Energy consumption of household appliances and electronics by 2030: a modelling and forecasting exercise applied to France

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Abstract

As part of a major forward-looking analysis into 2030 and 2050, the French Energy Agency (ADEME) has commissioned several studies on expected trends in various areas of energy use. One of them has investigated the consumption of home appliances by 2030.

The study is based on predictions about socio-economic, behavioural, regulatory, and technological changes over the next 15 years, that have then been processed into a year-by-year stock modelling. The assumptions use a mix of past trend continuation and educated guesses derived from the literature and existing forecasting studies in different fields. In areas where prediction is particularly challenging (e.g. home ICT equipment), a set of contrasted sub-scenarios has been proposed.

As a result, the study provides detailed sheets specifying and justifying the starting point and evolution for the main aspects, energy use per household and total weight for the 25 studied products. The list includes fridges, freezers, washing machines, driers, displays, internet gateways, ovens, etc. Quantified conclusions can be drawn on how some categories are expected to dramatically shrink (e.g. cold appliances) while other may rise significantly (e.g. building automation equipment). The final study output – delivered in the form of an open model that can be rerun with additional scenarios – can be useful to identify priorities for policy intervention and prepare decision-making in the coming 15 years.

The study also casts new light on the relevance of 2020/2030 energy efficiency goals in EU Member States, and the importance of pursuing EU Ecodesign and Energy Labelling policies as well as further addressing user behaviour issues.

Background

In the last three decades, the electricity consumed in residential buildings in France has grown significantly. Buildings codes are now targeting and reducing the energy used by heating, cooling and lighting equipment. By contrast, other electricity-using devices such as appliances and electronics are becoming an increasingly important challenge.

The French Environment and Energy Efficiency Agency has issued in 2014 long-term energy transition scenarios in the context of the preparation of public policies (ADEME, 2014). Several forecasting studies have been launched in support, to look at consumption trends by 2030 in various areas. One of the studies focused precisely on the electricity used by households in France. The specific objective of this study was to issue product-level forecasting to assess the potential importance and impact of the different types of residential appliances on energy demand by 2030. The work has been carried out by a consortium involving modelling experts, energy and socio-demographic specialists.

Such a study is useful to quantify the actual impact that can be expected from current and new technologies, regulations and behavioural change on electricity consumption trends in the mid-term. It can also inform decision-makers on the need for additional policies targeted at household energy consumption. Although the geographical scope is limited to France, lessons learned can be useful for similar economies especially in the EU as products traded on the common market are comparable.

Methodology

A way to estimate the electricity consumption of home appliances and electronics by 2030 in a country is to assess through a model the evolution of the stock of products installed and used in homes year by year from a recent date to 2030. A set of hypothesis has to be made on essential input to the stock model:

- Demographics (evolution of the number and composition of households).
- Annual sales of products, that are driven by equipment and renewal rates.
- Technological change (trends in energy efficiency and lifetime of products placed on the market).
- Usage patterns (potential modifications in user behaviours from now until 2030).

25 major energy-using product groups have been included in the analysis: fridges, freezers, washing machines, tumble driers, dishwashers, ovens, mini-ovens, hobs, stoves, microwaves, coffee machines, kitchen hoods, other small kitchen devices, irons, vacuum cleaners, screens, computers, tablets, internet gateways/boxes, game consoles, digital players, printers, mobile devices, smart meters and smart home sensors. They are regrouped in 6 categories: cold, washing, cooking, cleaning, electronics and home automation. Together, they represent a large majority of the electricity currently consumed and likely to be consumed in the future in households outside heating and lighting.

For each product group, the analysis has been conducted in three steps:

- Preparing the aforementioned hypothesis for the period 2013–2030 based on available socio-demographic, market, technological, regulatory and behavioural information.
- Running the stock modelling over the period 2009–2030 based on this input. The starting date is 2009, a year for which the state of the stock of energy-using products had been thoroughly investigated in a previous study (ADEME, 2012). Recent data up to 2013 have also been taken into account whenever available.
- Deducing the evolution of electricity consumption for an average household, as well as for the overall consumption for the entire country, and presenting and discussing in detail the results for 2030 and intermediary steps (e.g. 2015, 2020 …) both at the aggregated and disaggregated levels.

SOCIO-DEMOGRAPHIC ASSUMPTIONS

Overall assumptions regarding population and number of households are based on existing demographic scenarios by renowned institutions (INSEE) and taking care of consistency between the different forecasting studies commissioned by ADEME. As an example, the number of households in France is expected to grow from 26,860,000 in 2009 to 31,900,000 in 2030.

Hypothesis regarding consumer and user behaviours have been split into:

- Sectorial trends applying to whole product categories or practices (e.g. washing, cooking, watching screens, etc.). These general evolutions are driven by socio-demographic as well as lifestyle changes. Although it is difficult to be certain about the latter, cautious assumptions have been made based on a continuation of trends observed over the last decade: population aging, diminution of the average number of persons per household, increase in the use of larger screens for home leisure, reduced time dedicated to cooking, etc.
- Specific trends for each equipment, regarding the evolution of household equipment and duty cycles. Here the continuation of past trends is adjusted to take into account foreseeable changes based on educated guesses. Examples are e.g. the extinction of disc players (replaced by network streaming), or the growing capacity of washing powders to work at lower temperatures (thus changing user practices).

As regards trends in the size/capacity of appliances, a mostly linear continuation of past evolutions has been used, without considering specific additional rebound effects that could emerge (e.g. people favouring larger appliances just because they know they are more efficient). Similarly, we have not considered rebound effects *per se* in usage patterns, although we have taken into consideration the growing use of some products (such as screens).

TECHNOLOGICAL ASSUMPTIONS

There are relatively few technological studies investigating the future energy performance of household products, especially beyond 2020 (one useful example is AECOM, 2011). Besides, industry experts who have been approached for the study were also reluctant to express firm views on what they plan ahead and how the efficiency of products they place on the market is likely to evolve.

This being said, experience shows that for many household appliances market trends are now strongly influenced by regulation, such as the EU Energy Label (which frames the interest for manufacturers to invest in and deploy more efficient technologies) and EU Ecodesign measures (which set mandatory levels of performance to be achieved by all products on the market). Considering that ultimate technical potentials have still not been reached, it can be assumed that future market progress will still go hand in hand with regulatory development in the coming 15 years.

Two main methodological approaches have been followed to predict trends in the efficiency of products placed on the market and purchased by consumers:

- For large appliances and equipment that are well known and for which energy efficiency is usually already an important market driver, detailed regulatory assumptions (e.g. pace and levels of new energy labelling classes and ecodesign standards) have been made based on past policy experience and information on technological potentials. Markets are supposed to respond to these regulatory levels in a similar way they have done before. Such products include e.g. white appliances and main kitchen equipment.

- For smaller products that are usually understudied, poorly influenced by energy considerations or relatively new on the market, a more simplistic forecasting approach has been applied in the form of a (reasonable) linear efficiency gain assumption till 2030. This is the case for e.g. irons, small kitchen equipment, 3D printers, etc.

As regard technical product lifetime, conservative assumptions have been made in general, i.e. a stability of the average lifespan observed in the last decade. (See Figure 1[1].)

ALTERNATIVE SETS OF HYPOTHESIS

For a number of products, forecasting future evolutions in the next 15 years has proved particularly challenging, due to uncertainties on the trend that will dominate. For each of these cases, instead of a single trend it has been decided to develop a pair of scenarios relying on differentiated hypothesis representing two contrasted options. This way, the impact on final results can be assessed. The actual specifics of these sets of hypothesis have been based on literature review, interviews, and discussions among the study team. The list includes:

- Electronics and computing equipment: as we are witnessing a strong and fast development of cloud technologies, our digital content and computing needs may fully migrate outside our homes and be accessed through simple thin clients. In this assumption, a number of our current devices (e.g. PCs, digital players, game consoles, etc.) would simply disappear. However, a second possible hypothesis is the continuation of current trends whereby consumers accumulate new electronic devices for every need they have.
- Screens: current energy efficiency progress is particularly driven by the use of LED. This development is likely to continue and lead to ever bigger and efficient screens. However, an alternative hypothesis can also be envisaged in which the critical material resources for the production of efficient displays (such as rare earth) become progressively so scarce, restricted or expensive that manufacturers have to revert to older technologies and switch from screens to projectors for large images.
- Home automation: smart home and smart meter technologies are currently being developed, and should be beneficial for saving energy in heating and lighting. But the actual impact of these new technologies on other appliances is still unclear. A first optimistic assumption estimates that the automation of certain functions leads to an average 15 % reduction in the use of energy for fridges, ovens and hobs, network gateways, screens and loads of mobile products (through use optimisation, sensors, presence detection, etc.). A more pessimistic alternative supposes that these technologies have no significant impact on energy use.
- Vacuum cleaners: the first hypothesis foresees a limited share for robot vacuum cleaners (only 15 % of household equipment by 2030, the product remaining a gadget), while the second is based on a strong motivation and market uptake for the robot technology (used in 50 % of homes by 2030).

MODELLING

The stock model uses the previous socio-demographic and market assumptions to simulate the evolution of products installed in households year by year until 2030. From this, an average energy performance of the stock can be calculated and a subsequent average power use level (in on and standby modes) can be derived for each product category. This value can then be multiplied by the average duty cycle, which leads to annual energy consumption figures. The electricity consumption for an average household is the multiplication of the latter by the average installation rate. Power demand can also be modelled over a typical day to assess the evolution of power demand curves and peaks.

This detailed model can provide other interesting output on an annual basis, such as the structure of the stock by product age, or the share of products in the stock by performance levels (e.g. energy classes).

The stock model is open and flexible. The owner (ADEME) can reuse it in the future to compute additional scenarios or modify/adjust some of the hypothesis.

Results

AGGREGATED RESULTS PER HOUSEHOLDS

In all cases, the energy consumption per household steadily declines and the final level in 2030 is 19 % to 33 % below that of 2013. This reduction, largely driven by technological progress and regulation, overcomes the detrimental trends on some products (e.g. growing TV screen sizes, increase use of some electronics, etc.)

The alternative scenarios that have the highest influence on the result are those related to the impact of smart home technologies on consumptions and to the availability of critical resources for efficient display technologies.

Surprisingly the alternative scenarios related to electronics and computing equipment do not impact so much the overall result, because they lead to comparable energy consumption. The energy that can be saved in homes by migrating digital content and computing needs to the cloud and dematerialising some devices is counterbalanced by increased power needs by the central home gateway. (This would be less the case if media gateways improve their energy management and standby levels beyond what is foreseen in the study assumptions).

The highest reductions are realised in cold appliances (fridges and freezers), a continuation of already existing trends. In 2030, cold appliances represent less than 15 % of the energy consumption of the 25 product groups (compared to 23 % in 2013).

IT and electronics also reduce their consumption, largely driven by efficiency progress in screens. The share of displays in the total consumption of electronics shrinks from 57 % in 2013 to 33 % in 2030 in case there is no constraint on critical resources for screen production. This is however not the case anymore under the alternative scenario under resource constraint.

Other categories show more modest reductions (15 to 30 % from 2013 to 2030), which are in part eaten up by the growing power use of home automation and smart metering technologies.

1. New energy classes: At energy efficiency index (EEI) values of 0.38, 0.3 and 0.22, respectively. It can be noted that a few models qualifying for A4+ and even A5+ are already available on the European market (see www.topten.eu).

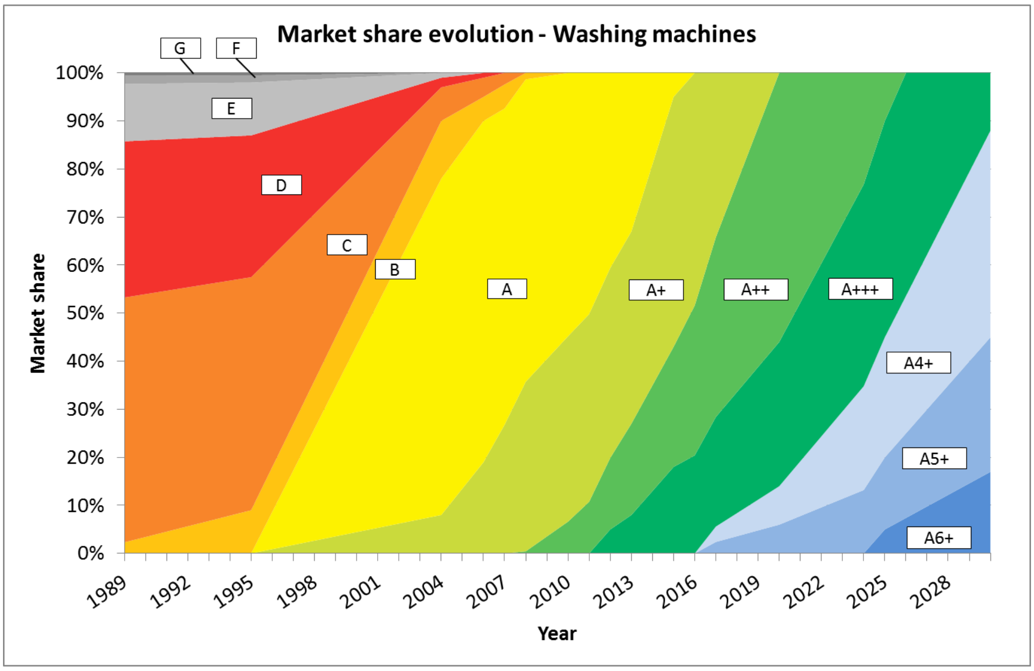

Figure 1. Example of the forecasted market share evolution for washing machines. Before 2013, the figures are based on real market data. From 2013 onwards, the assumptions include the addition of two new energy classes in 2016 and a further additional class in 2024. (Note: the new classes are named 'A4+', 'A5+' and 'A6+' on the graph by convenience, irrespective of possible other decisions when current labels are updated by the EU.)

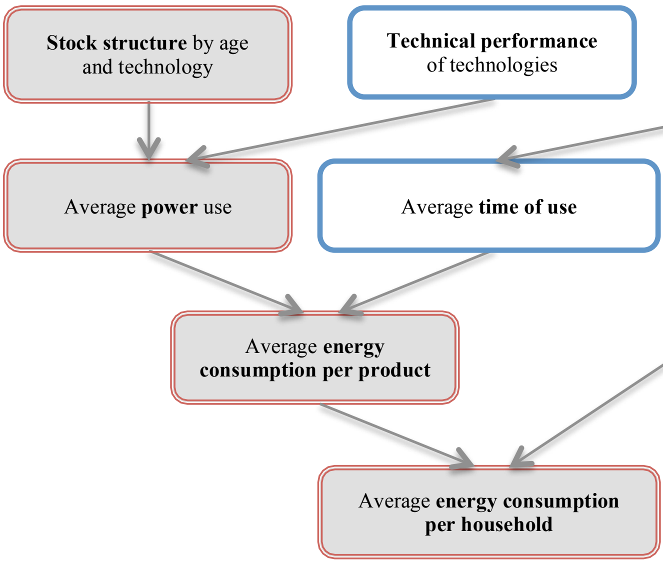

Figure 2. Main steps of the modelling process. In light the parameters that are based on hypothesis, in dark the ones derived from the modelling and calculation steps.

AGGREGATED RESULTS FOR TOTAL CONSUMPTION

Applied to all households, the total energy consumption figure also shows a decline after a peak around 2015, but the reduction is less steep due to the increasing number of households. According to the different alternative scenarios, the reduction ranges from a quasi-stabilisation to nearly -20 % from 2009 till 2030.

Last, the study also included considerations on daily peak demand, and the potential benefits from smart appliances to smoothen peaks. It appears that about half of the forecasted 2030 power demand could be managed in this manner, while the other half would still contribute to peaks because the usage is hardly displaceable (e.g. leisure electronics, kitchen appliances, etc.).

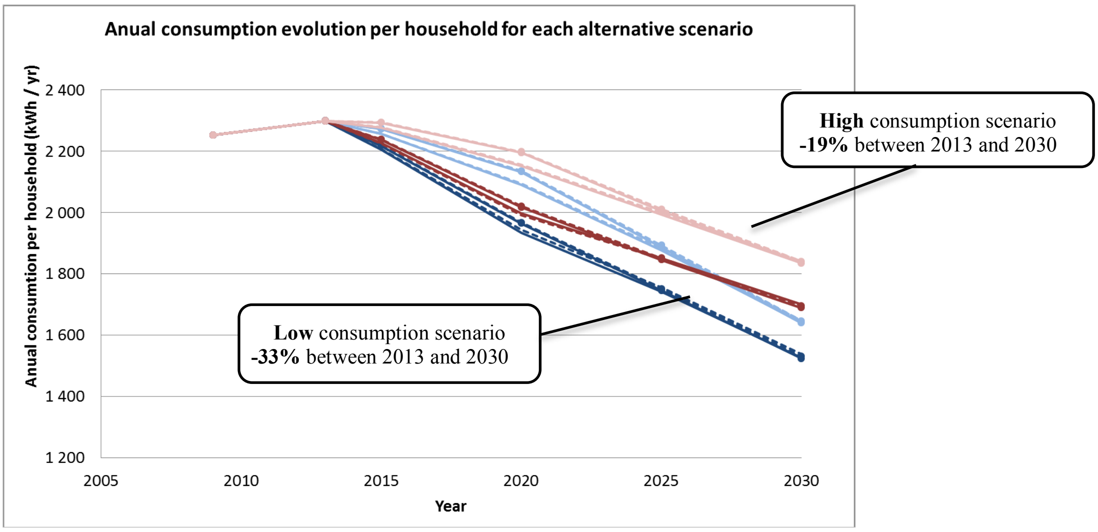

Figure 3. This graph shows the evolution of the energy consumption per household for the 25 product groups according to the different alternative scenarios.

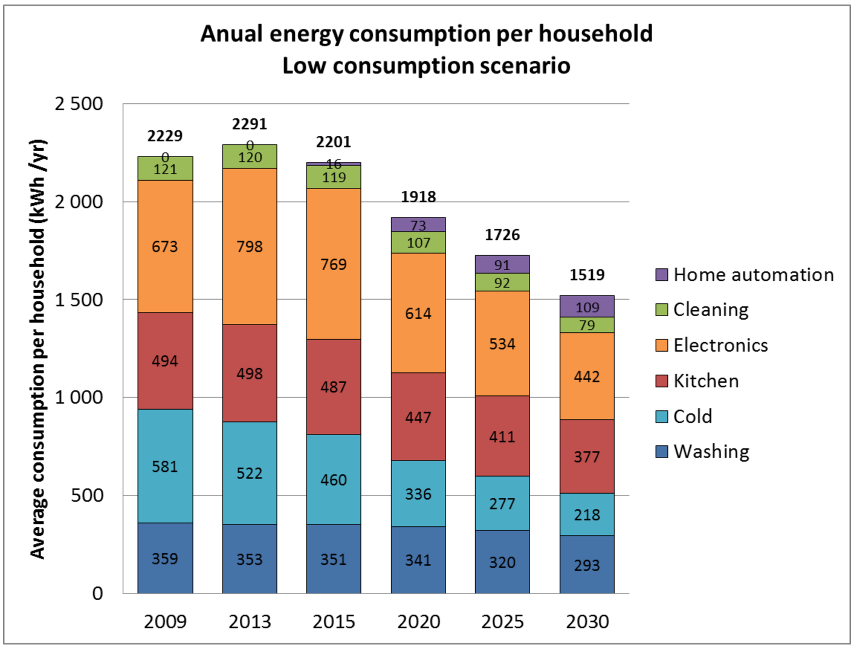

Figure 4. This graph shows the share of the different product categories in the evolution of the energy consumption per household in the most aggressive combination of scenarios.

Limits and discussion

There are obviously limits to such a forecasting exercise:

- Predictions about future technologies is challenging, especially in the IT and electronics sectors. Brand new products unheard of are likely to appear on the market and are not included in the analysis. (Nonetheless, we have anticipated some of this by forecasting a doubling of the energy used by mobile devices by 2030.)
- The reliability of the data characterising the starting points (2009 and 2013 update) is not always very strong. Current market data on energy efficiency levels are sometimes incomplete (especially for understudied products that are not covered by energy labels), and information on average duty cycles can be relatively old or based on partial surveys.
- The analysis is mostly based on common energy performance metrics that are used in EU regulations and build on standardised measurement methods, that may not be perfectly representative of real life use of products (they don't account for e.g. aberrant uses, degradation of product performance over lifetime, etc.). Wherever possible (e.g. for washing machines) adjustments have been made to better reflect French duty cycles.

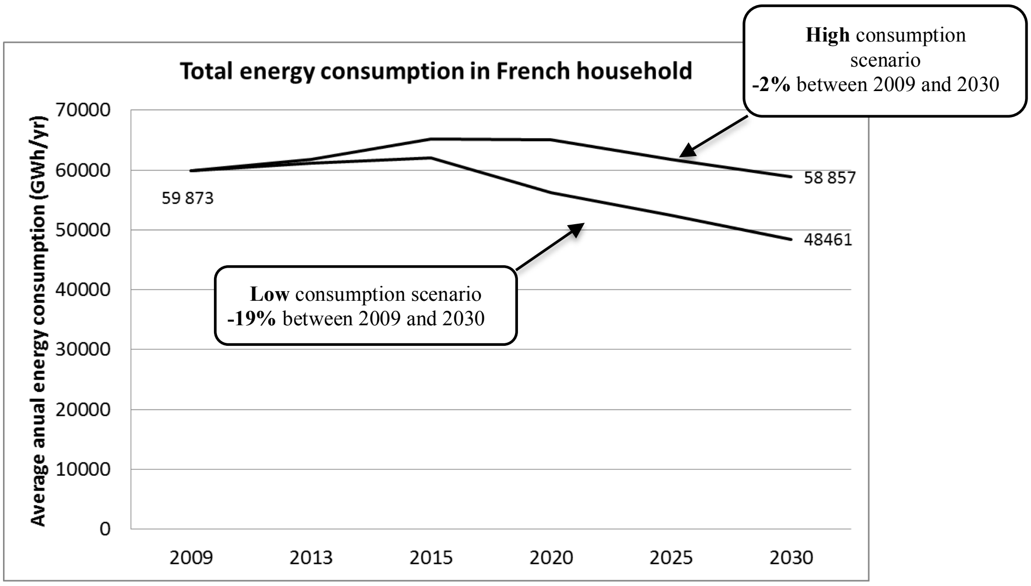

Figure 5. This graph shows the total electricity consumption in French households for the 25 product groups.

Table 1. Comparison between the three forecasting exercises regarding product consumption levels in 2030 and expected improvement rates between 2010 and 2030.

	Average energy use per product in the 2030 stock (kWh/year)			Evolution of the energy use per product in the stock between 2010 and 2030		
	This study	Fraunhofer ISI, 2013	Négawatt, 2011	**This study**	Fraunhofer ISI, 2013	Négawatt, 2011
Washing machine	**94**	121	116	**-32 %**	-35 %	-34 %
Tumble drier	**175**	189	424	**-53 %**	-22 %	-30 %
Dishwasher	**140**	146	275	**-33 %**	-30 %	-36 %
Fridge	**130**	163	191	**-60 %**	-35 %	-25 %
Freezer	**164**	180	423	**-56 %**	-24 %	-25 %
Std. vacuum cleaner	**17**	–	52	**-56 %**	–	-20 %
Iron	**21**	–	74	**-36 %**	–	-4 %
Oven	**57**	338	198	**-37 %**	-8 %	-10 %
Hobs	**162**		237	**-33 %**		-14 %
Screen (no constraints)	**76**	176	217	**-69 %**	-24 %	-17 %
Media gateway	**94**	72	83	**-33 %**	-26 %	-20 %
Audio player	**30**	–	26	**-29 %**	-25 %	-21 %
Desktop PC	**59**	145	154	**-14 %**	-20 %	-20 %
Laptop	**16**	70		**-30 %**	-29 %	

- The analysis does not take into account the possible emergence or reinforcement of rebound effects associated with more efficient technologies. It is important that public institutions continue motivating citizens not to waste energy despite progress in technical efficiency. Increasing energy prices may have an impact in this sense.
- The modelling is restricted to energy in use, while for some products the embedded energy (energy consumed for the production, transport and end-of-life of the product) represents a growing share of the product's environmental impact. In the study report, some qualitative considerations have been included with respect to this aspect.

One way of assessing the robustness of the study results is to compare them to similar forecasting exercises that have been developed in the recent years. Two of them have been identified:

- 2030 scenario for Germany by Fraunhofer Institute for Systems and Innovation (Fraunhofer ISI, 2013): this scenario is based on a bottom-up stock modelling (FORE-CAST-Residential), using Bass curves for new technology dissemination. The latter are adjusted according to policy intervention. The starting point is 2010. The modelling is particularly sophisticated in the simulation of purchasing decisions by consumers. The low policy intensity scenario (LPI) is the closest one in terms of assumptions regarding EU regulations.

- French Négawatt scenario (Négawatt, 2011): this popular scenario for France has been developed by a group of energy experts. It simulates the adoption of ambitious but realistic energy efficiency policies (including energy performance standards on products). There is no formal stock modelling, the assumptions on the evolution of consumption levels are based on past trends and educated guesses. The starting point relies more on measurement campaigns in actual homes than regulatory values.

The following comments can be made:

- For washing appliances, the results are remarkably comparable. Négawatt is much less optimistic on tumble driers, but they probably lacked information on heat pump driers in 2011 and the recent revision of the EU energy label.
- For cold appliances, efficiency gains are substantially higher in this study compared to the other two, due to more optimistic assumptions on technological dissemination. It is to be noted that cold appliances in the current German stock are significantly more efficient than in the French one, thus leading to less potentials.
- For cleaning equipment, this study is the only one taking into account the recent adoption of Ecodesign and energy labelling regulations for vacuum cleaners, that are likely to deeply transform the market.
- For kitchen appliances, the hypothesis on duty cycles in this study are much lower than in the other two, leading to lower figures (not only in 2030 but also for the starting point). This study also foresees higher efficiency potentials, thanks to the recent revision of the Energy label for ovens, the growing share of induction and the deployment of smart cooking technologies.
- For electronics and IT equipment, results are remarkably comparable, except for screens. There has been unprecedented progress in the energy efficiency of TVs and other displays placed on the market since 2009. This study is probably the only one taking full stock of this spectacular breakthrough that is still going on, with much more optimistic potentials by 2030.

Conclusion and recommendations

This modelling exercise reveals that it is possible to achieve a 20 % cut in the energy used by home appliances and electronics in France by 2030, despite trends for bigger appliances and increasing number of households.

However, there are conditions for this most optimistic scenario to be realised:

- EU Ecodesign and Energy Labelling regulations need to be pursued at a steady pace, with frequent reviews, so that the market transformation effect continues as before. Additional policies to support the purchase of best technologies would also be welcome.
- The dematerialisation of digital and IT devices in homes needs to be accompanied by a strong pressure on internet and media content providers to increase the efficiency and power management of gateways.
- There needs to be no significant constraint in the coming 15 years on critical resources to produce efficient products, especially displays. The development of alternative technologies such as OLED (organic LED) may be an opportunity.
- The development of smart home and home automation systems needs to target not only increased comfort but also energy savings on appliances.
- Duty cycles and user behaviour matters more and more as technical efficiency progresses. It is important to ensure that users are well informed and encouraged to use their products in an optimal way.

It would also be relevant to increase the focus on products and devices that are currently not covered by EU regulations and are usually understudied. Getting more robust data on their energy use and potentials would help improving the quality of forecasting exercises such as this one.

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