consumption grows more than natural gas consumption, which indeed significantly shrinks in the two sustainable scenarios. This sort of result is unattainable by the nested CES structures common to most prominent CGE models (cf. section 2 above).

3.3 Quintile results

As already evoked, IMACLIM-P tracks the income and expenditures of 5 living-standard household quintiles, which allows some inspection of the distributive impact of the prospective scenarios. This disaggregation of the standard "representative household" is based on data from the 2006 *Budget de Famille*(BdF) household expenditure survey conducted by the French national statistical agency INSEE. The survey details a comprehensive disaggregation of the budget of 10,240 households of metropolitan France in several hundred expenses, together with extensive series describing the income sources and the social and economic characteristics of the households and individuals therein. All demographic, labour market and national accounts

[13] Astrong positive correlation between total housing surface and housing rents is modelled by acknowledging the sharply decreasing returns implicit in the high level of average margin of the production of housing services in 2006 statistics.

[14] The modal shift between private and public transports is crudely modelled as a CES of purposely low elasticity (Ghersi, 2014).

statistics of the "households" agent necessary to the calibration of IMACLIM-P are broken down into income quintile statistics *prorata* the share of each quintile in the weighted sum of the survey's corresponding variable. In other words: the statistical weight of each household provided by the survey (corresponding to the number of similar households at the national level) is applied to its demographics, sources of income and consumptions; the resulting series are aggregated quintile by quintile; the share of each quintile in each series is applied to the corresponding national accounts statistics to derive quintile-specific statistics.[15]

In our simulations to 2035, each quintile thus calibrated (*i*) sees its income evolve specifically depending on the relative weight of the 6 aggregate income sources detailed by the model; (*ii*) performs consumption trade-offs that, for lack of quintile-specific behavioural data, are only differentiated as far as substitutable energy is concerned (both in its mix and substitutability to insulation and more efficient end-use equipment), based on exogenous deviations of the central elasticities calibrated on Giraudet (2011).

Some supplemental assumptions structuring the projected distributional impacts should be borne in mind when interpreting our results:

- The aggregate variations of the active, retired and total populations taken from INSEE and COR are uniformly applied to the corresponding populations of each quintile. However quintile 1 (Q1) groups a lower share of pensioned people than the other 4 quintiles (16% of the total *vs.* 20% to 22%)—which reflects the relative wealth of the 2006 retired population. Given the strong growth of this demographic category, total population of Q1 mechanically grows less than that of other quintiles.[16]
- The job creations of our 4 scenarios benefit all the unemployed population with equal probability—we assume identical shifts of the unemployment rates of each quintile (in relative terms, not percentage points). Considering how widely the 2006 rates revealed by the *Budget de Famille* survey differ (from 29% for Q1 to 3% for Q5), this assumption induces large variations of income distribution: the share of the active population of each quintile shifting to employment decreases sharply with the quintile.
- The average net wage *per* worker evolves uniformly across quintiles as well. Unlike the former one this hypothesis limits the changes in income distribution by assuming a stabilisation of the average wage differentials between quintiles. Similarly, the share captured by each quintile of the gross operating surplus (GOS) of households (projected as a constant proportion of total rents), as well as that of an aggregate of other transfers, is assumed constant.

The two latter assumptions combined strongly influence the relative evolutions of the aggregate gross disposable incomes of quintiles (Table 4). As 2006 unemployment rates strictly decrease with quintiles, the employment gains of the scenarios benefit more the lower quintiles.Consequently, the relative situation of the lower quintiles significantly improves with unemployment reduction, from scenario WCS to scenario SGS+. This shows in the Gini index variations induced by the scenarios, from a quasi-stability of income distribution in the WCS scenario to a significant decrease of income inequality in the SGS+ scenario.

[15] Only exception to this rule, the income tax is disaggregated according to INSEE computations, although their undocumented method could not be reproduced. No sense could indeed be made of the suspiciously high (substantially higher than those of the third quintile) income tax payments of the second quintile.

[16] Considering that we assume a uniform decrease of the number of persons by household across quintiles, our 2035 households groups are not quintiles strictly speaking anymore. The variations are small enough to warrant sticking to our denomination, for the sake of clarity.

GDI variation from 2006 to 2035	Quintile 1	Quintile 2	Quintile 3	Quintile 4	Quintile 5	*Gini*
Worst case scenario	+19%	+32%	+35%	+36%	+32%	*+0.1%*
Unsustainable growth scenario	+24%	+37%	+40%	+41%	+37%	*-0.8%*
Sustainable growth scenario	+35%	+48%	+49%	+50%	+46%	*-3.4%*
…& efficient labour market	+40%	+50%	+51%	+52%	+48%	*-4.8%*

Variations are measured in real terms by the use of quintile-specific price deflators. The 'Gini' column reports the recorded variation of the standard Gini index, computed for the 5 quintiles of IMACLIM-P. A decrease of the index indicates a reduction of income inequality.

Table 4 Gross Disposable Income (GDI) variations from 2006 to 2035
Source: IMACLIM-P modelling, authors' computation.

Detailed quintile results indicate however that this decrease is caused by some moderate catching up of Q2 to Q4 over Q5, but that this catching up never occurs for Q1, which even under the most favourable SGS+ scenario grows 8 to 12 points less than the other quintiles. The main reason behind this systematic lag is our assumption that public deficits are contained by social budget cuts, in a context where pensions, even if only indexed on inflation, require a massively higher share of public resources. This assumption is obviously quite detrimental for Q1, whose income depends for a much larger share on such budgets. Of course it has some consequences on income poverty and thus fuel poverty under the LIHC measure, which we will further detail below.

Another key to our fuel poverty outlook is the evolution of the ratio of domestic energy expenses over gross disposable income, which we call the energy effort ratio (EER). A first glimpse at EER variations reveals a striking divergence between the scenarios impacts on Q1 EER *vs.*Q2 to Q5 EER (Table 5). Q1, which expectedly has the highest EER in 2006 (4.38%), registers systematic EER increases, whereas other quintiles see their EER as systematically reduced. Beyond the particular impact on Q1 income of reduced social transfers, which we already underlined, this is the combined consequence of twomore assumptions:

- The particularimpacton Q1expenses of assuming convergence of specific electricity consumptions to a nationally uniform *per capita* average. This assumption, based on a loose observation of current convergences of both the levels of equipment and the practices sustaining specific electricity consumptions, implies a 73% increase of Q1 specific electricity consumption, to be compared to a 24% to 33% increase for Q2 to Q4, and to a 7% increase for Q5.
- The lesser ability of Q1 to adapt to energy prices hikes by changing their fuel mix or resorting to insulation or more-efficient heating equipment—this reduced capacity is however our own exogenous assumption of a deviation from the aggregate households elasticities drawn from Giraudet (2011), for lack of quintile-specific behavioural data.

Energy effort ratio		Quintile 1	Quintile 2	Quintile 3	Quintile 4	Quintile 5	*Together*
2006 Energy effort ratio		4.38%	3.63%	3.22%	2.89%	2.18%	*3.00%*
2006 to 2035 variation	Worst case scenario	+0.36 pts.	-0.14 pts.	-0.18 pts.	-0.21 pts.	-0.18 pts.	*-0.13 pts.*
	Unsustainable growth scenario	+0.32 pts.	-0.20 pts.	-0.25 pts.	-0.27 pts.	-0.22 pts.	*-0.18 pts.*
	Sustainable growth scenario	+0.60 pts.	-0.19 pts.	-0.35 pts.	-0.35 pts.	-0.22 pts.	*-0.18 pts.*
	…& efficient labour market	+0.55 pts.	-0.23 pts.	-0.39 pts.	-0.38 pts.	-0.24 pts.	*-0.21 pts.*

Table 5 **Energy effort ratio variations from 2006 to 2035**
Source: IMACLIM-P modelling

Of course this particular sensitivity of Q1's EER across all scenarios hints at higher fuel poverty rates for this quintile (cf. *infra*).

4 Fuel poverty estimates

4.1 Macro-micro disaggregation methodology

Our macro-micro disaggregation procedure resorts to the "micro-accounting with reweighting" micro-simulation method described by Agenor*et al.*(2004). It is based on the central assumption that the diversity of demographic compositions and income and expenditure structures of the 10,240 households of the *Budget de Famille*2006 household survey is broad enough for these households to provide an exhaustive typology of 2035 households—at least once their incomes and consumptions are adjusted according to the modelling results of IMACLIM-P (cf. *infra*). This hypothesis is less daring than it may seem, since the typology is to be understood on a limited number of aggregate, somewhat abstract, "linking aggregate variables",*i.e.*for each household of the survey:

- The demographic composition, synthesized in 4 variables: number of retired, employed and unemployed actives, and total number of persons in the household—these of course match the demographic groups distinguished by IMACLIM-P within each household quintile.
- The income structure, aggregated in 6sources: activity income, pensions, unemployment benefits, other social income, property income and gross operating surplus (imputed rents).
- The budget structure, aggregated into 9 expenditures following the goods disaggregation of IMACLIM-P: housing (real and imputed rents), housing maintenance and renovation (to record renovation expenses), public transports, automotive fuels, electricity, natural gas, domestic fuels (including bottled gases) coal and derivatives (whose consumption is assumed nil in 2035) and a composite goods remainder.
- The housing surface, which in IMACLIM-P corresponds to the volume consumption of the housing good, thanks to the 'hybrid' calibration of the model.

We cannot think of any reason why the 2035 households could not still be characterisable along these aggregate dimensions for the moderately contrasted CAS scenarios. The methodological bet is rather that the 10,240 households surveyed by INSEE cover the field of possible household organizations along the selected aggregate dimensionsat our 29-year horizon.

Starting from there, the disaggregation methodology is a two-step procedure. A first step, as we have suggested, is to adjust incomes and expenditures of each of the 10,240 households of the survey to translate the projected aggregate 2006 to 2035 variations computed by IMACLIM-P for their specific quintile:

- To each of the 6 sources of income we apply the 'nominal' (calculated in the unit of the*numéraire* of the model, the international composite good)*per capita*variation of the corresponding resource for the matching quintile, as computed by IMACLIM-P—correspondence between the model and the survey series were already established when the series were used to calibrate the model.
- Similarly, to each of the 9 disaggregated expenditures we apply the 'nominal' of the corresponding consumption budget for the matching quintile, as computed by IMACLIM-P.

The second stage of disaggregation consists in modifying the 2006 representativeness weights of the 10,240 types of households (whose incomes and consumptions are now scaledup to the projected 2035 economy), to reproduce, for each of the quintiles projected by IMACLIM-P, (*i*) the 4 demographic counts of the total, retired, occupied and unemployed populations; (*ii*) the 9 aggregate expenditures; (*iii*) the 6 aggregate sources of income; (*iv*) the total housing surface; (*v*) an exogenous household count, which is based on a trend of the average number of persons*per*household derived from INSEE data. Once the reweighting completed, we are left with a pseudo survey of 2035 households quite comparable to the 2006*Budget de Famille*survey, which allows computing the prevalence of fuel poverty with the indicators described in the following section. Let us immediately stress that the numerical problem posed by the reweighting of households is clearly under-determined. To single out one of its solutions we simply minimise the sum of squares of the deviations of household weights to their 2006 values.

4.2 Fuel poverty indicators

We measure the extent of fuel poverty according to two indicators: the 10% need-to-spend threshold (NST) of Boardman (1991) and the low income-high costs (LIHC) indicatorintroduced by Hills in 2012.

The 10% NST classifies households with a ratio of fuel expenses to income in excess of 0.1 as fuel poor.

$$Fuel\ poor\ = \frac{Required\ fuel\ costs}{Income} > 10\%$$

This definition has been the standard measure of fuel poverty in the United Kingdom until 2013 and it was also used in France to first measure the extent of fuel poverty based on the French Housing Survey in 2006. As we have seen in our introduction, this ratio has some limitationsthat prompted Hills (2012) to recommend adopting a new indicator to measure the extent of fuel poverty: the LIHC indicator. This indicator captures households that have a combination of low income and high energy costs by establishing two specific thresholds:

- The low-income threshold corresponds to 60% of the national equivalised median income, oncecorrected from housing costs and domestic energy expenses. The 60% value is chosen in consistency with official income poverty measurements and the correction of housing and domestic energy costs is introduced to focus on a residual income that is arguably a better measure of actual living standard.
- The high-energy cost threshold is simply the median across all households of the required equivalised energy expenditures. The required expenditure is theoretically assessed as that necessary to maintain a satisfactory indoor temperature (21°C in the main living area and 18°C in other habitable rooms).

This updated measure was recently applied to French data from the 2006 National Housing Survey (ONPE, 2014; Legendre and Ricci, 2015). Notably, ONPEprovides two estimates by alternatively considering observed energy expenses and an estimation of required expenses based on housing surface—a trustful indicator of heating requirements. The fuel poverty rate comes outat 10.3% with the first measure *vs.*13.0% withthe second, which underlines the possible importance of restriction behaviour (ONPE, 2014). Legendre and Ricci (2015) compute a rate of 9.2% using equivalised income and actual energy expenses; the divergence with the 10.3% computation by ONPE (2014) mainly stems from not equivalising energy expenses.

In what follows we use both measurement methods on the disaggregated pseudo-data obtained by our macro-micro disaggregation of IMACLIM-P quintile results. In our calculations of the LIHC indicator, we consider the size and composition of households to better characterise their standard-of-living, as recommended by Hills: we assign to each individual a number of consumption units using the OECD equivalence scale,[17]and thendeflate each household's income and domestic energy expenses by its number of consumption units to obtain equivalised statistics. More specifically, for income we use gross disposable income net of housing and domestic energy costs, again strictly following Hills; for energy expenses we rely on reported expenditures, for lack of the necessary time to implement robust estimation methods of required expenditures.

To compute the 10% NST indicator we use non-equivalised energy expenses and non-equivalised, uncorrected gross disposable income.[18]

4.3 Fuel poverty results

To define a reference to our 2035 outlook we open this last section on a short overview of what our two measures reveal when applied to 2006 BdF data. As expected, theycomputecontrasted2006 fuel poverty rates:13.4% according to the 10% NST (3.4 million households) and 7.5% according to the LIHC (1.9 million households)(Table 6;Table 7). These numbers slightly differ from those of other French studiesfor the same 2006 year (Devalière *et al*., 2011; ONPE, 2014; Legendre and Ricci, 2015) for the double reason that they areconstructed ona different household survey and based on slightly different methodologies (cf. *supra*). Fuel-poor households are highly concentrated in the first three quintiles with the 10% NST indicator (30.8% of Q1, 16.5% of Q2 and 9.9% of Q3 households) *vs.* the first two quintiles with the LIHC indicator (21.5% of Q1 and 11.5% of Q2 households). The unrestrictive nature of the 10% NST measure also shows in the high 3.4% of 5th quintile households that are estimated fuel-poor, although such households are presumably in economic conditions that shield them from suffering from high energy expenses. Interestingly, the LIHC exhibits residual fuel poverty rates for the higher income quintiles although this seems at odds with its focus on low-income households. The apparent contradiction only stems from the indicator considering equivalised income net of housing and domestic energy expenses rather than the gross equivalised income on which quintiles are built.

By 2035, our prospective modelling projects 4.4 (13.7%) to 4.9 (15.4%) million fuel-poor households under the 10% NST, *vs.* 2.5 (7.9%) to 2.8 (8.8%) million fuel-poor households under the more focused LIHC measure (Table 6; Table 7). Both measuresthus concur in estimating a systematic increase, across all macroeconomic scenarios, of not only the total count but also the prevalence of fuel-poverty from 2006 to 2035. Even though the favourable growth and employment assumptions of the sustainable scenarios lead to an increase of households' incomeand a reduction of income inequalities, they do not succeed in reducing the extent of fuel poverty in 2035 compared to 2006. Part of the explanation is of course thesupplementary burden of a 127€/tCO_2tax, at least as far as the 10% NST measure is concerned.

One other striking result is that, in contrast to higher quintiles, the share of Q1 households in fuelpoverty increases sharply under all scenarios and with both indicators (Table 6; Table 7). This echoes the systematic significant increase of EER specific to Q1, which we commented section 3.3. The impact of the sustainable assumptions on Q1 fuel poverty is howeverinversely assessed by both methods: with the 10% NST indicator, SGS and SGS+increase Q1 fuel poverty compared to WCS and UGS, whereas they limit it under the LIHC measure. This illustrates the quite different natures of the two measures: the 10% NST focuses on the

[17] 1 for the first household member, 0.5 for each additional member above 14 and 0.3 for each child under that age.

[18] To put the standard-of-living of homeowners and renters on a comparable scale, we still augmented homeowners' incomes with imputed rents and diminished them with mortgage payments, property taxes and renovation costs. All the necessary series including estimated imputed rents are available from the BdF survey.

absoluteenergy effort ratio and consequently reacts to the strong carbon tax of SGS scenarios, whose impact turns out to dominate,for Q1,the income gains from higher growth and employment, and also from higher social transfers thanks to the carbon tax proceeds fuelling public budgets; the LIHC considers only expenses and income in relation to the median across all households, which leads it to ignore the carbon tax (which impacts all households similarly) and to rather reflect the decrease of income inequalities that the higher employment and social transfers allow.

		Quintile 1	Quintile 2	Quintile 3	Quintile 4	Quintile 5	*Together*
Total households, 2006		5.178	5.184	5.186	5.178	5.177	*25.904*
Fuel-poor households, 2006		1.595 *30.8%*	0.858 *16.5%*	0.516 *9.9%*	0.315 *6.1%*	0.176 *3.4%*	3.459 *13.4%*
Total households, 2035		6.275	6.425	6.392	6.376	6.526	31.995
Fuel-poor households, 2035	Worst case scenario	2.296 *36.6%*	1.250 *19.5%*	0.735 *11.5%*	0.452 *7.1%*	0.188 *2.9%*	4.921 *15.4%*
	Unsustainable growth scenario	2.247 *35.8%*	1.207 *18.8%*	0.683 *10.7%*	0.412 *6.5%*	0.179 *2.7%*	4.729 *14.8%*
	Sustainable growth scenario	2.395 *38.2%*	1.125 *17.5%*	0.534 *8.3%*	0.327 *5.1%*	0.166 *2.5%*	4.546 *14.2%*
	…& efficient labour market	2.352 *37.5%*	1.084 *16.9%*	0.489 *7.6%*	0.308 *4.8%*	0.159 *2.4%*	4.392 *13.7%*

Table 6 **Fuel-poor households according to the 10% NST measure, 2006 *vs.* 2035 million units (*shares of quintile or total count*)**
Source: INSEE, Budget de Famille *survey, authors' computation for 2006; IMACLIM-P modelling and authors' computation for 2035.*

		Quintile 1	Quintile 2	Quintile 3	Quintile 4	Quintile 5	*Together*
Total households, 2006		5.178	5.184	5.186	5.178	5.177	*25.904*
Fuel-poor households, 2006		1.114 *21.5%*	0.596 *11.5%*	0.158 *3.0%*	0.041 *0.8%*	0.028 *0.5%*	*1.937* *7.5%*
Total households, 2035		6.275	6.425	6.392	6.376	6.526	31.995
Fuel-poor households, 2035	Worst case scenario	2.077 *33.1%*	0.598 *9.3%*	0.067 *1.0%*	0.038 *0.6%*	0.020 *0.3%*	2.800 *8.8%*
	Unsustainable growth scenario	2.094 *33.4%*	0.588 *9.1%*	0.069 *1.1%*	0.049 *0.8%*	0.021 *0.3%*	2.821 *8.8%*
	Sustainable growth scenario	2.056 *32.8%*	0.380 *5.9%*	0.075 *1.2%*	0.069 *1.1%*	0.025 *0.4%*	2.606 *8.1%*
	…& efficient labour market	2.033 *32.4%*	0.353 *5.5%*	0.075 *1.2%*	0.055 *0.9%*	0.025 *0.4%*	2.541 *7.9%*

Table 7 **Fuel-poor households according to the LIHC indicator, 2006 *vs.* 2035 million units (*shares of quintile or total count*)**
Source: INSEE, Budget de Famille *survey, authors' computation for 2006; IMACLIM-P modelling and authors' computation for 2035.*

With the 10% NST indicator Q2 fuel poverty also increases from 2006 to 2035 in all scenarios, but contrary to Q1 it increases less under SGS and SGS+: with higher employment and growth, but also with a share of the carbon tax proceeds recuperated in the form of better maintained transfer payments, the income of Q2 progresses enough to cover its carbon tax payments, which are besides cut down, compared to Q1, thanks to higher elasticities of substitution of the non-specific domestic energy expenses. Q3 and Q4 fuel poverty decreases under the two sustainable scenarios, in rate for SGS and even in absolute numbers for SGS+, which demonstrates the distributional achievement of that scenario. At last, Q5 stands out as an opposite to Q1: however inclusive the

10% NST method, its fuel poverty rate systematically decreases and even its total count of fuel-poor households is stabilised or reduced except in the WCS, where it only progresses by 7%.

With the LIHC indicator, the prevalence of fuel poverty in Q2 to Q5 decreases in almost all scenarios, with the exception of Q4 under SGS and SGS+—the relative nature of the measure makes the variations less systematic. The two sustainable growth scenarios lead to a particularly large decrease of Q2 fuel poverty rate compared either to 2006 or to the unsustainable scenarios. This again translates the quite better performance of Q2 relative to other quintiles in those two scenarios, where it strongly benefits from both higher employment, and a larger share of the carbon tax recycling through higher social transfers than Q3 to Q5.

Fuel povertyrates or counts do not give aneconomic grasp of thefuel poverty phenomenon and we must turn to the underlyingenergy expensesto get one. We start by reportingthese expenses as shares of the total residential energy expenses for each quintile and scenario. Because by definition fuel-poor households are larger consumers of domestic energy, the shares of the fuel-poor in total expenses turn out much higher than the fuel poverty rates (compare Table 8 to Table 7).[19]Then from 2006 to 2035 the aggregate share of fuel-poor expenses increases slightly, from 10% to about 12% under the different scenarios. This slight increase is however not evenly distributed among quintiles. Expectedly, Q1 distinctively fares worse than the other quintiles, with a share of fuel-poor expenses systematically increasing from a third to *ca.* a half of total Q1 residential energy expenses. In contrast the weight of fuel-poor expenses decreases (Q2, Q3) or stabilises at quite low levels (Q4, Q5) for the higher quintiles.

		Quintile 1	Quintile 2	Quintile 3	Quintile 4	Quintile 5	*Together*
2006 observation		34%	16%	4%	1%	1%	*10%*
2035 projections	Worst case scenario	51%	11%	2%	1%	0%	*12%*
	Unsustainable growth scenario	51%	11%	2%	1%	0%	*12%*
	Sustainable growth scenario	48%	8%	2%	1%	1%	*12%*
	…& efficient labour market	47%	7%	2%	1%	1%	*11%*

Table 8 **Share of LIHC fuel-poor households in quintile or total residential energy expenses, 2006 *vs.* 2035 estimates**
Source: INSEE, Budget de Famille *survey, authors' computation for 2006; IMACLIM-P modelling and authors' computation for 2035.*

To further assess the economic importance of the fuel poverty phenomenon we compare the fuel-poor expenses withgross domestic product (GDP). The aggregate weight of fuel-poor residential energy expensesturns out stable from 2006 to 2035across all scenarios: 0.21% of GDP, barely decreasing to 0.20% under the most favourable SGS+ scenario. For Q2 to Q5, the corresponding quintile-specific ratio is always lower than or equal to its 2006 value (except a small increase for Q4 under SGS). For Q1, however, it increases from 0.12% to about 0.16% of GDP: if the total social weight of fuel poverty is stable in all scenarios, the social weight of the fuel poverty of Q1 households, arguably more of a concern to the policymaker, significantly increases, although it remains a small fraction of total national income. This 0.16% fraction is to be put in perspective with the 0.2 decrease of fiscal pressure (the ratio of total fiscal receipts over GDP) registered even under the two carbon tax scenarios (Table 3).There appears to be large room for manoeuver in public budgets to consider some partial socialisation of the fuel poverty expenses of Q1, even under the double constraint of contained public deficits and fiscal pressure.

[19] For the sake of concision and considering its better focus on the phenomenon, we report our few last results under the LIHC method only.

		Quintile 1	Quintile 2	Quintile 3	Quintile 4	Quintile 5	*Together*
2006 observation		0.12%	0.06%	0.02%	0.00%	0.00%	0.21%
2035 projections	Worst case scenario	0.16%	0.04%	0.01%	0.00%	0.00%	0.21%
	Unsustainable growth scenario	0.16%	0.04%	0.01%	0.00%	0.00%	0.21%
	Sustainable growth scenario	0.17%	0.03%	0.01%	0.01%	0.00%	0.21%
	…& efficient labour market	0.16%	0.02%	0.01%	0.00%	0.00%	0.20%

Table 9 **Ratio of LIHC fuel-poor residential energy expenses to GDP, 2006 vs. 2035 estimates**
Source: INSEE, Budget de Famille *survey, authors' computation for 2006; IMACLIM-P modelling and authors' computation for 2035.*

5 Conclusion

In this paper we develop a prospective analyse of fuel poverty in the 2035 France outlined by 4 alternative macroeconomic scenarios of the *Centre d'Analyse Stratégique* (CAS), an influential advisory body to the French government. Our methodology combines a computable general equilibrium approach, which includes an innovative systemic modelling of households' energy demand, and a micro-accounting with reweighting extension based on the exploitation of comprehensive household survey data. We quantify fuel poverty in our 2006 reference year and in our projected 2035 scenarios with the alternative historical 10% need-to-spendthreshold (10% NST) and the low income- high cost (LIHC)indicator recently proposed by Hills (2012).

Under both indicators and for all 4 macroeconomic scenarios explored our prospective results reveal an increase of the aggregate number and prevalence of fuel poverty. Detailed quintile results furthermore show that this increase is strongly concentrated on the poorer quintile 1 (Q1) households, while Q2 to Q5 households see their fuel poverty rates, and in many instances even their absolute numbers of fuel-poor households, decrease. The particular brunt borne by Q1 households is explained by their particular sensitivity to (*i*) one public policy assumption common to all our scenarios: that of a containment of public deficits (at their 2006 level) through a general cut in social transfers including pensions and unemployment benefits; (*ii*) another generalised assumption of a convergence of *per capita* specific electricity consumptions, which impacts them all the more as it is posited independently of price variations. It is also caused by Q1's households lesser capacity to adapt to energy prices hikes by changing their fuel mix or resorting to insulation or more-efficient heating equipment—this reduced capacity is however our own exogenous assumption, for lack of quintile-specific behavioural data.

On a more optimistic note, despite the aggregate increase of the phenomenon the aggregate social cost of fuel poverty, which we measure by pitting fuel-poor domestic energy expenses against GDP, remains stable at *ca.* 0.21% of GDP in 2006 as in each 2035 scenario (under the more focused LIHC measure). The particular increase of Q1 fuel poverty shows in the fact that Q1 shifts from concentrating half this cost in 2006 (0.12% of GDP) to three quarters of it in 2035 (0.16% to 0.17% of GDP). This concentration should of course be of concern to French policymakers. Our macroeconomic results however demonstrate that public budgets preserve room of manoeuvre to consider some socialisation of Q1 fuel-poor expenses, even under the double constraint of contained public debt ratio and fiscal pressure.

Of course the leeway in the many assumptions we have to make to flesh out, in our extensive modelling framework, the few macroeconomic indicators of CAS, warns against over-interpretation of our results. We only pretend to put into consistency a set of prospective assumptions that we hope to have underlined enough, which still allows us to outline the particular influence of some of them on our 2035 outlook. The wide potential of our modelling architecture is thus barely touched upon by these first results. The exploration of prospective assumptions and policy variants aimed at alleviating Q1's fare constitutes the matter of further research.

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