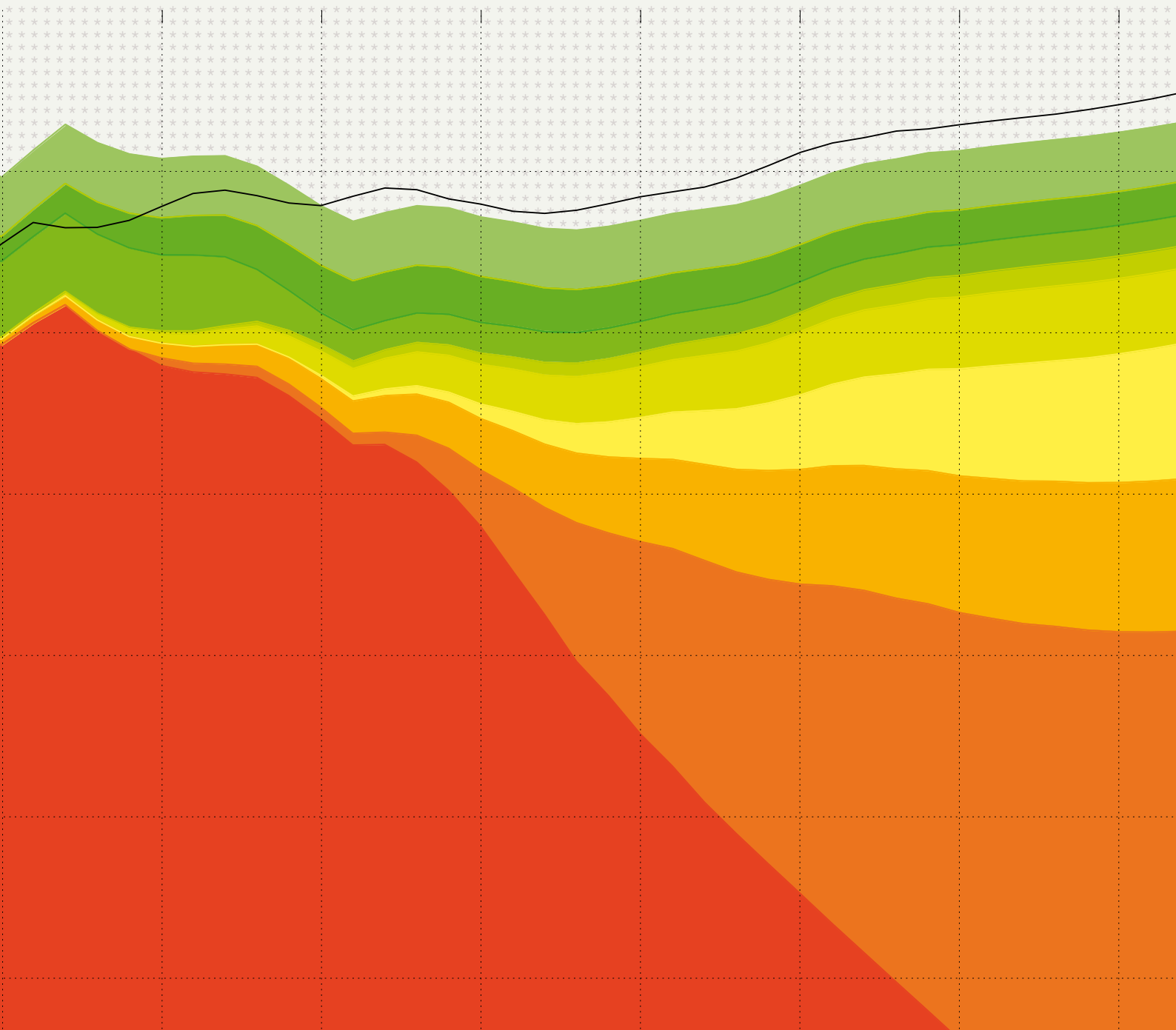




Building a low carbon scenario for France

How a participatory approach can enhance social and economic acceptability



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Introduction

This publication presents the French case study of the European ENCI-LowCarb research project: **Engaging Civil Society in Low Carbon scenarios**¹.

The core activity of this project was the development of a methodology for the transparent integration of stakeholders' contributions in the scenario design process to enhance the stakeholders' acceptance of the resulting low carbon pathways. This attempt at integrating acceptability in scenario-making constitutes an important step to distinguish what is technically and economically feasible from what is acceptable. Today, a wide range of published scenarios emphasize the fact that they are built on public consultations or stakeholders' contributions. However, transparency is lacking concerning the methodology relative to how contributions were taken into account and translated into assumptions that can be used by the modeling tool. The project ENCI-LowCarb aimed at exploring this scientific gap.

Energy scenarios outline possible low-carbon futures built around assumptions on fossil fuels prices evolution, technological choices and the mechanisms of energy demand and supply, among others. Scenarios are influential tools in political decision-making processes since they shed light on the long-term impacts of today's investment decisions, especially regarding infrastructures. This is why it is crucial that these pathways derive from discussions with main stakeholders.

In this report, the French project team (CIRED and RAC-F) has the pleasure to present energy scenarios for France which derive from a collaborative scenario design process including the participation of a wide range of French stakeholders (civil society organizations including trade unions and non-governmental organizations, private companies, banks, statewide and local authorities).

Participating stakeholders were asked to define or select acceptable CO₂ emissions mitigation measures. Their contributions were implemented in the technico-economic model Imaclim-R France to create a scenario that is economically and technically consistent as well as acceptable by stakeholders. This methodology allowed an assessment of the level of achievable emissions reductions with stakeholders' «acceptable» measures.

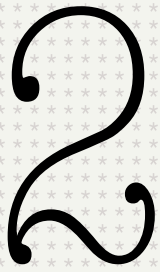
This project report is organized as follows: **part 2** presents the methodology of the collaborative scenario design process in detail, **part 3** describes the low carbon scenario - the outcome of the stakeholder discussions. **In part 4**, other drivers of CO₂ emissions and additional measures are explored. Chapter 5 introduces additional sensitivity analysis. **Part 6** concludes.

The energy scenarios presented in this report do not reflect the views of CIRED or RAC. The "acceptable" scenario derives from the outcome of the stakeholders' group discussions, without necessarily representing the vision of any individual stakeholder. In addition, further analyzes carried out depart from the "acceptable" scenario to explore uncertainties and possible measures to reach ambitious mitigation targets. The analyzes contained in this report are based on the results of modeling exercises carried out with the Imaclim-R model, which is designed to provide a coherent picture of energy and economy

at a medium and long-term horizon. The various scenarios considered in this document represent coherent technico-economic pathways resulting from technical, economic and behavioral assumptions incorporated in the Imaclim-R framework after discussions with stakeholders and sectoral experts. In such a modeling approach, the quantitative figures given as model outcomes have no predictive value, but serve as a basis for characterizing and revealing the major mechanisms at play in the complex dynamic system made of several economic sectors and agents linked by multiple socio-economic interactions.



¹- The project (April 2009 - March 2012) was funded by the 7th Framework Program for research of the European Commission. The project team consisted of two research institutes - CIRED and PIK - as well as three NGOs - RAC-France (coordinator), Germanwatch and INFORSE-Europe. More information on the project: www.enci-lowcarb.eu



Methodology:

steps towards a “collaborative scenario design”

I. The need for involving stakeholders

Many energy scenarios are based on public or stakeholders consultations. However, few attribute importance to the scenario design process and explain in a transparent way how contributions are taken into account and integrated in a modeling tool, that is to say how the translation process was carried out from an idea supported by contributors to its representation in the modeling tool.

A first question one might ask is: “Why is stakeholder involvement important when discussing energy scenarios?” First, most stakeholders can provide additional expertise to the technical and economic hypotheses as well as initiate discussions around sensitive issues. Second, the exchanges with stakeholders bring to light the main cleavages and obstacles to reaching a decarbonized society. Thus, the dialogue can lead to finding a common ground for possible solutions and outlining a robust strategy. Finally, consultation with stakeholders enhances the ownership of the created scenarios by the stakeholders.

In conclusion, there are many reasons why stakeholders should be consulted and if possible actively integrated in the scenario-making process. Today, the challenge is to avoid limiting the influence of stakeholders to a non-interactive communication (as in the case of online consultations). If scenarios aim at representing the contributions of stakeholders, a deeper thought has to be given to the design of the process to make it interactive. Gathering people for multi-stakeholder discussions, collecting their contributions and then elaborating the scenario behind closed doors can be a source of disengagement for participating stakeholders.

Therefore, the innovation of the ENCI-LowCarb project resides less in the resulting energy scenarios than in the process itself. The project hypothesis consisted in stating that if national stakeholders can recognize their contributions in the resulting scenarios (even if those were amended by the contributions of others), they would eventually be more supportive of this scenario than in a case where a non-transparent procedure was followed. Using collaborative procedures can increase stakeholders' acceptance and generate political support for energy scenarios and the resulting policy measures. Reaching this positive outcome also implies more involvement for both stakeholders and modelers - particularly in terms of time and shared understanding of the issues at stake and of the functioning of the used modeling tool.

A transparent stakeholder consultation process requires the existence of a common ground: model parameters and input variables of the model have to be carefully translated into tangible, real-life, implications which stakeholders can assess. The considerations emerging from the stakeholder consultation can then be translated back into technical model parameters, i.e. political framework conditions, which will result in different low carbon energy system scenarios. This “translation work” is necessary to work with such modeling tools and needs a considerable effort of communication to avoid the feeling that all contributions are entering a black box without any traceability.

The modeling work of this project was following two main principles:

- * **Acceptance:** Reaching a maximum degree of stakeholders' acceptance.
- * **Realism:** Satisfying technical and economic limits.

Social acceptance or stakeholders' acceptance?

Within the frame of the ENCI-LowCarb project it was not possible to evaluate “social acceptance”, and the focus was rather on “stakeholders' acceptance”. Social acceptance has different aspects that cannot be assessed with the available project tools. In the context of energy system strategies, social acceptance has three dimensions (Wüstenhagen 2007)²: (i) socio-political acceptance, referring to the acceptance of technologies and policies by the public, key stakeholders and policy-makers, (ii) community acceptance of site-specific local projects and (iii) market acceptance, referring to the process of the adoption by consumers and investors of innovative low-emission products. Community acceptance is a highly important topic concerning the building of new energy infrastructure (electricity grid, windmills, nuclear waste depositions etc.) but it cannot be directly represented in a modeling tool with no spatial dimension.

Within the ENCI-LowCarb project, one challenge was the use of macro-economic hybrid models for the scenario design task (IMACLIM-R³ and REMIND-R⁴), which are often characterized as “black-boxes”⁵. This implies at least a basic introduction to the model dynamics: What are the main mechanisms? What is the degree of detail of the sectoral representation? What are exogenous and endogenous variables? etc). The form of the modeling tool indeed shapes the form of the dialogue. ★

II. The IMACLIM modeling tool

Imaclim-R France⁶ is a computable general equilibrium model. This model was used for the collaborative scenario design process of French energy scenarios within the project ENCI-LowCarb. It models the evolution of the French economy split into 15 sectors: energy sectors (crude oil, refined oil, gas, coal, and electricity), transport sectors (freight terrestrial transport, water transport, air transport, public road passenger transports, and rail passenger transport), construction, energy-intensive industries, agriculture and services.

The Imaclim-R model computes, between 2004 and 2050, the evolution of the economy and the energy system with a strong consistency. This is why Imaclim-R is what is called a hybrid model compared to economic models or to technical models. The first type of models focuses on economic dynamics but includes a weak representation of the energy system. The second type of models focuses on technologies and energy but has a poor representation of economic constraints and dynamics (particularly the interaction between prices and demand for energy and commodities).

In Imaclim-R, energy is explicitly representing both: values and physical quantities so as to capture the specific role of energy sectors and their interaction with the rest of the economy. The existence of explicit physical variables (e.g. number of cars, number of dwellings or energy efficiency of technologies) allows a rigorous incorporation of sector-based information about how final demand and technical systems are transformed by economic incentives. In Imaclim-R, each year the equilibrium provides a snapshot of the economy and gives GDP, sectoral prices, sectoral

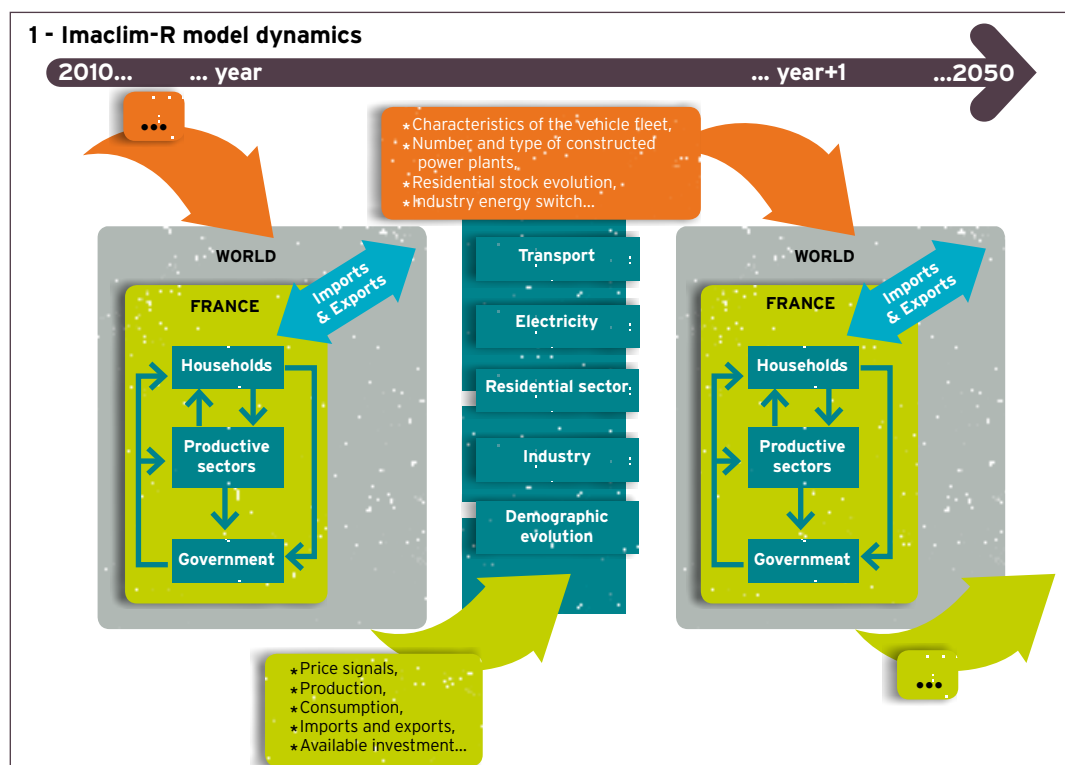
2- Wüstenhagen R, Wol-sink, M, Bürer MJ 2007, 'Social acceptance of renewable energy innovation: An introduction to the concept', *Energy Policy*, vol. 35, no. 5, pp. 2683-2691.

3- www.imaclim.com/centre-cired.fr/spip.php?article129&lang=env

4- www.pik-potsdam.de/research/sustainable-solutions/models/remind

5- Sandrine Mathy, Meike Fink, Ruben Bibas (2011): "Quel rôle pour les scénarios Facteur 4 dans la construction de la décision publique ?". *Revue Développement Durable et Territoires*, Numéro Spécial sur le Facteur 4; Vol. 2, n° 1 | Mars 2011: <http://developpementdurable.revues.org/8802>

6- Imaclim-R France is part of the Imaclim models family developed by the CIRED.



investments, households consumption in each sector, unemployment rate and international trade. Two successive annual equilibria are linked by “dynamic sectoral modules” such as an electricity module, a residential module, etc. These sectoral modules represent the specific sector dynamics given economic constraints (including available investment in the sector, intermediate consumptions and energy prices) and physical constraints (e.g. inertia in technological infrastructures and appliances limiting the extent of energy efficiency).

Imaclim-R France is an open economy model. Thus, an important modeling assumption is that crude oil, gas and coal prices are exogenous, they are calibrated on the World Energy Outlook report by the International Energy Agency (2011). A limitation of Imaclim-R France is that it computes only energy-related CO₂ emissions. Other greenhouse gases are not represented).

The collaborative scenario design process relies on Imaclim-R France for integrating all the inputs from stakeholders. Therefore, the modeling tool strongly determines the form of the interaction with stakeholders, the format of the meetings as well as the manner to discuss the issues. Indeed, the fact that Imaclim-R is built recursively with dynamic sectoral modules prompted us to organize sectoral experts’ meetings first, then sectoral stakeholders meetings so as to embrace the vastness of debates when decarbonizing triggers a structural transformation of the sector. Then, with all the richness of the debate embarked in the model, a step back was taken to look at the interactions between all the different sectors in a cross-sectoral feedback seminar. The following part describes this process in more details. *

III. Description of the collaborative scenario design process

The collaborative scenario design process developed within the project was divided in several steps:

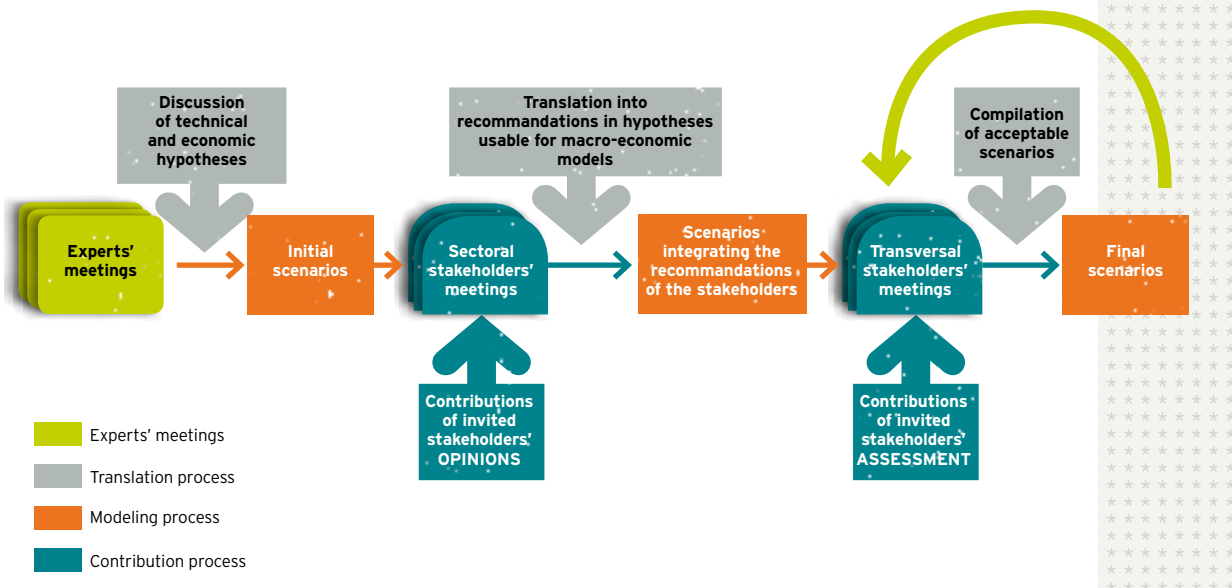
1. Organization of experts’ meetings.
2. Stakeholder mapping: Identification of national stakeholders.
3. Organization of sectoral stakeholders’ meetings
4. Translation of stakeholders’ contributions into model parameters.
5. Organization of a cross-sectoral feedback seminar.

1. Expert meetings

In order to assess the degree of economic and technical realism of the modeling tools, expert meetings were organized in order to correct and update exogenous hypotheses (costs, potentials, investments, learning curves etc.) as well as the dynamics of the models itself: investments in the electricity sector or the dynamics of the residential



2 - Collaborative scenarios creation process



sector. Experts' meetings were organised concerning the residential, transport and power sector.

2. Stakeholder mapping - Identification of the national stakeholders

In order to select and to invite those stakeholders who play an essential role in the energy sectors at stake (residential, transport, electricity), we adopted the methodology of a stakeholder mapping via a "power-interest-grid". Based on this analysis, main stakeholders were identified and a contact list was established.

"Power versus interest grids typically help determine which players' interests and power bases must be taken into account in order to address the problem or issue at hand."⁷

The aim of the ENCI-Project was to select mainly those stakeholders situated in the quadrants to the right: "Key-Players" and "Show consideration". As the evaluation concerning the "interest and influence" of specific actors is highly personal,

the interviews were repeated with at least three different experts of the concerned sector in order to crosscheck the evaluations.

Structure of the interviews:

- I. Discussion on the main sector specific challenges.
- II. Establishment of a list of actors, development of a typology of those actors (private companies, ministries, associations, trade unions, banks...).
- III. Mapping of the identified actors on the power-interest grid.

3. Organization of sectoral stakeholders' meetings

In order to create scenarios with a high degree of "stakeholder acceptance" the project team ENCI-LowCarb invited the selected representatives of national stakeholder organizations to sector-specific meetings (transport, residential, electricity etc.). During these meetings, stakeholders could express their vision on the evolution of technology choices, policy measures and economic incentives necessary and acceptable to reduce CO₂ emissions. The meetings were recorded to collect a maximum of usable information; all stakeholders answered a questionnaire and minutes were taken from the ongoing discussions.

It was decided to limit the number of stakeholder to 15 to foster in-depth discussions.

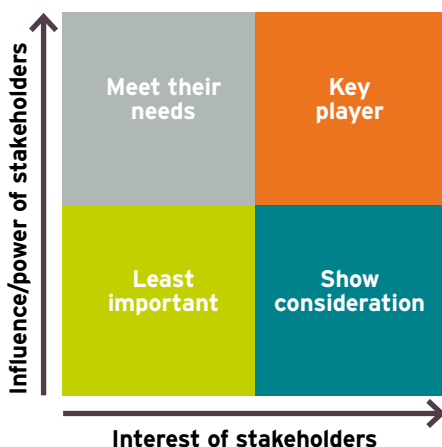
The meetings were divided in three steps:

1. Presentation of the project methodology.
2. Gathering input concerning the main sector specific topics.
3. Detailed presentation of several selected subjects and discussion with the invited stakeholders.

A questionnaire was developed for each of the subjects under point three, and energy scenarios were modeled based on the answers of the stakeholders to these questionnaires and the content of the ongoing, moderated discussions.

⁷ Bryson, J. (1995) *Strategic Planning for Public and Nonprofit Organizations*, San Francisco, CA: Jossey-Bass.

3 - Power versus interest grids



Example of the translation process : residential sector - refurbishment

One of the main obstacles for the refurbishment of houses identified by the stakeholders' is the still predominant aversion of homeowners to refurbish their houses or apartments even if many financial incentives exist. The aversion is even higher if one is non-occupying homeowner. A barrier for owners is that the access to tax incentives and subsidies is conditioned to a high personal financial contribution. Even the access to a zero-interest loan is difficult without collaterals. The stakeholders' recommended solutions to overcome this barrier: the creation of an obligatory refurbishment fund for jointly-owned buildings and a long-term third party financing. As these solutions cannot be integrated one-to-one into the modeling tool, alternative modeling strategies had to be developed. For instance it is possible within the Imaclim-R tool to change the specific "risk-aversion level" of the different agents (occupying and non-occupying homeowners etc.).

The refurbishment obligation did not reach consensus of the majority of stakeholders'. However, an important minority was in favor. In addition, it can be a very impactful tool for triggering the needed structural change in the residential sector. Therefore, the refurbishment obligation was included in the less consensual scenario including additional measures in chapter 4.



between transport and residential choices concerning topics like "urban sprawl" or electricity and housing related issues considering the question of electric heating. However, it was important to break down the energy system in "sub-sectors" in the beginning in order to be able to define clear visions and policies.

The main objective of the cross-sectoral meeting was to get a feedback on the first version of the "acceptable mitigation scenarios". The stakeholders' comments were then incorporated into the model. Points of disagreement arising from the evaluation of the outcomes of the first meetings were presented in the form of scenario variants.

The emissions reduction in the scenario only based on policy measures that are acceptable in the eyes of at least half of the stakeholders was too low to achieve neither the necessary reduction consistent with the recommendations of the IPPC nor the French objective for 2050 - a reduction about -75% of the emissions against 1990.

Indeed, the policy measures that were judged acceptable only achieved a CO₂ emissions reduction of 68% compared to 1990.

Within the ENCI-LowCarb project, we decided to present in a transparent manner additional measures (section 4) that are not considered acceptable by a majority of the stakeholders but which are necessary to achieve ambitious climate targets. These measures need further political discussion.*

4. Translation of stakeholders contributions in modeling parameters

Between the evaluation of the contributions of stakeholders and the modeling exercise, an important step was the translation of the stakeholder visions into model parameters.

The information gathered within the sector specific stakeholder meetings was translated by the project team into model parameters and added together to a first version of the "acceptable mitigation scenarios". Points of disagreement were laid open and handled by the development of scenario variants.

5. Organization of a cross-sectoral feedback seminar

As the first round of stakeholder meetings was sector-specific, the second one was cross-sectoral in order to overcome the artificial separation of energy system related questions between sectors. It is difficult to overlook existing interactions

An acceptable low carbon energy scenario for France



Introduction

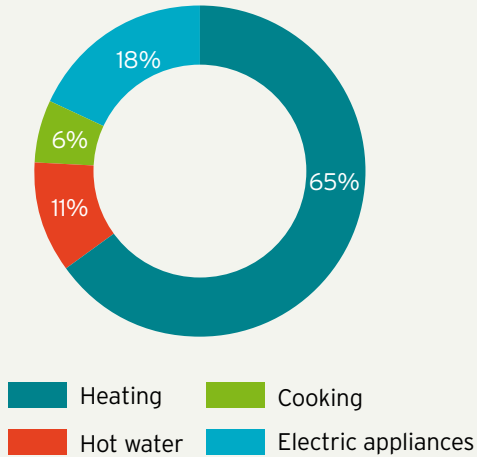
The scenario detailed over the following pages was elaborated with the specific collaborative approach, which was explained in part 2. The technical, economic and political variables that served as input for the scenario were directly defined by the stakeholders in collaboration with the modeling team.

The focus of the project was to evaluate “stakeholder acceptance” rather than “social acceptance” in the broader sense. Indeed, social acceptance goes beyond the project approach as it includes for example the dimension of “local acceptance” and would require a much broader sample of participating stakeholders and even of individual citizens.

The developed scenario presents a set of policy measures and technical variables that were judged “acceptable” by a majority of the selected stakeholders. The presentation of different elements of the scenario is divided in the following subchapters: residential sector, transport sector, industry and services sector, electricity sector and macroeconomic analysis. The presentation concludes with an overview on the ambition of the energy scenario in terms of CO₂ emissions reductions.

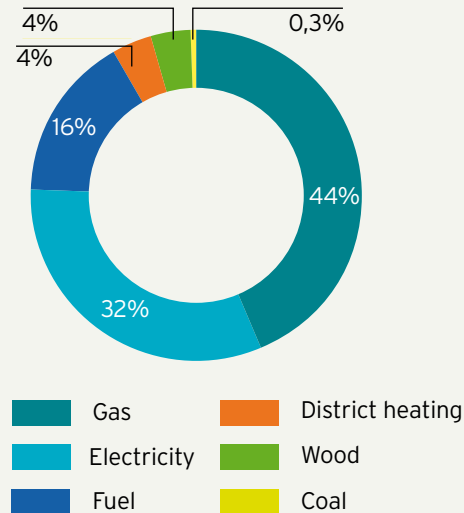
Residential sector

4 - Composition of the residential final energy consumption - 2010



The most important energy sources used for heating are gas and electricity, providing 76% of heating for the building stock. Fuel and wood is mostly used in individual housing whereas district heating concerns almost exclusively apartment buildings.

5 - Final energy mix for heating in the residential sector - 2010



The residential sector in France consists of 32.6 million dwellings, 6% of them being vacant and 10% of them being secondary residencies. 57% are individual houses and 43% apartment buildings. Nearly 60% of the overall building stock has been constructed before the adoption of the first thermal regulation in 1975.

I. Overview

In 2009, the residential sector emitted 16% of the overall CO₂ emissions - this share has remained approximately stable since 1990. However, the emissions of the residential sector increased about 15% in absolute terms. This number goes to 22% if the emissions from electricity production and district heating are included (those are generally counted under "energy industry").

In 2010, the residential sector was responsible for 30% of the final energy consumption. In comparison to 1973, the consumption has increased about 25%, but has remained stable since 2000. The main energy consuming service is heating with 65% of the final energy consumption.

Approximately 30% of all dwellings correspond to the energy efficiency class D. Less than 1% satisfies the criteria for class A and hardly more 3% achieve class B.

The existing building stock has a long lifetime because of the low share of destructions, about 20-30000 dwellings each year. New constructions mainly contribute to the growth of the building stock and not to replace demolished buildings.

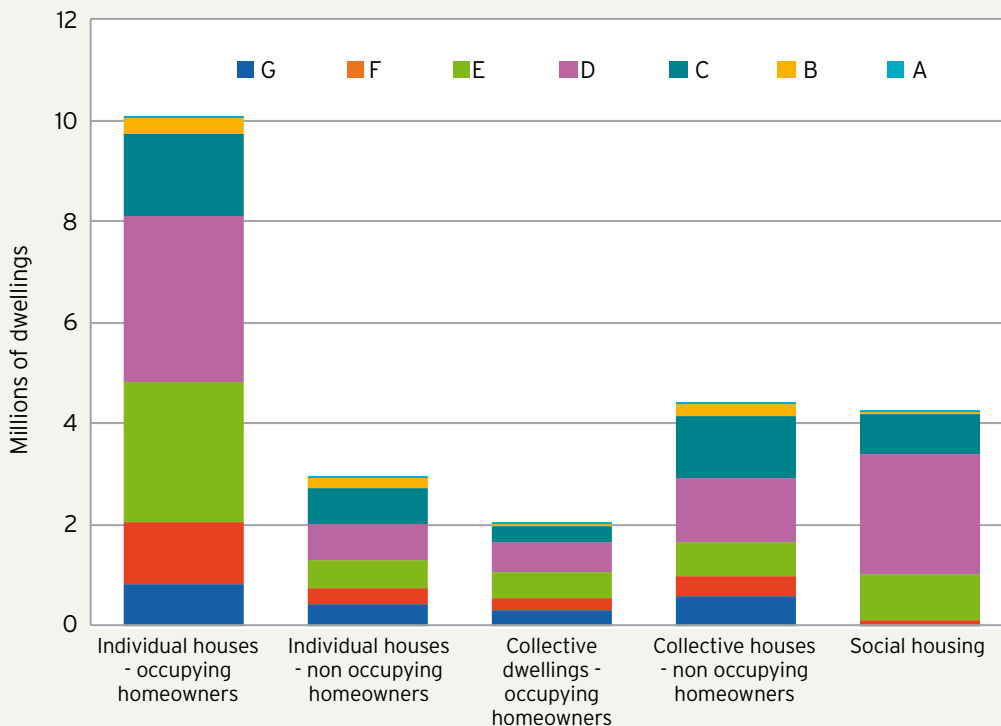
How to increase the performance and rate of refurbishment is the main challenge for climate and energy policies within this sector since two thirds of the residential stock in 2050 are already built!

Climate & energy objectives:

The French legislation includes several objectives concerning the residential sector:

- * A reduction about 38% of the primary energy consumption of the residential sector until 2020.
- * A 40% reduction of the primary energy consumption of public buildings.
- * Refurbishment of all social housing dwellings having a higher energy consumption than 230 kWh primary energy/m²/year until 2020.
- * Up from 2013 an annual refurbishment rate of about 400.000 dwellings.

6 - Building Stock Composition, primary residences in 2007



II. Representation of the residential sector in Imaclim-R

This section gives a short description of the representation of the residential sector in the modeling tool Imaclim-R.

1. Technological representation of the building stock

Imaclim-R describes the dynamics of the French household sector through the construction of new buildings and the retrofitting of the existing ones. Only primary residences are considered here and auxiliary heating appliances are not taken into account (e.g. auxiliary electric heating and firewood for fireplaces). The residential building stock is disaggregated by energy carrier (electricity, gas, fuel oil, wood, coal); by energy class, as labeled by the French energy performance certificate, from A (50kWh/m²/year of primary energy) to G (over 450 kWh/m²/year of primary energy); and by agents and typology of housing (occupying or non-occupying homeowners of individual or col-

lective dwellings and social housing). No explicit technologies are represented. Therefore, implicit packages of measures on the envelope (insulation, glazing) and the heating system reach the various levels of thermal performance. Each year, population growth, increased surface per person and the compensation of some building demolition create a demand for new constructions. The performance of the buildings constructed from 2008 onwards is split into three categories: the 2005 thermal regulation level (from 250 to 120 kWh/m²/year of primary energy, depending on the local climate), starting from 2012 low consumption buildings (50 kWh/m²/year) and zero-energy buildings in 2020, which produce at least as much energy with renewable sources as they consume with energy-efficient appliances.

2. Drivers of energy savings

In existing buildings, energy efficiency improvements result from investments to upgrade existing dwellings to upper energy classes (e.g. transitioning from G to F... until A; from F to E... until A), as well as from fuel substitution. Such transitions

include the lifecycle cost of each option, including investment costs and lifetime-discounted energy operating expenditures. Heterogeneous discount rates are used to account for the “landlord-tenant dilemma”, which splits incentives between five types of investors: occupying or non-occupying homeowners of individual or collective dwellings, in addition to social housing. Imperfect information is emphasized through the calibration of “intangible costs”. The intangible costs add to the overall costs when the agent takes the investment decision but are not paid when actually refurbishing, thus fill the gap between observed technology choices and choices that would be made under perfect information, by estimating the monetary value of this gap. The gap is narrowed in the long-term by a decreasing function of intangible costs with cumulative knowledge, representing information acceleration or the “neighborhood effect”. Overall, energy efficiency improvements (i.e. increased quantity and/or quality of retrofits) are derived from changes in the relative profitability of various retrofitting options, induced by energy price increases and sustained by retrofitting cost decrease.

III. Policy measures in the residential sector

1. Tax credits

The purchase of refurbishment elements, which increase energy efficiency like double-glazing, insulation, efficient boilers or heat pumps, is eligible to income tax credits. The rates range from 15 to 50% of investment costs. Increased rates and an extended eligibility base compared to the former subsidy scheme are modeled from 2009 until 2050 through a uniform tax rebate of 30% of the investment. Tax credit for all transitions to upper energy classes are capped at 8,000€ per dwelling.

2. Zero-interest loans for retrofitting actions

0% interest loan apply for retrofit packages with a maximum amount at 30,000€ per dwelling. The credit duration period is about 10 years for individual houses, and 15 years for social housing and collective dwellings.

3. Progressive tariff

This measure aims at reducing electricity consumption by increasing the prices above a fixed base consumption. In the scenario the progressive tariff is applied on all household electricity consumption. For all households, any consumption above 60 kWh/m² is paid at an augmented tariff. The prices per additional kWh increase of 5% after 2014 in case the consumption exceeds this limit and of 10% after 2030.

4. Biogas

The biogas penetrates gradually between 2012 and 2050. Its share reaches 17% in the gas in 2050.

5. Thermal regulation for new buildings

From 2012, new constructions respect a maximum primary energy consumption level about 50 kWh/m²/year of primary energy. After 2020, the standard increases: new buildings have to be net producers of energy.

6. Carbon tax

A carbon tax gives a price signal to reduce highly carbonized energy consumptions and to shift the energy production system to low carbon technologies. The carbon tax used in the project scenario is equal to 32€/tCO₂ in 2012, increasing gradually to 56€/tCO₂ in 2020, to 100€/tCO₂ in 2030, to 200€/tCO₂ in 2040 and to 300€/tCO₂ in 2050. In this scenario, the carbon tax income is given back to households through lump-sum transfers.

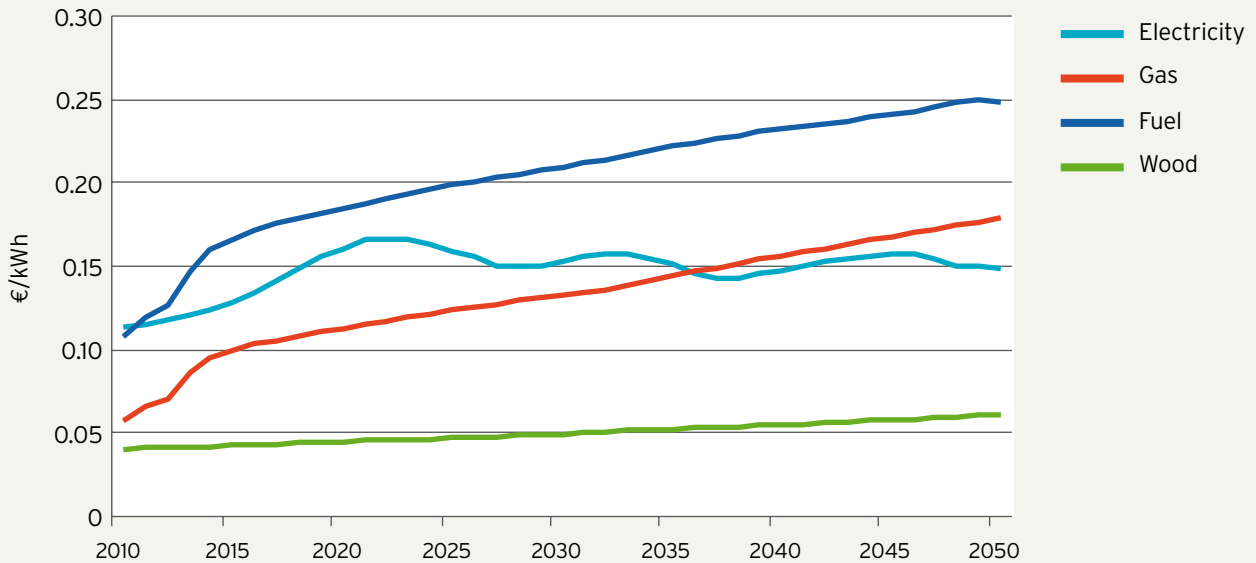
One of the main obstacles for the refurbishment of houses identified by the stakeholders is the still predominant aversion of homeowners to refurbish their houses or apartments even if many financial incentives exist. The aversion is even higher if one is only tenant. A barrier for owners is that the access to tax incentives and subsidies is conditioned to a high personal financial contribution. Even the access to a zero-interest loan is difficult without collaterals. The stakeholders recommended solutions to overcome this barrier: the creation of an obligatory refurbishment fund for jointly-owned buildings and a long-term third party financing. As these solutions cannot be integrated one-to-one into the modeling tool, alternative modeling strategies had to be developed. For instance it is possible within the Imaclim-R tool to change the specific “risk-aversion level” of the different agents (house owners, occupying and non-occupying homeowners etc.).

The refurbishment obligation did not reach consensus of the majority of stakeholders. In addition, it can be a very impactful tool for triggering the needed structural change in the residential sector. Therefore, the refurbishment obligation was included in a scenario with additional measures in section 4.

IV. Evolution of energy consumption in the residential sector

Energy efficiency gains arise from retrofitting of inefficient dwellings and from fuel switches. Over the scenario period, the existing building stock shows a progressive disappearance of the

7 - Final energy consumer prices in the residential sector



low-efficiency classes G to D, and a gradual penetration of classes C due to economic incentives and learning-by-doing which decreases retrofitting costs. Most of the retrofitted stock reaches class C in 2050. Nearly no ambitious retrofit to class B or A appear, since these retrofitting options remain too costly for households given the economic incentives and energy prices in the scenario. Even the existence of an obligatory renovation fund for jointly-owned buildings and the availability of third-party financing do not decrease the risk aversion of the owners of individual houses and jointly-owned buildings enough to make such ambitious transitions happen. The pace of the transition is highest for social housing, this being consistent with the French legislation which requires refurbishment of all social housing to reduce the energy consumption of the dwellings exceeding 230 kWh/m²/year before 2020 to 150 kWh/m²/year⁸. Furthermore, this share of the residential building park is the most structured and is not facing the same challenges as it is the case for jointly-owned buildings where complicated decision making procedures delay action.

The graphs on page 14 and 15 illustrate the transformation of the residential building stock according to the energy label transitions and the evolution of the energy mix for individual houses, social housing, jointly-owned buildings and new constructions. In all subcategories of existing buildings, transitions to upper energy classes appear jointly with an important energy substitution from gas and fuel towards electricity for heating that corresponds in the model to a significant penetration of heat pumps (7 millions). This substitution is driven by the evolution of relative final energy consumption prices.

At the end of the period, final energy consumption per square meter for heating is divided by 3.2, total final energy for heating by 2.4 and total primary energy for heating by 1.8.

Given a behavior function, the model computes⁹ the gap between the theoretical energy consumption for heating and real energy consumption after a retrofit action or in new energy efficient buildings, e.g. the rebound effect. In this scenario, given the assumptions of high global prices for fossil energy, and additional fiscal measures (progressive tariffs on electricity and carbon tax on fuel and gas), the rebound effect is quite limited. It is negative until 2034 and is limited to 4% on final energy consumption in 2042.

Concerning energy uses other than primary heating in residential, the shares of gas and fuel (mainly for cooking and for secondary heating devices) remain stable. The specific electricity¹⁰ consumption slightly increases until 2050 (+24% compared to 2010). This evolution is the combined effect of improved energy efficiency (autonomous following current trends and induced by a 40% increase in electricity prices between 2010 and 2020) which is more than compensated by the development of new electric appliances mainly multimedia devices and the population increase (+15%).

Globally, the final energy consumption (heating and other uses) per capita is divided by 2 and the total final energy consumption decreases by 37% between 2010 and 2050. The CO₂ emissions of the residential sector (excluding electricity emissions that are included in the power sector) decrease of 75% between 2010 and 2050. ✨

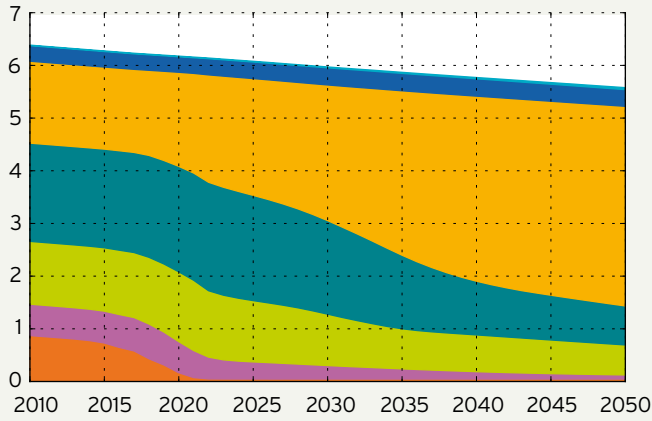
⁸ These figures correspond to primary energy.

⁹ The model builds on a logistic relation that links the "service factor" (which reflects the gap between effective and conventional energy consumption) to the annual heating expenditure, as a proxy for the price of the heating service. It states that the higher the efficiency of the dwelling, the higher the service factor, thus inducing sufficiency relaxation. Conversely, the higher the energy price, the lower the service factor, thus inducing sufficiency strengthening. Investments that move a dwelling from a domain of low efficiency to a domain of higher one (e.g. from class F to class C) increase the service factor, i.e. induce a rebound effect. Similarly, switching from a given energy carrier to one fuelled by a cheaper energy (e.g. from fuel to wood) within the same efficiency domain implies a higher service factor.

¹⁰ Specific electricity refers to electric consumption in other residential uses, mainly electric appliances, including secondary heaters.

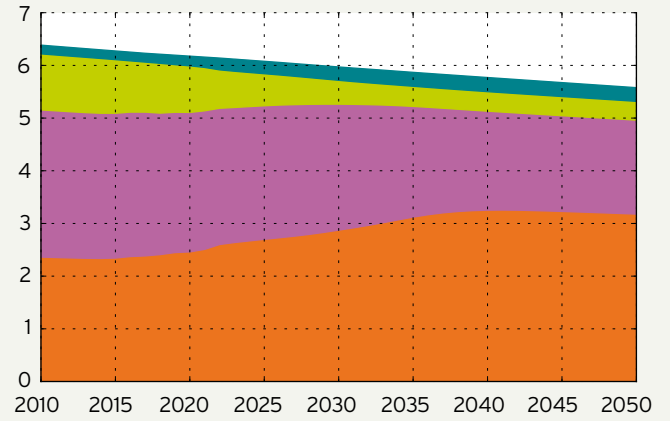
ENERGY LABELS

8 - Jointly-owned housing stock (million dwellings)

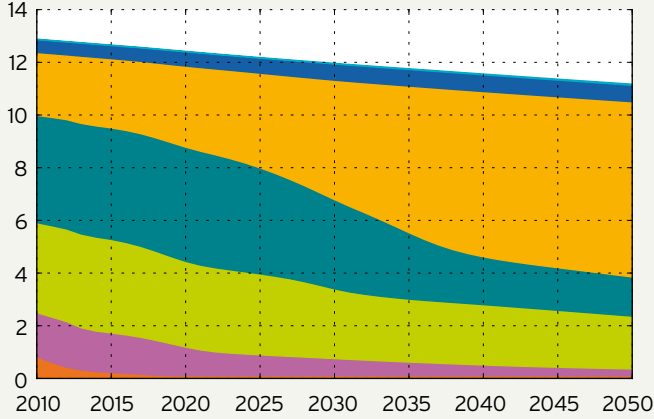


ENERGY MIX

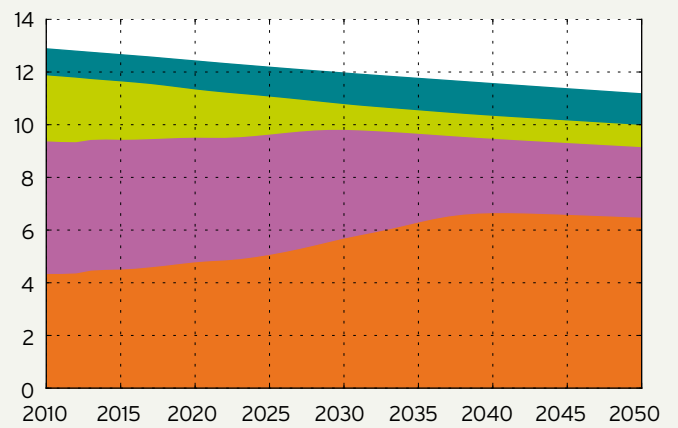
9 - Jointly-owned housing stock (million dwellings)



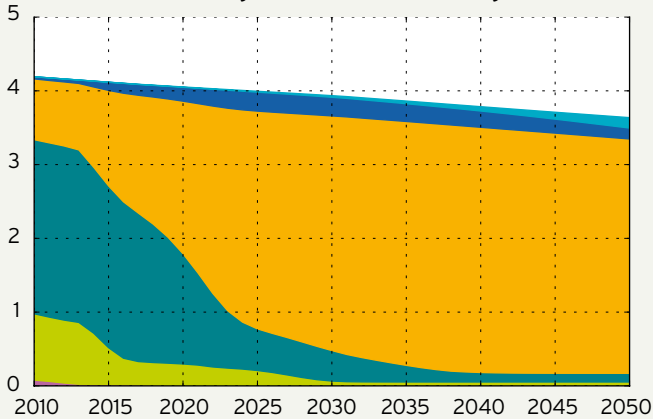
10 - Individual houses (stock million dwellings)



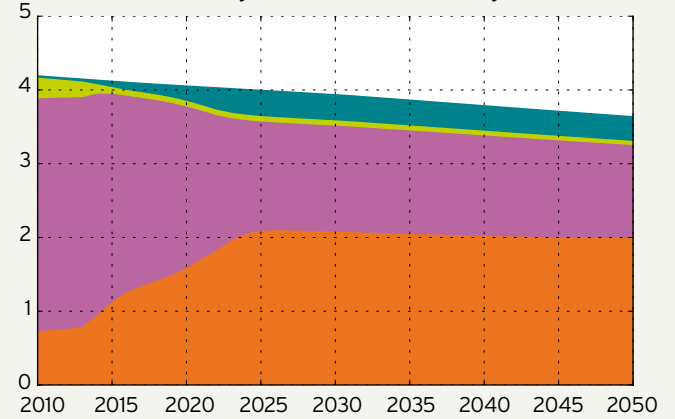
11 - Individual houses (stock million dwellings)



12 - Social housing (stock million dwellings)

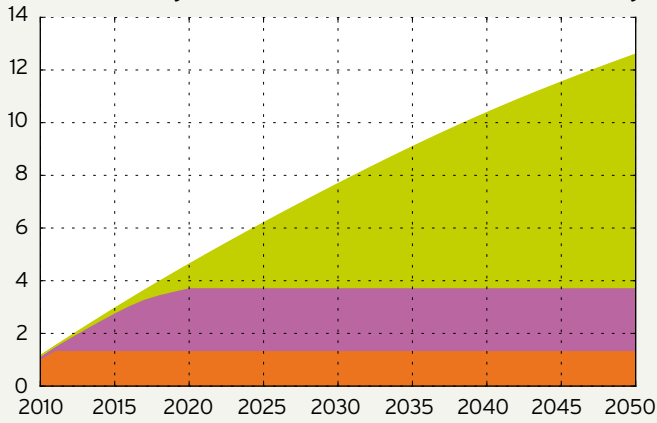


13 - Social housing (stock million dwellings)



ENERGY LABELS

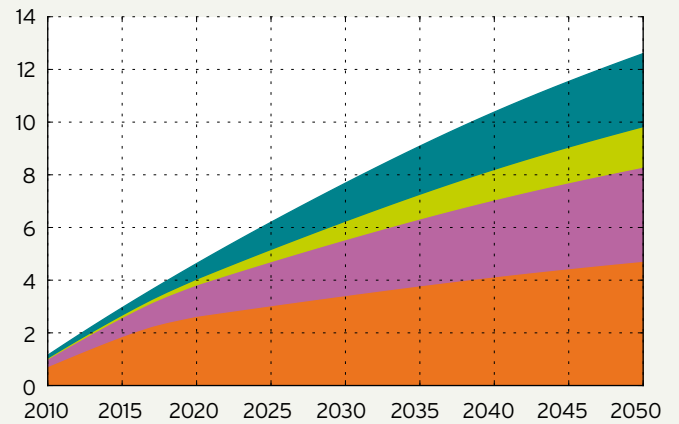
14 - Housing stock - built after 2007 (million dwellings)



BEPOS BBC RT2005

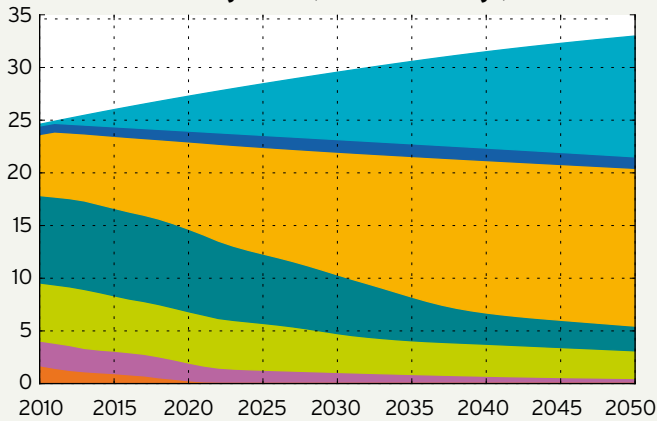
ENERGY MIX

15 - Housing stock - built after 2007 (million dwellings)



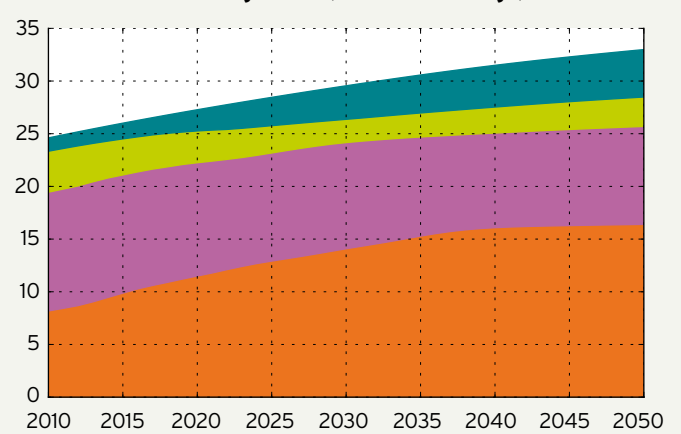
Wood Gas
Fuel oil Electricity

16 - Total housing stock (million dwellings)



A (<50 kWh/m²/year) E (231 to 330 kWh/m²/year)
B (51 to 90 kWh/m²/year) F (331 to 450 kWh/m²/year)
C (91 to 150 kWh/m²/year) G (> 450 kWh/m²/year)
D (151 to 230 kWh/m²/year)

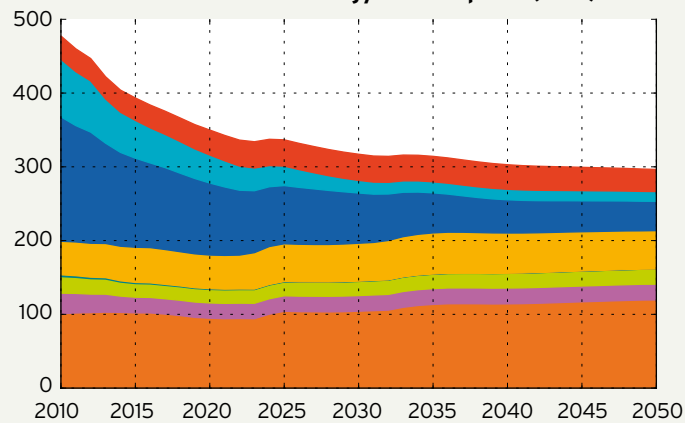
17 - Total housing stock (million dwellings)



Wood Gas
Fuel oil Electricity

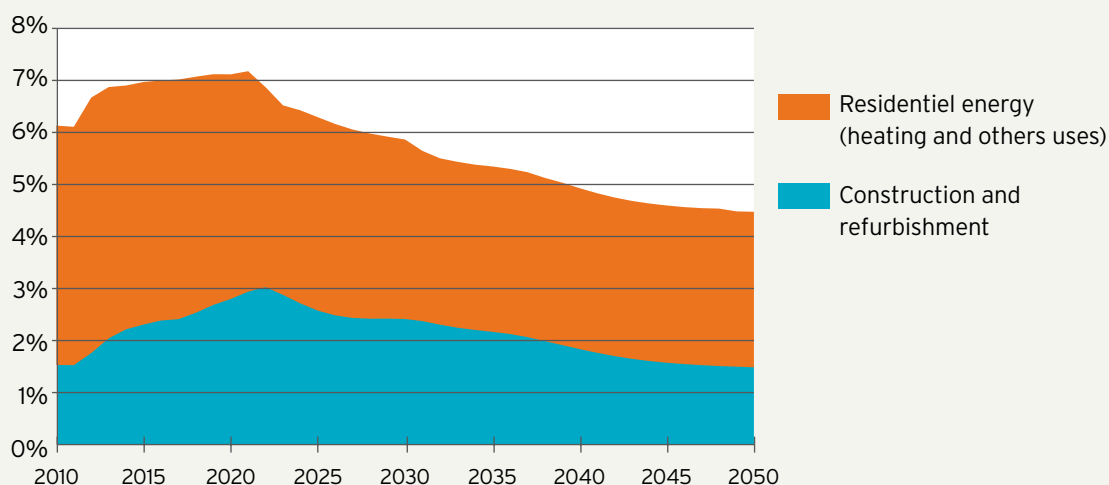
CONSUMPTION

18 - Residential final energy consumption (TWh)



Wood - heating Coal other uses
Fuel oil - heating Fuel oil - other uses
Gas - heating Gas - other uses
Electricity - heating Electricity - other uses

19 - Households budget shares for residential



V. Investment and policy costs in the residential sector

The governmental subsidies for the transformation process of the residential building park decrease over the scenario period. Households carry the main share of the charges used for the refurbishment of the residential sector and energy efficient constructions.

The households' expenditures for energy consumption, refurbishment and construction in the resi-

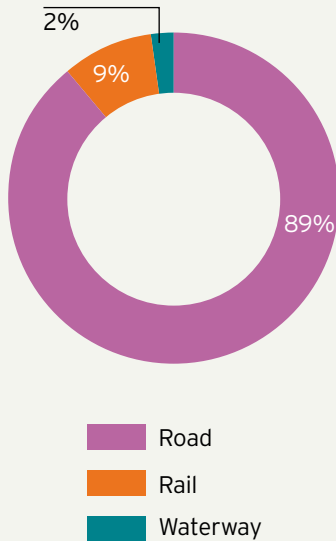
dential sector decrease over the scenario period from 6 to 4,5% of the overall household budget. The energy expenditures peak in 2012. Energy efficiency measures reduce the energy consumption and thus the allocated energy budget of households.

The expenditures for construction and refurbishment peak later in 2022 which is consistent with the transformation process of the residential building stock and the investments necessary for the switch from class D to C. *

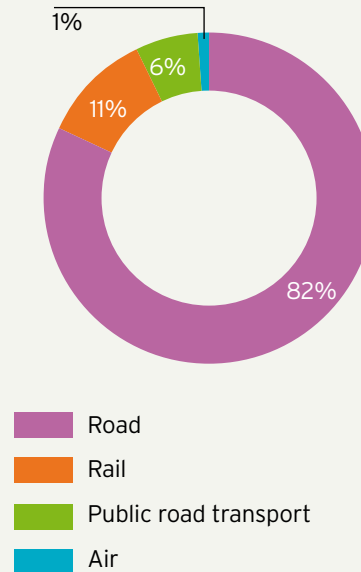
	2020	2030	2040	2050
Policy measures costs for the government (Billion €)				
Tax credit	-3.3	-2.5	-0.8	-0.5
Eco-loan	-3.3	-1.9	-0.6	-0.4
Additional costs for households (Billion €)				
Construction	-9.5	-9.4	-7.7	-6.3
Refurbishment	-14.9	-10.3	-3	-1.8

Transport sector

20 - Modal split in freight transport - 2010



21 - Modal split in passenger transport - 2010



I. Overview

The transport sector is responsible for nearly 40% of the CO₂ emissions in 2010. Its emissions increased of 16% between 1990 and 2010. The main cause of these emissions is the fuel combustion for road transport. Regarding the modal split, both passengers transport and freight transport are highly dominated by road transportation.

The trips for less than 50 km represent 89% of the journeys. Trips over 500 km correspond to only 1.3% of the journeys but 40% of the traveled distances. Irrelevant in terms of km but important in number of journeys are our feet: walking represents 22% of local mobility but only sums up to 2% of the traveled distances.

In 1990, the transport sector was responsible for 29% of the total French final energy consumption; in 2010, it increased to 32%. But in absolute numbers, this evolution represents an increase of 25%.

The investment in transport infrastructures in the recent decades shows that the road transport mode was clearly favored. The road network increased from 5,300 km in 1980 to 11,054 km in 2008. Between 1994 and 2008, the highway traffic has increased about 55%. The high-speed rail network (TGV) has only increased from 1,574 km in 1994 to 1,847 km in 2008 - but the number of passengers raised about 146%.

Freight traffic decreased about 15% during the economic crises in 2009 but since then, it is slowly returning to its former level.

Climate and energy objectives:

The French legislation includes several objectives concerning the transport sector:

- ★ A 20% reduction of the greenhouse gases emissions in 2020 (base year 2005).
- ★ The adoption of an eco-tax on heavy road freight transport in 2011 (has been delayed).
- ★ Increasing the traffic share of all transport modes except air and road from 14% to 25% in 2022. The intermediate objective in 2012 corresponds to an increase of 25% compared to 2007 (the share has decreased since then therefore the objective is not likely to be achieved).
- ★ The construction of 2,000 km of high-speed train before 2020.
- ★ 50% reduction of the energy consumption by passenger and km of the air traffic before 2020.★

11- Imaclim-R France only represents domestic air traffic.

II. Representation of the transport sector in Imaclim-R

Imaclim represents two different kinds of transport activities: transports are either bought transport services that are used by individuals or satisfying a sector specific transport demand (air transport¹¹, water transport, terrestrial freight transport, terrestrial passenger transports - taxis or collective transports), or self-produced services (with individual cars or non-motorized transports).

¹²⁻ This means that a 1% price increase induces a 0.4% decrease in consumption

For **passenger transports**, a “**time-budget constraint**” sets an upper boundary for the time spent daily in transportation. This methodological choice relies on the empirical rule named “Zahavi’s law”. It shows that since many decades, each day, households on average spend the same amount of time on transport. The modal choices depend on the relative prices and speed of each mode. Each mode is characterized by a speed that decreases with a higher utilization rate of a specific transport infrastructure. Indeed, the more people use a specific transport infrastructure (each infrastructure has a given capacity limit depending on the dedicated investments), the higher the risk of congestion is, which reduces its speed. As people are bound to a stable time budget, when a specific transport infrastructure is close to congestion, other modal choices will be preferred. The maximum capacity of each modal infrastructure depends on the investment allocated to the specific infrastructure.

The **evolution of transport infrastructures** is represented according to public and private investment decisions. In the reference scenario, the infrastructure development follows the evolution of the modal transport demand, either through governmental spending in infrastructures or through private investment from transport sector investors. Climate policies are translated for example in an investment transfer from road construction to public transport infrastructures.

The **evolution of the motorization rate** is linked to the evolution of households’ income and to the urban density but is quite insensitive to fuel price changes. On the contrary, climate policies such as urban planning may lead to a decrease in the motorization rate in the long term.

The **efficiency of the fleet of individual cars** depends on the households’ consumption choices and on technical change. The vehicles fleet is disaggregated according to the year of first circulation and to the energy label (conventional from G to A, hybrids or electric). This representation includes the specifications of the vehicle related to costs, energy efficiency, fixed and variable maintenance costs.

The **evolution of energy prices** is integrated in the evolution of the transport service price for each transport service sector (for example in the train or bus ticket price) and for individual transport through fuel prices at the time of purchase and at the time of effective consumption.

Energy consumptions for freight transport result from the following energy efficiency improvements assumptions:

- *In air transport, intermediate fuel consumptions decreases by 0.7% each year. It reflects technological improvement in plane design to lower kerosene

consumption and traffic management measures to increase occupancy rates.

- *In water transport, energy consumption per unit of transported good remains unchanged.
- *In terrestrial freight transports, the average liquid fuel consumption is the result of a fuel price elasticity¹² set to -0.4 and to a maximum 25% energy efficiency improvement. The evolution of intermediate energy consumption in these sectors reflects at once technology changes, modal shifts (particularly between rail and road freight transport) and modifications of structural components of this sector resulting from changes in relative weights of transported materials of sub-sectors that compose it.

The **freight transport** demand in Imaclim-R is the aggregated demand from goods transport demand for each productive sector. The **freight content of economic growth** is directly linked to the consumption styles and to the structure of the economy (more services or more industrial production). On the contrary, freight activities are only weakly sensitive to energy prices. Modal freight choices rely on logistics and the organization of the supply chain. Given the uncertainty of the reaction of firms to energy price variations (concerning organizational and logistical decisions), these parameters and their evolution are set exogenously as scenario variables.

In the reference scenario, the energy consumption for freight transport is only influenced by the energy efficiency improvement of heavy trucks.

In the mitigation scenarios, assumptions related to spatial organization may lead to a decoupling of economic growth and freight transport and by this to a decrease of freight transport demand. Assumptions related to a change of consumption styles or to the structure of the economy may lead to a general dematerialization of economic growth that induces a decrease in freight transport needs. These orientations of the economy are only investigated in alternative scenarios in part 4. ✳

III. Policy measures in the transport sector

1. Urban and local transports

Urban planning: Economic incentives and regulations aim at limiting the increase in urban sprawl. These measures are considered to have an impact only from 2030 because of inertia. The increase in urban sprawl slows down gradually until 2030. After 2030, the trend is reversed and the urban density increases again.

Urban transports investment program: Investments in urban transports (buses, tramways) are doubled during 15 years from 2012. A retrofitting

railway program is implemented to enhance regional rail traffic and intermodality is improved. The time inertia in the construction of infrastructures is taken into account.

Teleworking: the assumption related to teleworking is that an average of one day of work out of ten is carried out by teleworking, taking into account that not all activities can be subject to teleworking.

Cars occupation rate: Incentives (promotion by firms of employee transport plans as well as car-pooling) are considered to increase the cars occupation rate for urban transport from 1.25 to 1.5.

2. Long distance travels

Rail investment program: Investments in road infrastructures are limited to covering the maintenance of infrastructures only. A shift of investments from road to rail for 20 years aims at ensuring the retrofit of existing railways infrastructures to allow an increase of rail market shares for regional transports. The construction of new high-speed infrastructures favors the competitiveness of high-speed trains against airplanes.

Kerosene tax: A tax on kerosene consumption for air transport is introduced in 2012. It represents 400€/toe.

3. Individual cars and technological change

Bonus-malus: The "bonus-malus" measure on the emissions reductions of new vehicles is extended until 2050. It is calibrated in order to foster the penetration of clean vehicles (label A+, A and B) and to obtain a positive annual financial balance for the government budget or at least close to 0.

4. Freight transports

Heavy truck environmental tax: an eco-tax on the liquid fuel consumption of heavy trucks is introduced in 2012. It is calibrated to bring in 1.3 billion€ in 2012.

Logistics: Policies aiming at improving supply chains for production and distribution reduce the transport content of consumption. This is represented by an annual decoupling of freight transport needs of 1% per year for all sectors.

Infrastructures: A program is implemented to develop alternatives to the road for the freight transport by improving the supply chain of rail freight transport and developing rail freight capacity. This is represented in the model by additional investments in the freight sector from the government. The inertia in this sector is considered to be important. This is why the exogenous assumption is that the modal share of rail transport in freight reaches only 20% in 2030.

Carbon tax: A carbon tax gives a price signal to reduce highly carbonized energy consumptions and to shift the energy production system to low carbon technologies. The carbon tax used in the project scenario is equal to 32€/tCO₂ in 2012, increasing gradually to 56€/tCO₂ in 2020, to 100€/tCO₂ in 2030, to 200€/tCO₂ in 2040 and to 300€/tCO₂ in 2050. In this scenario, the carbon tax income is given back to households through lump-sum transfers.*

IV. Evolution of energy consumption in the transport sector

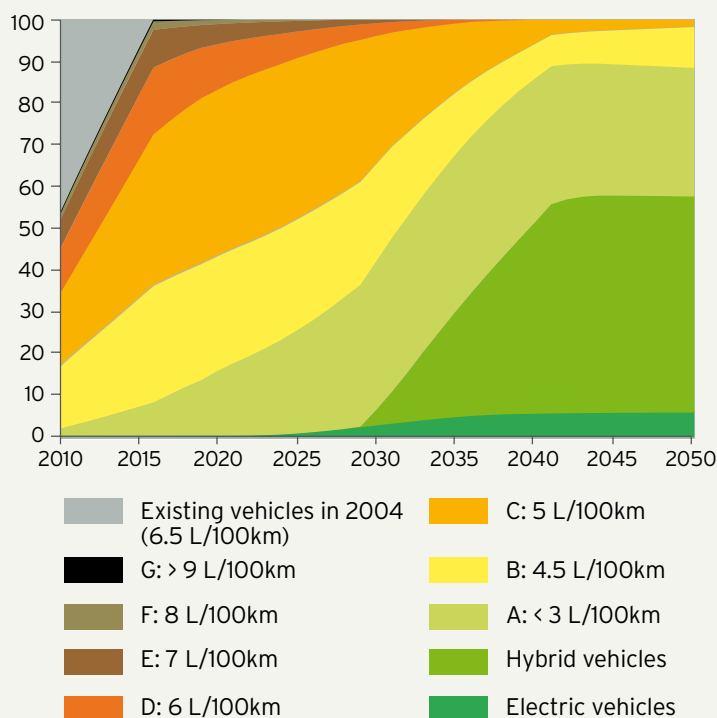
In this scenario, two mitigation strategies are implemented for passenger mobility: Limiting current increase in individual mobility with urban planning and incentives to limit voluntarily mobility demand.

1. Penetration of decarbonized vehicles

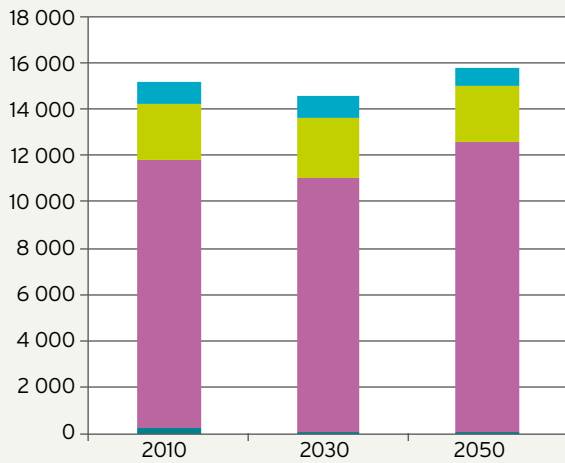
The bonus-malus measure is calibrated from 2010 to 2050 to result in a positive or neutral financial balance for the government. It is reevaluated every five years to favor energy efficient vehicles. The most emitting vehicles disappear. Electric vehicles occupy only niche markets for urban mobility with a penetration limited to 5% of the total vehicles fleet in 2050. They refer to car sharing systems in urban areas. Hybrid range extender¹³ vehicles massively penetrate after 2030. They are best suited to urban use but can also be used for long journeys.

¹³ Range extender hybrid vehicles are designed to counter the small autonomy of electric vehicles and the high cost of batteries. The motor includes both a combustion and electric motor. The small internal combustion engine is used only as a generator to power the electric motor or to recharge its batteries. Unlike a conventional engine, which operates over a wide variety of power settings and operational conditions, the range extender can be operated under optimum conditions at all times. Compared to a classical hybrid vehicle, range extender hybrid vehicles have a bigger electric engine that is not assisted by the internal combustion engine

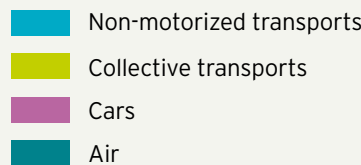
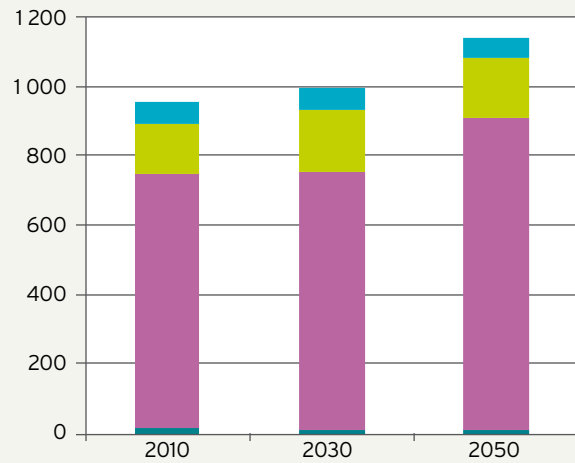
22 - Composition of the vehicles fleet (%)



23 - Annual total individual mobility (km)



24 - Annual global mobility (G passengers. km)



14- ADEME (2010) "Analyses de Cycle de Vie appliquées aux biocarburants de première génération consommés en France", Rapport final.

2. Biofuels development

The scenario is based on the biofuel development scenario in the "World Energy Outlook 2006". In the policy scenario in 2030, 147 Mtoe of biofuels are produced in the world (7% of the total demand for road transport fuels). Biodiesel accounts for 15% of the biofuel use. In Europe, biodiesel use drops from well over 50% of the consumption to under 30% in 2030.

The biofuel consumption in the here presented scenario is about 5 Mtoe in 2020 and 16 Mtoe in 2050 (respectively 9% and 39% of total refined petroleum products). A technology switch takes place around 2030 concerning the first-generation ethanol production (from agricultural sugars and starches) towards second-generation biofuels (ligno-cellulosic ethanol) as production costs of the latter decrease. The use of second-generation biofuels attenuates most of the negative impact of the biofuels first generation: competition with food production, use of agricultural production and additional emissions due to land use change (that can even exceed those of classical fossil fuels¹⁴).

3. Evolution of the individual mobility

On average, the mitigation scenario leads to a slight increase of individual mobility on the long term (+3% compared to 2010 level). This translates into a 19% increase of total passengers' mobility. Nevertheless, in the middle term (2030), the increase of energy prices and the inertia in developing alternative collective transports lead to a constrained mobility with a 4.5% decrease in individual mobility and a 4% increase in total passengers mobility compared to 2010 levels.

This mitigation scenario is therefore not a restriction or a rationing scenario but a scenario with mobility management that takes into account bottlenecks and asymptotes in urban sprawl and motorization rates.

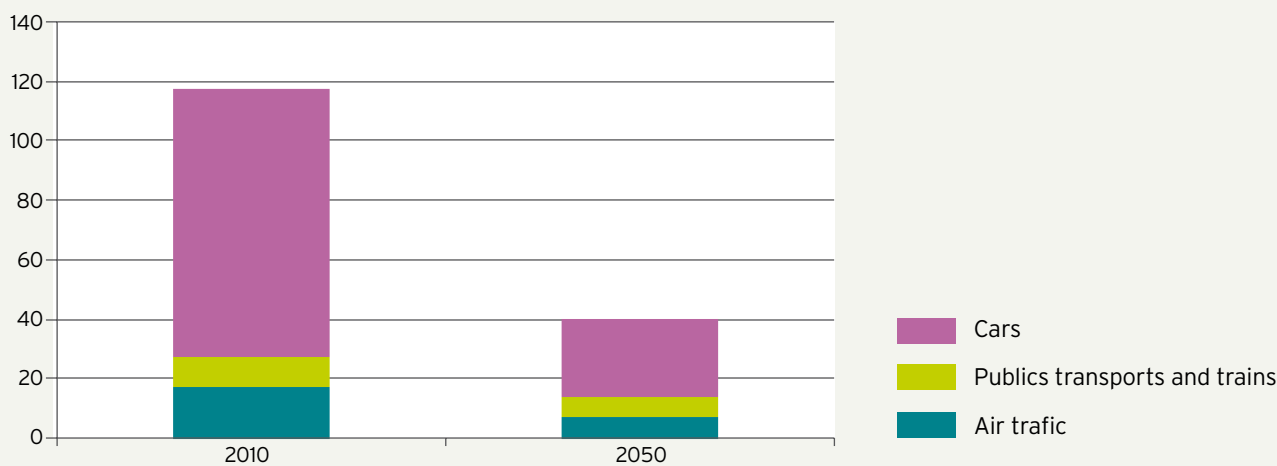
4. Urban and local mobility

The objective of policies and measures implemented for urban mobility is the limitation of the increase of urban sprawl, while favoring more collective transport infrastructures. Because of the inertia of the existing system, these measures begin to have a significant impact only after 2030. The mobility in urban areas mainly refers to a constrained mobility (daily commuting). The two determinants of the total urban mobility are the demographic trends in urban areas and the urban sprawl. The urban sprawl has an ambivalent impact over time: it keeps increasing, particularly urban areas outside Paris, until 2030, and starts decreasing after 2030. Congestion increases for all transport modes in urban areas, until more collective transports are available. In the short run, avoiding the impact of increasing oil prices relies on reducing mobility by teleworking and the increase of the vehicles occupation rate. These measures translate the generalization of employee transport plan in firms.

5. Long distance mobility

The general implementation of constraints for urban transports restrains long journeys: the widening of congestion in urban areas decreases the time available for long journeys particularly with a more expensive air transport (kerosene tax) and inertia in the development of road alternatives. This explains partly the decrease in total passengers' mobility in 2030. After 2030, more train transport

25 - Emissions in passenger transports (MtCO₂)



capacity is available and part of the time constraint is released.

Passenger transport emissions decrease by 66% between 2010 and 2050. This reduction results from the combination of (i) an average 70% reduction in oil consumption of individual cars, (ii) the penetration of biofuels and (iii) a 23% increase in car passengers-km. Emissions reductions in air traffic are the results of a slight decrease of demand and of a 40% energy efficiency improvement.

6. Freight transport

The eco-tax for heavy trucks enhances technical change towards more efficient technologies. In 2030, the energy efficiency of heavy trucks is 25% higher.

Overall, the emissions of the freight terrestrial sector decrease by 40% between 2010 and 2050. This results from (i) a 9% increase of the freight demand during the period, (ii) a 30% energy efficiency improvement for road transport per unit of good transported, (iii) a modal shift towards rail for 7% and (iv) 12% for biofuel penetration.

In total CO₂ emissions in the transport sector (passenger and freight) decrease by 60% between 2010 and 2050, and final energy consumption decreases by 41%.★

is fully attributable to the decrease in consumption of imported petroleum product. This would impact negatively the government income.

For the infrastructural investments, all the operations are done neutrally if compared to the reference scenario. Indeed, the total amount of investment does not change, only the repartition between transport modes. 6 billion euros are withdrawn from the road investment and dedicated half to urban road collective transports and half to railroads. ★

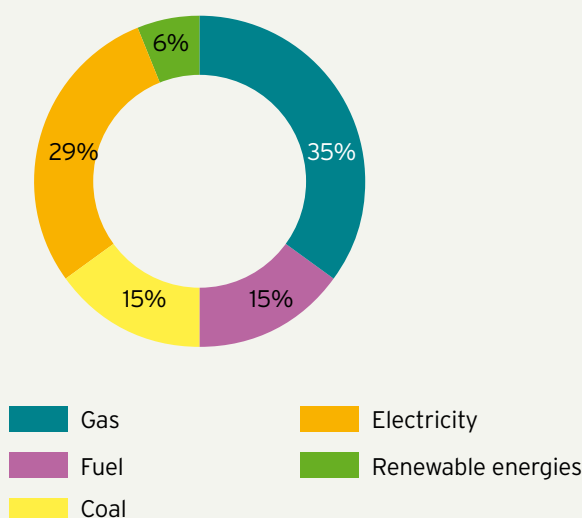
	2010	2020	2030	2040	2050
Fiscal measures (billion €)					
Heavy trucks eco-tax	0	1.3	1.1	1.1	1.2
Kerosene tax	0	1.6	1.1	1.4	1.3
Impact on domestic consumption tax on petroleum products	23.8	21.4	17.9	13.4	12.9
Carbon tax	0	13.7	18.1	23.9	34.8
Investments on infrastructures					
Urban transports	+3 billion € each year from 2012 until 2030				
Railways	+3 billion € each year from 2012 until 2030				
Road transports	-6 billion € each year from 2012 until 2030				

V. Investment and policy costs in the transport sector

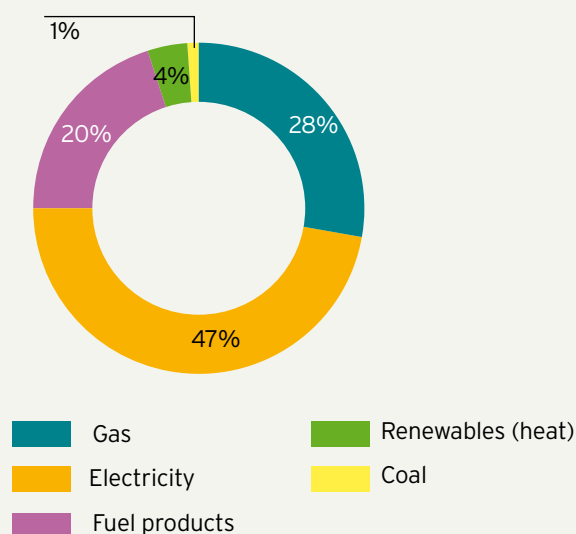
The fiscal measures applied to the transport sector positively impact the financial balance of the government, except for the domestic consumption tax on petroleum products whose receipts decrease significantly over time. Thus, the income of this tax decreases of 10% in 2020, 25% in 2030 and about 50% in 2050. However, the tax rate remains the same. Therefore, the income reduction

Industry and services

26 - Final energy mix of the industry sector - 2010



27 - Final energy mix of the tertiary sector - 2010



I. Overview

1. The industry

The energy mix of the industry sector is dominated by fossil fuels (65%). The industrial final energy consumption decreased from 27% (38 Mtoe) in 1990 to 22% (35 Moe) in 2010.

Several industrial sub-sectors contribute with more than 10% to the industrial emissions:

- * Non-metal minerals and construction materials (27%).
- * Chemical industry (24.7%).
- * Metallurgy and steel (17.1%).
- * Food industry (12%).

The industrial process emissions comprise emissions from fossil fuels combustion as well as emissions caused by chemical reactions such as during the heating of calcium carbonate for cement production. The abatement of these emissions can be realized through changing the process itself or using carbon capture and storage technologies (CCS) if the technology is available.

The recent economic crisis impacted the French industry production and the induced final energy consumption (-13% and even about -27% for the steel industry). However, in 2009-2010, along with the economy, the industrial production recovered, and the energy consumption increased about 21%. The CO₂ emissions of the industrial sector decreased about 22% between 1990 and 2010. In 1990, the industry emitted 28% (85 MtCO₂) of the global CO₂ emissions and in 2010 only 23% (67 MtCO₂).

The issue for the future is the industrial level of France consistent with a low carbon pathway. Indeed, the evolution of the imports of manufactured goods and the relocation of industry in France - desirable from an economic point of view - would critically affect industrial emissions.

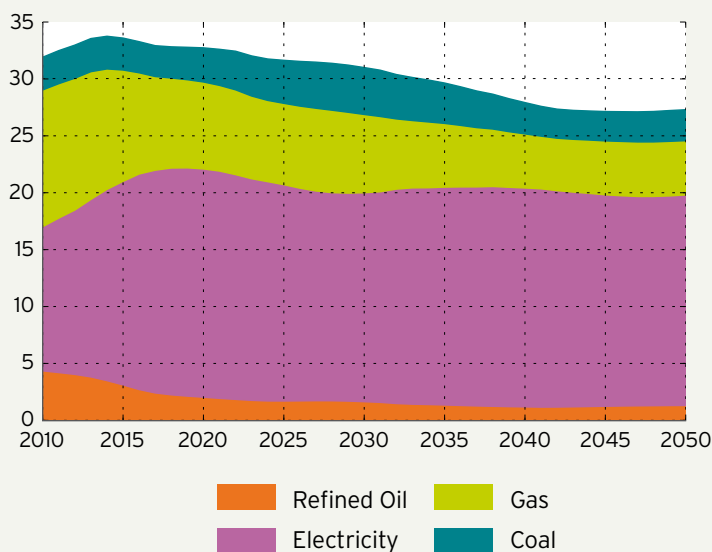
2. The services

The tertiary sector used 11% of the total final energy consumption in France in 2010 (21.7 Mtoe). The energy consumption mix is dominated by electricity (47%). In addition to the renewable share in the electricity mix, thermal renewable sources represent only 4%. The CO₂ emissions of the tertiary sector increased about 9% between 1990 and 2010, from 28 MtCO₂ to 31 MtCO₂.*

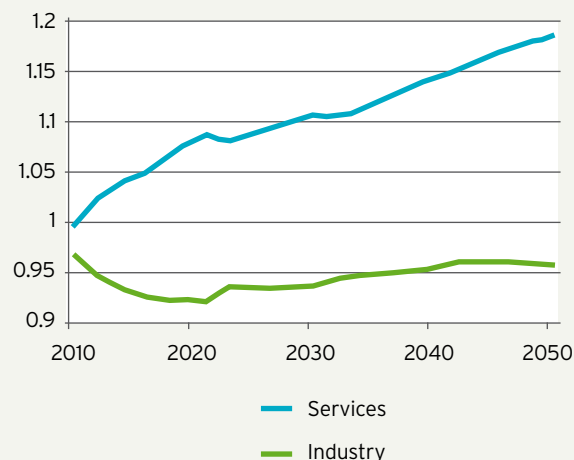
II. Representation of the productive sectors in Imaclim-R

The industry (apart from transport and energy) aggregates very diverse activities, preventing Imaclim-R from explicitly representing individual production units. Nonetheless, the inertia of the installed capacities and technologies remains explicit through a description in capacity vintages. Hence, the various industrial processes are summarized by the average consumption of inputs. Therefore, the variations of the average consumptions translate not only into the improvement of technologies but also into structural changes between the various subsectors aggregated (for instance reducing the share of energy-intensive services and increasing the share of other services). **Three**

28 - Final energy consumption of industry (Mtoe)



29 - Competitiveness index for services and industry



mechanisms are taken into account: (i) autonomous technical change over time, (ii) a trend in structural decrease of energy intensity (iii) the improvement of production techniques through more efficient technologies and energy substitutions induced by the evolution of energy prices.

In the mitigation scenario, the autonomous technical change is increased by 30%. In addition, increasing energy prices trigger some substitution relying on price competition (favoring less carbon-intensive energies) and endogenous technical change.

The same description applies for the tertiary sector.*

III. Evolution of energy consumption in the industry sector

In Imaclim-R France the industry sector¹⁵ roughly represents 26% of the final energy consumption in 2010. After energy efficiency improvement across the whole economy, the industry still accounts for 26% in 2050. Since the industry sector in the model includes the energy-intensive industries such as steel, aluminum and chemistry, the final energy demand is structurally very important, even if it decreases over time. However, behind a demand for energy that appears to remain stable, the energy efficiency of the industry sector is greatly improved. Indeed, the final energy used in the sector only decreases by 15%, when the level of activity increases by almost 35%, leading to an increase in energy efficiency of 37%¹⁶.

Furthermore, the energy sources undergo a major change. The supply of coal remains roughly the same, but most of the oil and half of the gas are replaced by electricity because of a very competitive electricity price compared to gas. Most of the competition stems from the relative prices of the two energies. The prices of electricity and gas are very close until 2025. Thereafter a gap appears, clearly favoring electricity (the prices for industry being 40% lower for electricity than for gas for the same amount of energy).

The switch from gas to electricity and the energy savings induce a decrease of the industrial CO₂ emissions¹⁷ from 53 to 23 MtCO₂ in 2050. The use of the CCS technology for process emissions could further reduce the carbon impact of this sector¹⁸.

The graph 29 illustrates the increase in competitiveness of France against global supply¹⁹. The higher the index, the more favorable the competition for France (without giving an absolute level, this graph shows the trend). The industry index remains close to 1 for the whole period, which indicates that industrial goods are neither more nor less competitive than at the beginning of the period. **One the other hand**, the services competitiveness index steadily increases, showing that the French tertiary sector improves its price competitiveness.

This is due to the evolution of energy costs in productions costs for these sectors. In the tertiary sector, energy efficiency improvement reduces energy costs. On the contrary, in the energy-intensive industries, energy efficiency improvement is structurally bounded. Therefore costs cannot be reduced as significantly.*

15- This sector includes steel, cement, chemistry, non-ferrous metals, equipment and paper in Imaclim.

16- This energy efficiency increase corresponds to a 37% reduction of energy intensity, computed as the ratio between final energy and added value (GDP) for the industry sector.

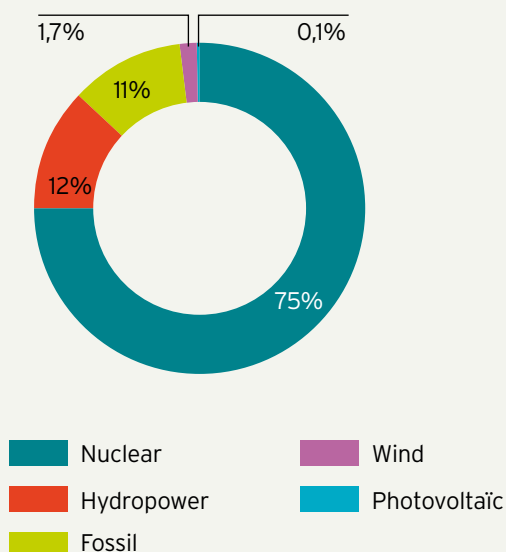
17- The industrial emissions correspond to direct emissions (excluding electricity generation).

18- This scenario is based on a conservative assumption for CCS: it only marginally penetrates the power sector and is not available for industry.

19- This index is computed as the ratio between the world price index and the French price index for industry. If there is a 80% increase in the world price and only a 20% increase in the French price, the competitiveness index equals $1.5 (= \frac{180}{120})$, which is in favor of the French goods. The base year for the computed indices is 2004.

Electricity sector

30 - Energy mix of the electricity sector - 2010



20- POPE Law (2005).

21- As expressed in France National Renewable Energy Action Plan.

22- The Load Duration Curve represents the hourly demand for capacities (in GW) against the capacity utilization (the number of hours that the capacities are called in a year). It is formed by taking the hourly demand for capacities (GW) and sorting this demand by decreasing order. The resulting curve shows synthetically the peak load, the base load and the possible discrepancies between the amount of peaking plants needed and the number of hours those are used.

23- The variable cost is the part of the power generation costs that is proportional to the production: mainly fuel costs, carbon taxes and any operation and maintenance costs that are proportional to the production.

I. Overview

In 1990, electricity represented 36% (83 Mtoe) of the primary energy mix but only 18% (26Mtoe) of the final energy due to the high share of nuclear in the mix. In 2010, 550TWh were produced. It represented 43% (115Mtoe) of the primary energy mix and 24% of the final energy. 67% of the primary electricity is lost in the transformation process.

In 2010, the renewable electricity share was about 15%, with a high share of hydropower. The electricity export import balance was positive in 2010 but the imports achieved a historical maximum about 19.5 TWh. 50 TWh were exported.

The CO₂ emissions of electricity production decreased about 19.7% in comparison to 1990. In 1990, 39 MtCO₂ (10% of the overall CO₂ emissions) were emitted by the electricity sector compared to 31 MtCO₂ (9%) in 2010.

68% of the final electricity production is consumed by the residential and tertiary sector, 25% by the industry and 3% by the transport sector. In comparison with the other European countries, electricity costs 25% less so average per capita consumption is 21% higher than the European average and even 49% higher considering only residential consumption. The French specificity of electricity demand is electricity heating (Joule effect) in one third of the buildings. This creates a high climate sensitivity of the power sector particularly during peak load hours in winter. Every cold wave enhances

the blackout risk as each degree less causes an additional consumption need of 2.3 GW. Another controversial question is the future evolution of the demand, for instance what will be the impact of new end-uses (electric vehicles, electronics...) on the total final energy consumption?

Climate and energy objectives:

The objective fixed in the French law²⁰ in 2005 to reach 21% of renewable energies in the electricity mix in 2010 was not achieved. The objective of reducing the energy intensity of 2% per year was not achieved either. The target²¹ for 2020 is a share of 27% of renewables in the final electricity production mix.★

II. Representation of the electricity sector in Imacim-R

The electric module of IMACLIM-R is designed in order to represent the specificities of the French power sector. It calculates the evolution of the demand load shape to take into account peak load capacity needs, the evolution of the hourly electricity price and the dynamics of investments in new power plants.

The demand side: The demand from each sector in Imacim is aggregated in a total hourly demand. The specificities of seasonal demand for electric heating, is integrated by deforming the shape of the hourly demand. For each year, the hourly demand is rearranged in a load duration curve²² (LDC) that classifies by decreasing order the level of capacity required. The load duration curve allows segmentation of the demand in three demand typologies: the "base demand" corresponding to the level of capacity required during more than 5000 hours a year, the "semi base demand" situated between 500 and 5000 hours and "the peak demand" corresponding to a needed utilization of capacities below 500 hours.

The supply side: The investment dynamics in the power sector are represented via profit-seeking investors who invest on the liberalized market. Electricity producing technologies are therefore competing on the spot electricity market. Different technologies have different total production cost curves (composed by investment, maintenance and fuel costs). Some technologies like nuclear or hydropower have high investment cost and low fuel cost. These technologies are usually more suited to satisfy base load demand. Other technologies have

low investment costs but high fuel costs (oil power plants). These technologies having a high variable cost²³ are used less than the base load production technologies and respond to peak load demand.

Balancing supply and demand: To satisfy a given demand, the least expensive capacities (in terms of variable costs) run first, more and more expensive technologies are added with increasing demand. The spot price is equal to the variable cost of the marginal plant, which is the last capacity to be called in service.

The profitability for each technology is determined by the difference between the income from electricity sales on the spot market and investment and operating costs. The (inframarginal) rent for a technology on the spot market is determined by the difference between the spot price and the variable production costs.

Investment dynamics: In this scenario, only projects with an expected return rate on investment superior to 8% are implemented, with preference to short return periods in case of multiple profitable investments possible. Technologies that are competing on the spot market are coal and gas with or without CCS, oil and nuclear (EPR technology).

Renewable energy technologies (hydropower, wind on-shore, wind off-shore, decentralized photovoltaic, solar plants, geothermal) do not compete in the merit order of the electricity spot market (since their production is non-dispatchable, which means "unavoidable"). In the scenario, most renewable electricity is absorbed and used; very little curtailment happens. The construction of renewable energy capacities is induced by feed-in tariffs high enough to ensure the profitability of the technology. The level of the feed-in tariffs decreases over time until these technologies become competitive. Feed-in tariffs are paid by all consumers through a contribution integrated in the electricity price (named Contribution to the Electricity Public Service - CSPE in France). The construction of renewables with variable production²⁴ triggers additional grid investments, thus increasing the electricity price for 1€/MWh in reference and 3€/MWh in the mitigation scenario²⁵.

Demand side management measures lead to a decrease in aggregated power demand but may also lead to a smoothing of the shape of the LDC. This also contributes to a lower marginal electricity spot price. ✪

III. Policy measures in the electricity sector

Progressive tariff: This measure aims at reducing electricity consumption by increasing the prices above a fixed base consumption. In the scenario the progressive tariff is applied on all household electricity consumption. For all households, any consumption above 60 kWh/m² is paid at an augmented tariff. The prices per additional kWh increase of 5% after 2014 in case the consumption exceeds this limit and of 10% after 2030.

Feed-in tariffs: Feed-in tariffs for renewable energies are economic incentives to facilitate the market penetration of these technologies to accelerate the learning effect. Feed-in tariffs are normally decreasing over time and end when the technologies achieve price competitiveness with other technologies.

Contribution to the Electricity Public Service²⁶: This tax is calibrated at base year. The increase in the value corresponds to the increase of the payment of feed-in tariff to renewable producers.

Carbon tax: A carbon tax gives a price signal to reduce highly carbonized energy consumptions and to shift the energy production system to low carbon technologies. The carbon tax used in the project scenario is equal to 32€/tCO₂ in 2012, increasing gradually to 56€/tCO₂ in 2020, to 100€/tCO₂ in 2030, to 200€/tCO₂ in 2040 and to 300€/tCO₂ in 2050. In this scenario, the carbon tax income is given back to households through lump-sum transfers.

Demand side management: Peak demand can be managed either with peak capacities (including oil-fuelled turbines, peak hydropower or pumped-storage plants) or with interruptible contracts remaining at the same level as today. In addition, when the electric consumption due to electric heating decreases, peak demand decreases and conversely.

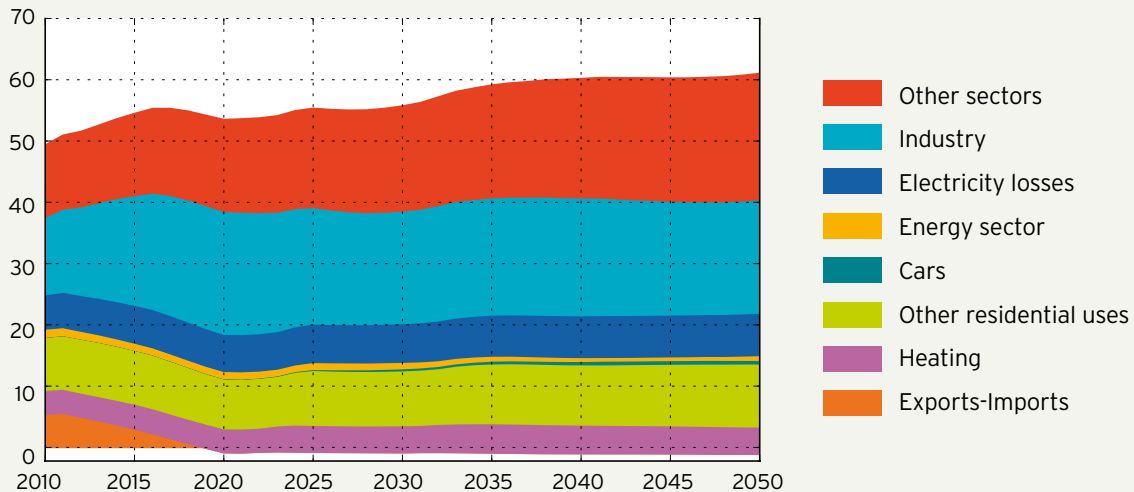
Interdiction of electric heating (Joule effect): Electric heating is not banned. However, the implementation of the thermal regulation up from 2012 de facto excludes electric heating (exception heat pumps) from the technology choices for new buildings. As the maximum energy consumption is defined in primary energy per m² per year and the conversion factor is about 2.58 (between primary and final electricity), electricity exceeds the limit.

24- Also known as « intermittent » renewables.

25- Cf. the following publications for costs evaluation:
- Deutsche Energie Agentur (2005): *Integration into the national grid of onshore and offshore wind energy generated in Germany by the year 2020*.
- Richard Green (2009): *Climate-Change Mitigation from Renewable Energy: Its Contribution and Cost*.
- House of Lords Select Committee on the European Communities, 12th Report, Session 1998-99.
- House of Lords, Economic Affairs Committee, 2008: *The Economics of Renewable Energy*, Session 2007-08, Economic Affairs Committee Publications.

26- This tax supports feed-in tariffs, electricity supply in isolated territories and social tariffs.

31 - Electricity demand disaggregation (Mtoe)



Lifetime extension of nuclear plants: The oldest existing nuclear plants (23GW) are decommissioned when their lifetime reaches 40 years. This decommissioning is smoothed in time in order to spread the construction of new capacity that is needed for the replacement over a wider time period. Lifetime of the remaining 40 GW of existing nuclear plants is extended to 60 years for an additional investment cost of 0.7bn€/GW. In 2050, still 10GW of the today existing plants are operating

Technologies acceptance: All technologies for electricity production are considered as acceptable, save shale gas.★

IV. Evolution of energy consumption in the electricity sector

The total electricity production increases over the scenario period from 50 Mtoe to 60 Mtoe in 2050. This increase of 20% is relatively low compared to the threefold increase in the same amount of time between 1973 and 2010. The main sectors responsible for the increase are the industrial and tertiary consumption mainly because gas is substituted by electricity.

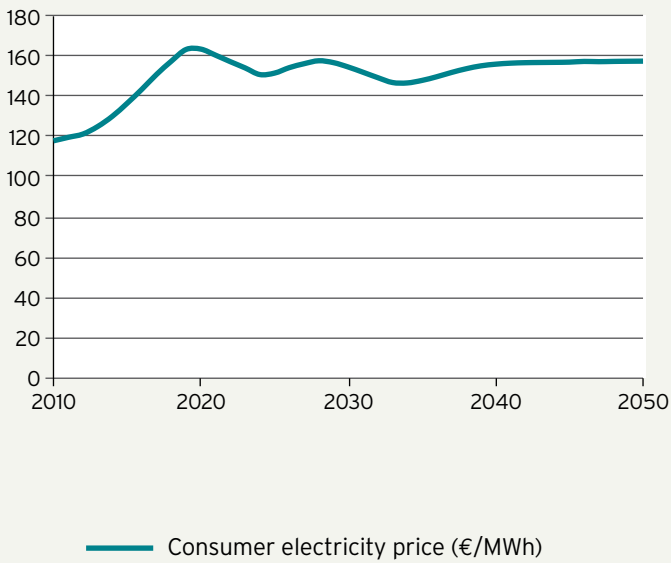
The stakeholders disapproved of the construction of new power plants for exports so the electricity exports in this scenario are rapidly declining.

France is no longer a net exporter of electricity after 2020; some imports (for less than 1 Mtoe or 12 TWh) remain throughout the period. The electricity imports (the part of the graph under zero) are used to satisfy the peaking heating demands in winter. The retrofitting of the residential sector that is increasing energy efficiency for heating and the switch from electric heaters to heat pumps reduces the electricity peak in winter. But approaching 2050 the peak increases due to a replacement from gas heating by heat pumps reaching a maximum of 103 GW.

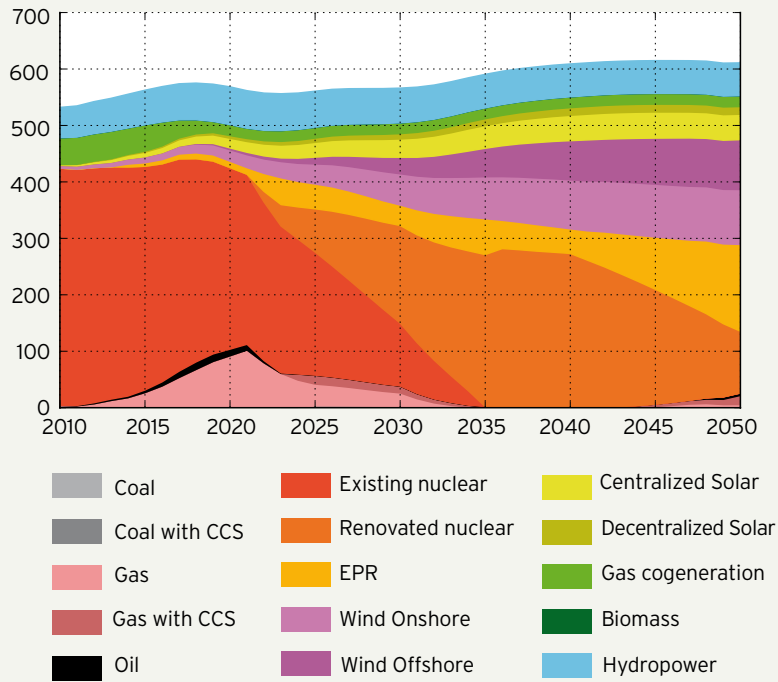
The partial fuel switch from gas to electricity in the industry sector takes place before 2020. On the contrary, the consumption of the services steadily increases at a rate exceeding 2% before 2025 and around 1% afterwards. The electricity consumption of energy producing industries (for example oil refineries) decreases slowly. Electricity transport losses are following proportionally the increasing electricity consumption.

In the residential sector, the electricity use for heating is slightly increasing as gas for heating is replaced by heat pumps. Residential uses other than primary heating decrease before 2020 (from 9 to 8 Mtoe) and increase until 10 Mtoe after 2020. Due to more and more new electricity devices (especially multi-media), the consumption especially for these energy services increases over the scenario period. Traditional domestic electricity services

32 - Consumer electricity price



33 - Electricity production mix (TWh)



like lighting, washing, cooking etc. decrease with increasing energy efficiency.

Before 2030, the consumption of electric vehicles does not appear on the graph since does not represent with 0.4 Mtoe an important share of the overall consumption. It increases until 2040 and stabilizes at 0.6 Mtoe. In this scenario, the charging occurs evenly during 24 hours a day since the electric vehicles fleet corresponds to car sharing systems. Thus, the supplementary demand due to charging adds to base load, and does not worsens peak imbalances thanks to the diversity and the dispersal of the demand.

Prices

The electricity prices for households show a sharp increase between 2010 and 2020, climaxing at 41% in 2020 compared to 2010. The price stabilizes thereafter around 160€/MWh (16c€/kWh). It represents an increase of 34% compared to the price in 2011. The peak in prices around 2020 is due to the combination of (i) the penetration of gas combined cycle replacing some of the nuclear capacities (ii) the acceleration in the installation of renewable capacities and (iii) the oil-fuelled turbine to face the variability of renewables. The stable long-term increase is due to renewables being more expensive than the old nuclear thermal power generation units and the need for new capacity building during the period.★

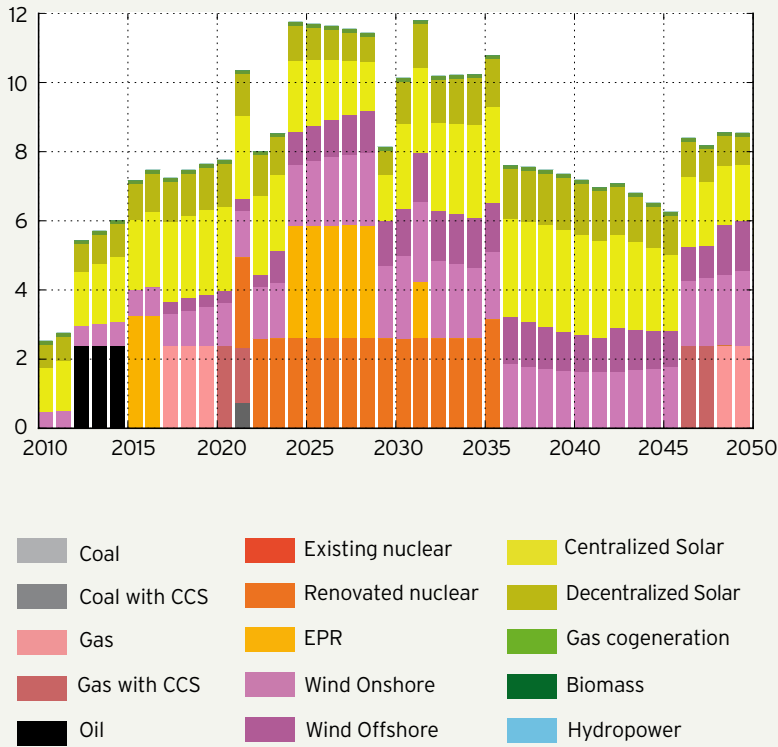
V. Investment and policy costs in the electricity sector

Investments

The investments in generation capacities throughout the period are mostly directed at building renewable capacities. The share of renewables in the electricity mix is 20% in 2020 and 50% in 2050. In addition, 43 GW of nuclear plants are extended during 20 years for 700 million euros per GW. Renewables and nuclear plants extension constitutes the bulk of the investment until 2050. In addition, 9 nuclear plants (European Pressurized Reactor) are built to compensate part of the decommissioning occurring between 2020 and 2030 for 2,9 bn €/GW, each of them with a capacity of 1630 MW. The investment amount steadily rises from 8 billion € in 2010 to almost 17 billion € in 2026 to finance the transition. After that, it steadily decreases to 6 billion € in 2050.

Average annual expenditures for electricity generation (Billion €)				
Period	2011-2020	2021-2030	2031-2040	2041-2050
Investment	12	15	9	6
Fuel costs	1	1.4	0.1	0.6
Carbon costs	8.7	10.9	2.8	3.5

34 - Investment in new capacities (GW)

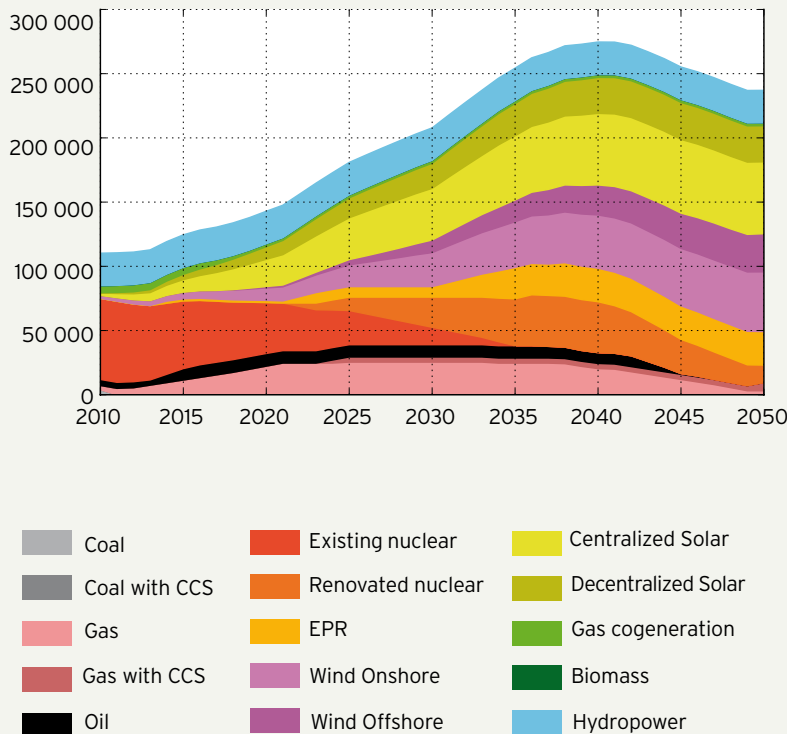


The period between today and 2025 is the most critical one. Indeed, the beginning of nuclear plants' decommissioning, in addition to the growing share of variable renewables and the uncertainties surrounding the electricity supply market induce the construction of power plants fuelled by fossil energies. Between 2010 and 2020 more than 10 GW of oil-powered gas turbines and gas-fuelled combined cycles plants are built, which explains the emissions peak with an increase of 49% in the electricity sector. This reinforces the emergency in implementing energy efficiency and demand-side management to avoid building these carbon-intensive power plants. However, this transition from a nuclear-dominated mix to a mix relying also on renewables is short-lived, with emissions receding after 2030²⁷. The fast decommissioning of the extended nuclear plants after 2040 creates some tensions in the electricity supply, leading to a return of some emissions in the electric sector, because of gas (mainly gas with CCS).

Policies costs

In the model, fiscal policies for the electric sector are reduced to the contribution towards financing feed-in tariffs and the carbon tax. The feed-in tariffs are neutral in the balance of the government since they are fully paid by the final consumers. Most demand-side management measures are paid for either by consumers or the electricity supplier. ✪

35 - Available capacities (MW)



Fiscal measures (Billion €)					
Feed-in tariffs	2010	2020	2030	2040	2050
Additional CSPE Income = feed-in tariffs expense	2.9	1.9	7.2	17.8	12.7
Carbon Tax	0	13.7	18.1	23.9	34.8

²⁷ Nuclear energy and renewable energies have no emissions in the scenario because their up- and downstream emissions are allocated in other sectors. For example the construction of the building for a nuclear power plant is captured by the building sector. Only the combustion emissions of the electricity sector are shown in the graph 47 that means only the emissions of fossil fuel based electricity production.

Macroeconomic impacts & scenario results

I. Global context and world visions

The scenario's global context sets up the framework for the study. This global vision answers the following questions. What outcome for international climate negotiations? How abruptly will the Peak-Oil shock western economies? What orientation for technical change? What consumption styles will prevail? For developed economies? For emerging economies?

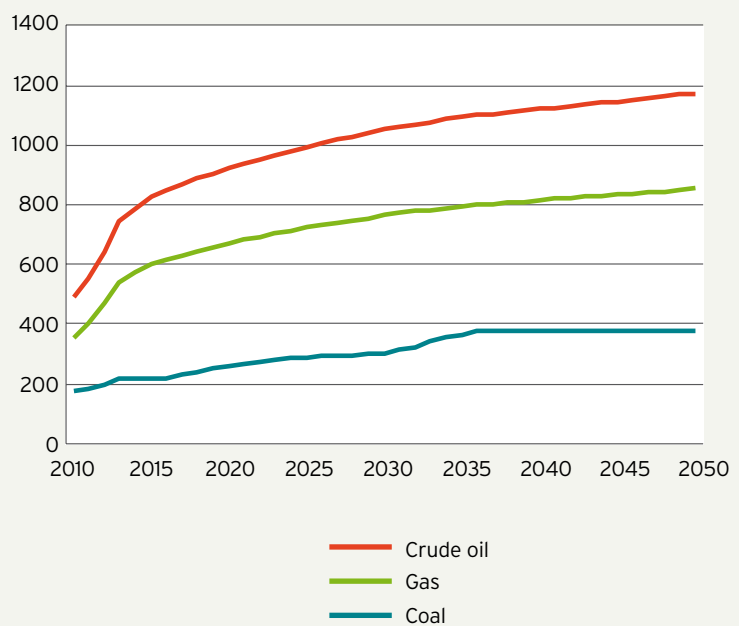
Consumption styles in Europe and in France are considered to remain material-intensive. We have not considered in this scenario any change in consumption styles or consumers' preferences. A decoupling of growth and resources use will be further investigated in section 4. In the scenario presented here, no global climate agreement is reached; climate policies coordination only exists at the EU level. This situation leads to a world with a high energy demand, and to high fossil energy prices. Energy prices follow the "World energy outlook" 2011, as required by the stakeholders (graph 36). Crude oil prices reach 160€/barrel in 2050. Because of this high fossil energy prices, technological innovation focuses on renewable and energy efficiency, as well as on carbon capture and sequestration.*

II. Macroeconomic dynamics of the mitigation scenario

1. Economic growth rate

The growth engine in Imaclim conventionally consists of exogenous demographic trends and labor productivity changes, and is fuelled by regional net investment rates and investments allocation among sectors. Endogenous disequilibria are

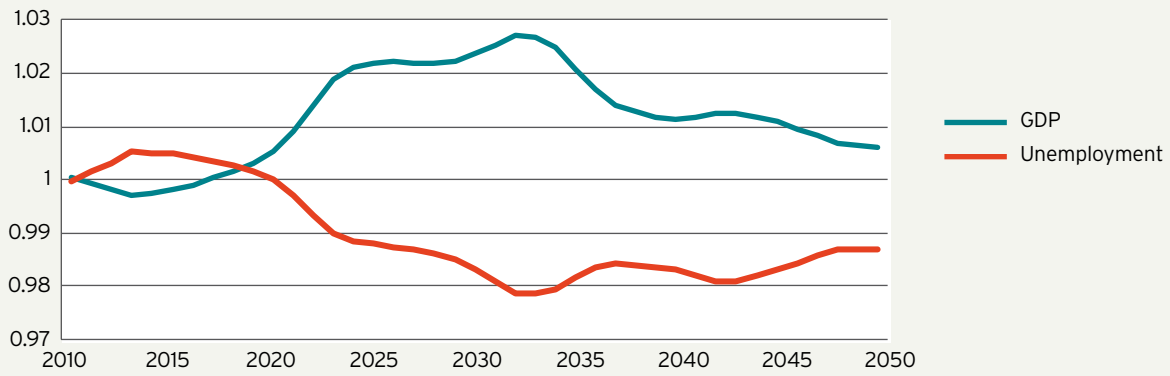
36 - World fossil energy prices (€/toe)



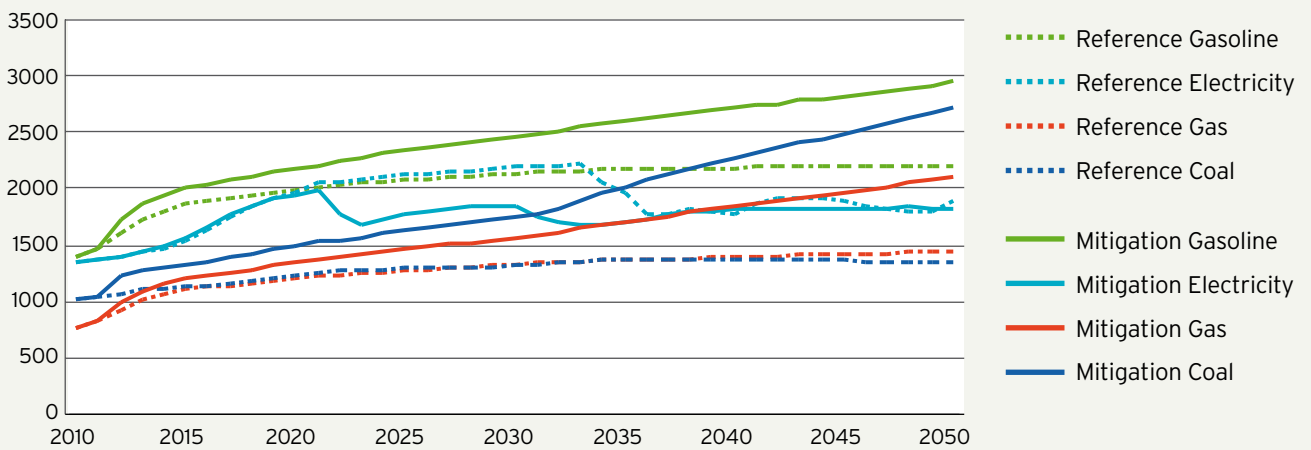
possible so as to capture transition costs after a policy decision or an exogenous shock. Investment decisions are driven by profit maximization under imperfect expectations in non-fully competitive markets.

The population follows the 2010 INSEE central demographic scenario and equals 72.3 million in 2050, i.e. a 15% increase compared to 2010. In the reference scenario (also called Business As Usual scenario, i.e. without climate policies), the average annual economic growth rate is about 1.24% between 2010 and 2050. The overall economic impact of the mitigation measures is positive, except in the short-term, with a negative impact until 2017 due to the introduction of the carbon tax in 2012. Thereafter, GDP is higher and unemployment is lower than in the reference scenario.

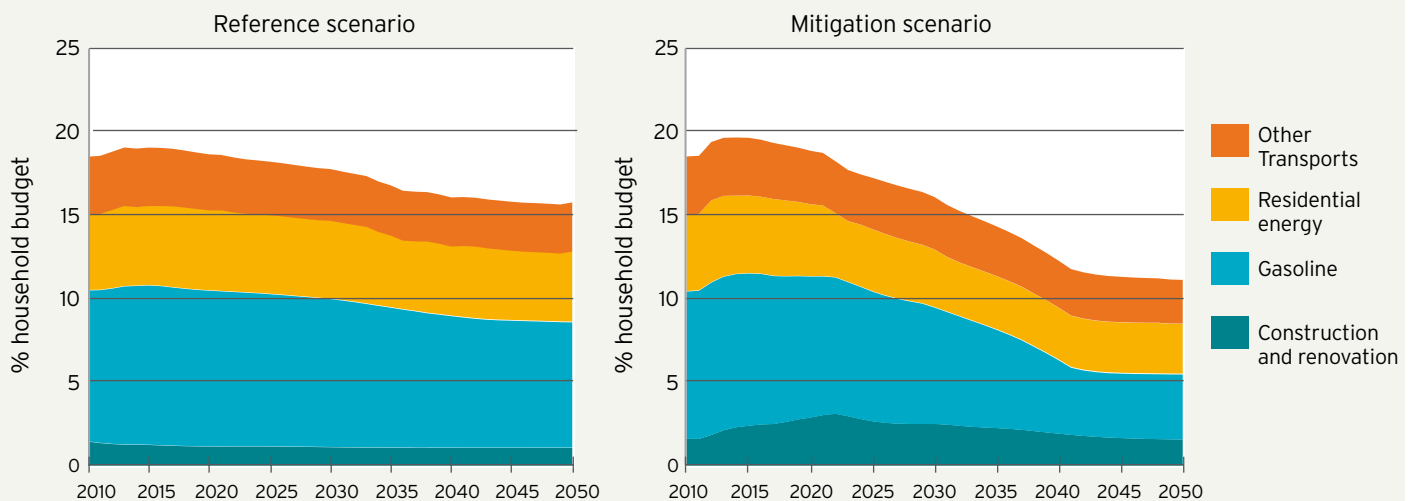
37 - Macroeconomic trends in Mitigation scenario / Reference (base 1 in 2010)



38 - Consumer energy prices €/toe



39 - Household expenditures



Annual average GDP growth rate

	2010-2020	2020-2030	2030-2050	2010-2050
Reference	1.19	1.29	1.2	1.22
Mitigation	1.24	1.47	1.11	1.24

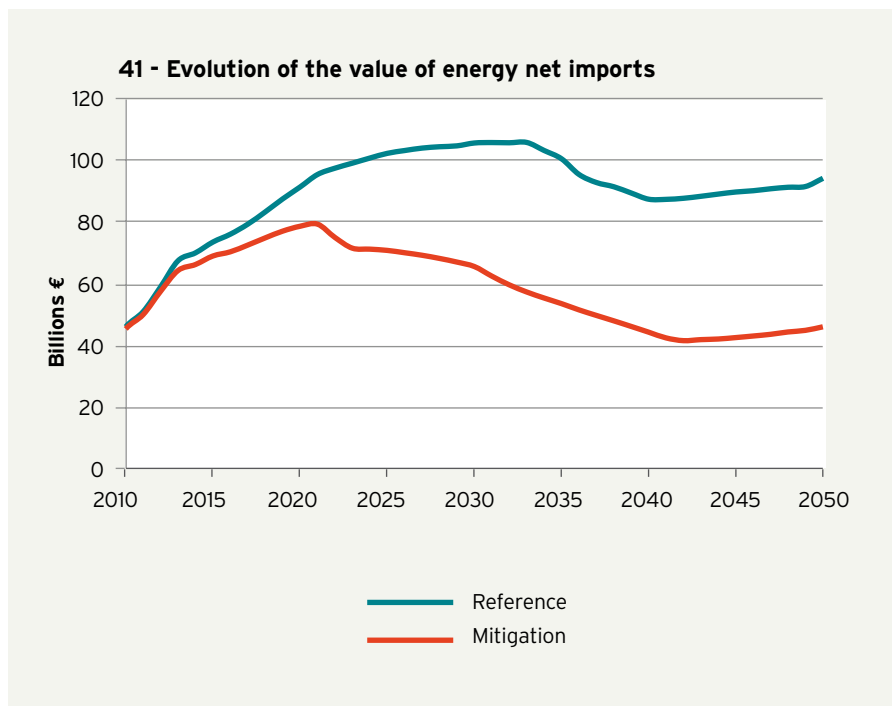
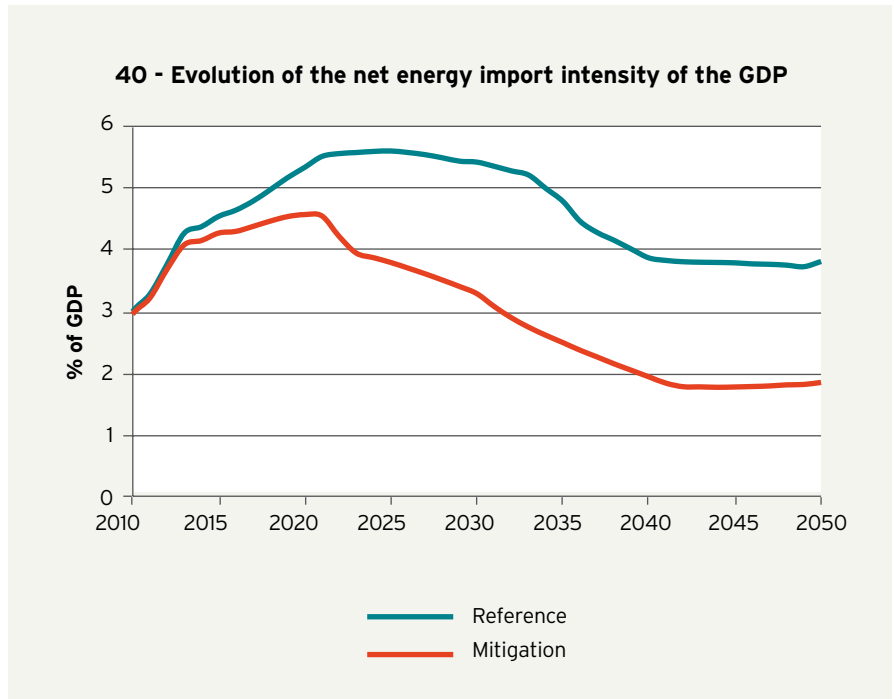
The impact is particularly positive from 2025 to 2035. At this date, the electricity price in the mitigation scenario is around 25% lower than in the reference scenario. Moreover, fossil energy prices get much more expensive than in the reference scenario because of the carbon tax. The combination of both factors induces a substantial energy switch towards electricity for productive sector and households. In addition, energy efficiency measures induce a decrease of the energy expenditures:

- *In the household budgets (which is not compensated by the increase in construction and additional renovation costs).
- *For services industries that are not energy-intensive, which furthermore reinforces the international competition of French goods.

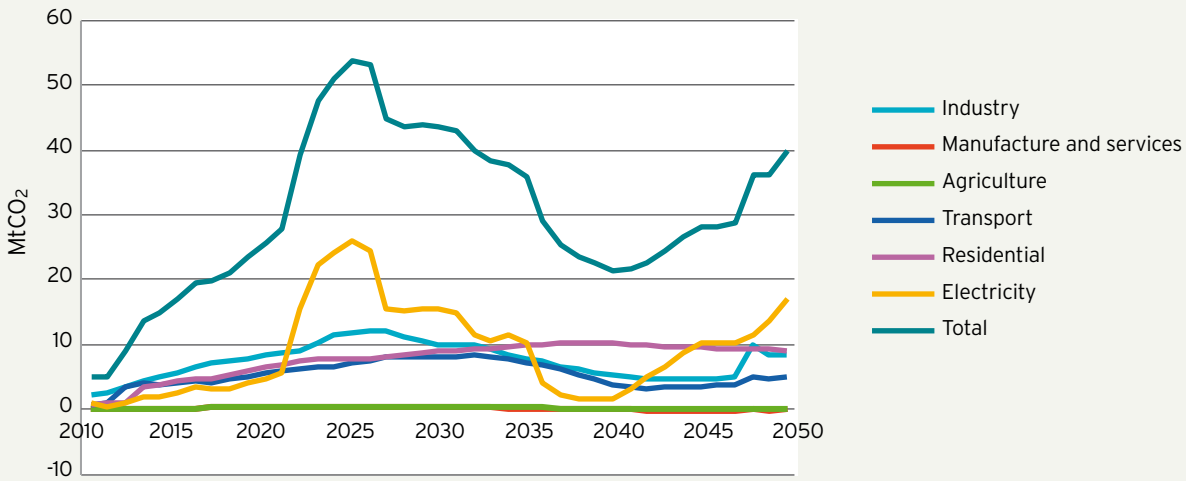
2. Energy efficiency, imports dependency and the energy bill

The development of non-fossil energies in conjunction with energy efficiency measures constitutes a protection against the negative impacts of the increase in energy prices and of the French import dependency. In the reference scenario, the energy import values represent more than 5% of GDP between 2019 and 2035. In the mitigation scenario, the energy import intensity of the GDP peaks in 2020 at 4.7% and gradually declines to a stable level 1.7% after 2040.

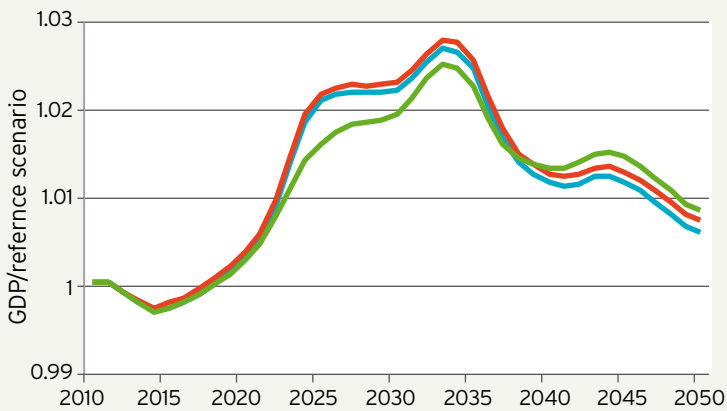
An often-overlooked fact is the dependency to uranium imports for the French energy mix. Even if the impact on the energy bill is negligible, the uranium consumption for nuclear power plants creates a dependency and increase energy vulnerability for France.*



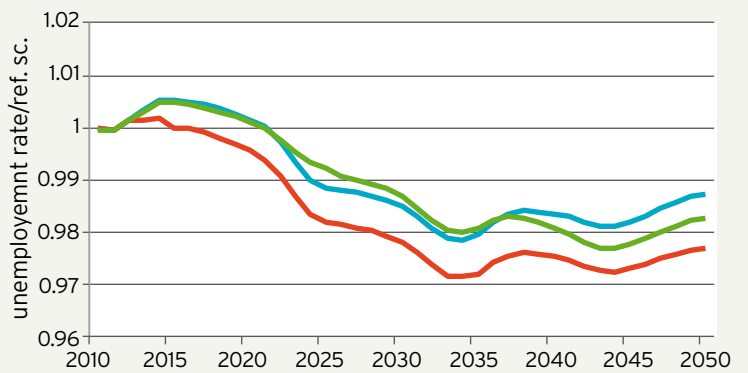
42 - CO₂ Emission reductions induced by the carbon tax



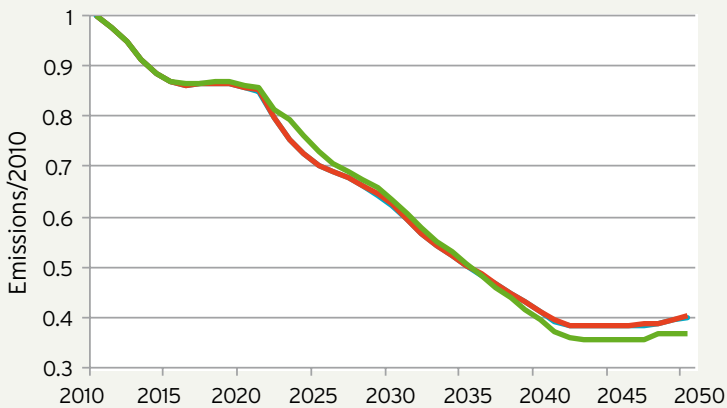
43 - GDP according to carbon tax recycling options



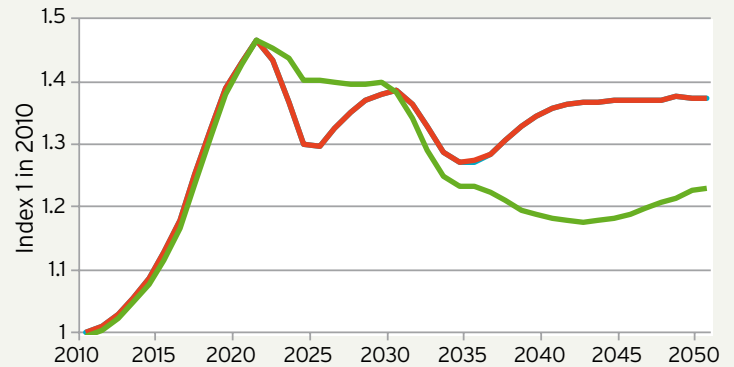
44 - Unemployment rate according to carbon tax recycling options



45 - Emissions according to carbon tax recycling options



46 - Consumer electricity price according to carbon tax recycling options



- Transfer to households
- Payroll taxes
- Renewables and energy efficiency

III. Carbon tax: a necessary measure?

1. The marginal impact on emissions reductions

One of the most emblematic measures of the scenario is the carbon tax. In order to disentangle its leverage power on emissions reductions, the marginal impact of the carbon tax on sectoral emissions reduction has been calculated. Thus, graph 42 illustrates the emissions reduction when the tax is implemented. As such, these emissions reductions are conditional to other policy measures implemented in the acceptable mitigation scenario. The emissions reductions would be much higher if the only policy measure were the tax.

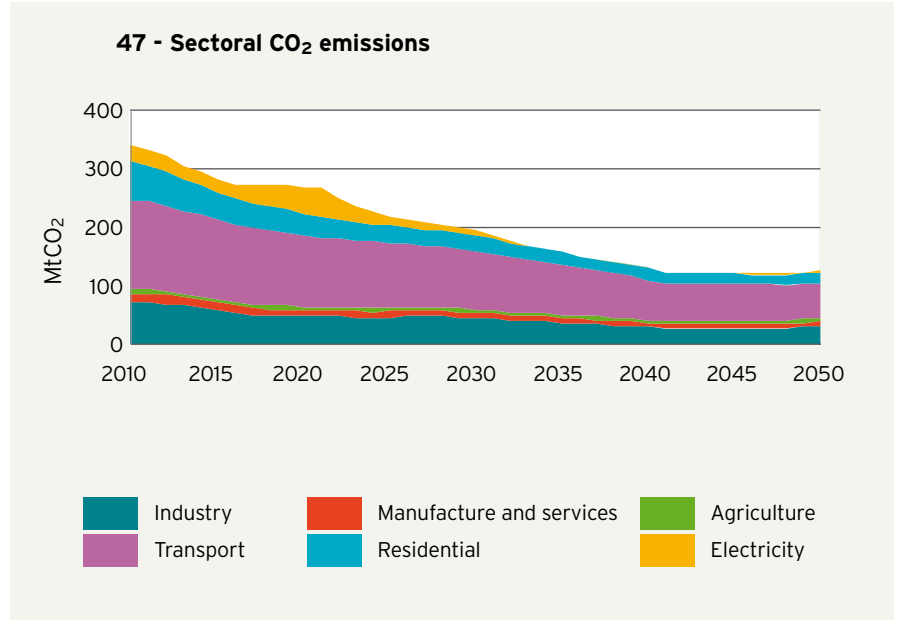
The carbon tax is very efficient in decarbonizing the power sector particularly during the transition phase between 2020 and 2030 and at the end of the period when a large amount of nuclear plants are decommissioned. The carbon tax is also decisive in the renovation decisions in the residential sector during the whole period. Finally, the industrial emissions are much higher in the short term without a carbon tax serving as a signal for investments.

2. Carbon tax recycling options

The carbon tax is exogenously set in the scenario and follows the recommendations of the "Quinet" governmental report²⁸ until 2030 (32€/tCO₂ in 2012, 56€/tCO₂ in 2020, 100€/tCO₂ in 2030) and then extrapolated until 2050 (200€/tCO₂ in 2040 and 300€/tCO₂ in 2050). The carbon tax pathway is anticipated in the power sector but in other sectors and households form myopic expectations, based on the yearly tax.

The recycling of the tax was a lump sum transfer to households by default in the description of the mitigation scenario in the previous sections. Two other options were investigated to take into consideration stakeholder contributions: i) recycling towards subsidies for renewable energy development and energy efficiency improvements, and ii) a recycling towards lowering salary taxes.

In graphs 43 to 46, the economic impacts of the three variants are given. In the long term, the recy-



cling towards subsidies for renewable development and energy efficiency improvements have the most positive impact on the GDP development. In addition, these variant leads to the most ambitious emissions reduction. On the other hand, the variant with a recycling towards lower payroll taxes has the most positive influence on the employment situation. The consumer electricity price varies widely depending on the chosen recycling option after 2035: the lowest price appears in the variant with a recycling towards subsidies for renewable development and energy efficiency and leads to an improved economic growth compared to other options.*

²⁸- Alain Quinet (2009) : "La valeur tutélaire du carbone", Centre d'analyse stratégique.

IV. CO₂ emissions reductions of the mitigation scenario

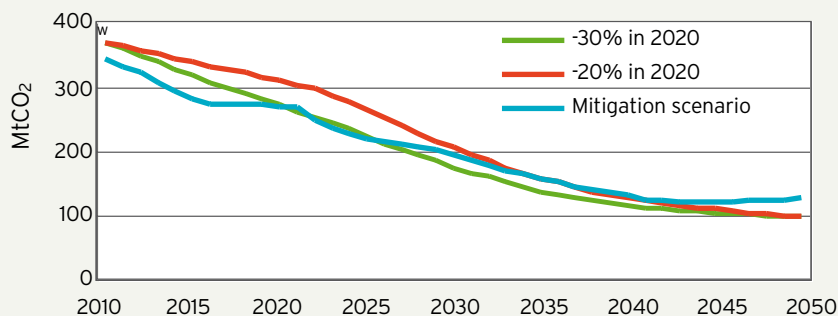
At the end of the period, the integration of all measures considered acceptable by stakeholders lead to CO₂-related energy emissions equal to 126 Mt CO₂. The following graph describes the sectoral contributions leading to this 60% decrease in emissions compared to 2010 and -68% compared to 1990.

The decarbonization of the electricity sector is difficult between 2015 and 2025 with the first wave of nuclear plants decommissioning. During this transition period, gas plants are built which

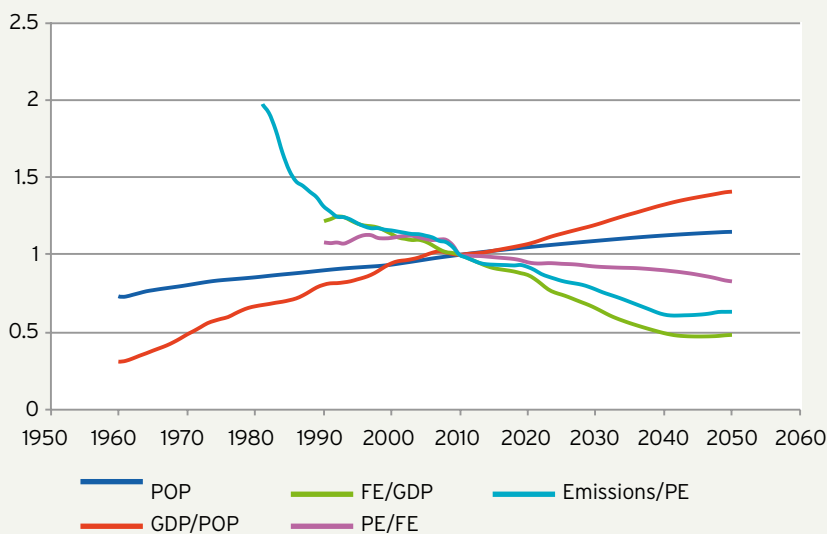
CO₂ sectoral emissions compared to 2010 (mitigation scenario)

	2020	2030	2040	2050
Industry	-33%	-37%	-59%	-57%
Manufacture and services	-36%	-39%	-49%	-49%
Agriculture	-24%	-30%	-42%	-40%
Transport	-19%	-35%	-55%	-60%
Residential	-44%	-62%	-72%	-75%
Electricity	49%	-68%	-100%	-86%
Total	-15%	-39%	-59%	-60%
Total (compared to 1990)	-31%	-50%	-67%	-68%

48 - Comparison of the mitigation scenario emission trajectory to Factor Four trajectories



49 - Evolution of the CO₂ emissions drivers (index 1 in 2010)



induces new emissions for the electricity sector. To limit these “transition emissions”, priority has to be given to very ambitious energy efficiency measures to decrease electricity demand during this transition period and to the development of renewable energies on the short term. The main difficulty for decarbonization is the transport sector, where emissions still represent 60 MtCO₂, i.e. half of 2050 total CO₂ emissions.

The CO₂ emissions gap in 2050 between reaching a Factor Four and this mitigation scenario represents 28 MtCO₂. This still represents 25% of remaining emissions in the mitigation scenario at the end of the period. Until 2042, the CO₂ emissions trajectory of the mitigation scenario is consistent with a Factor Four trajectory. The trajectory even achieves a 31% CO₂ reduction in 2020 (compared to 1990). However, emissions reductions decelerate at the end of the period and the emissions level plateaus at 126 MtCO₂. ★

V. Drivers of CO₂ emissions reductions

The “Kaya identity” breaks down the emissions evolution into several drivers as follows:

$$CO_2 = POP \times \frac{GDP}{POP} \times \frac{FE}{GDP} \times \frac{PE}{FE} \times \frac{CO_2}{PE}$$

It states that total emissions levels can be expressed as the product of five inputs: population (POP), per capita income ($\frac{GDP}{POP}$), final energy intensity of GDP ($\frac{FE}{GDP}$), efficiency of the transformation of primary energy into final energy ($\frac{PE}{FE}$) which refers to the efficiency of the French energy system, carbon content of primary energy ($\frac{CO_2}{PE}$).

In the graph, the evolution of each of these drivers is given between 2010 and 2050. It shows that during the period:

- * population increases by 15%,
- * the per capita income increases by 41%,
- * the final energy intensity of the GDP decreases by 51%,
- * the primary energy needed per unit of final energy consumption reduces by 18%
- * the CO₂ content of the primary energy reduces by 38%.

Globally, energy efficiency and structural changes represents two thirds of the emissions reductions and the penetration of decarbonized energy represents one third of the emissions reductions.

Against historic trends, population keeps increasing, albeit with a decreasing growth rate (from more than 1.5% per year in the 1960 until a predicted 0.2% in 2050). The GDP per capita growth was at a very high level (more than 4%) until the end of the 1970s, remained just below 2% until the 2000 and remains on average just below 1% over the simulated period. Final energy intensity of the GDP decrease, with a steadily growing speed (from -0.3% a year in the 1990s until -3% a year at the end of the 2020s), continuing the historic trend. After 2035, a shift in the simulated trend can be observed, no further reduction can be observed. The same analysis can be applied to the energy efficiency of the French energy transformation system. The carbon intensity of primary energy sharply decreases, continuing the trend set after the construction of nuclear power generation capacities in the 1990s. After 2040, the carbon intensity remains stable, thus preventing the scenario from reaching a Factor Four. The end of the period is the second wave of nuclear plants decommissioning. In the scenario, new gas plants are introduced at this time to bridge the gap between EPR and renewable production on the one hand and electricity demand on the other hand.★

Emissions reductions and emissions scope

It has to be notified that an important share of greenhouse gases emissions is not considered in the project scope. The scenario is only focusing on energy-related domestic CO₂ emissions. All agricultural emissions, except energy-related CO₂ emissions, were not taken into account, thus overlooking the issue of land-use change. Upstream and downstream emissions outside the domestic perimeter were not covered by the present study either. This last point refers to the difference between accounting emissions in terms of production on a territory or in terms of consumption (which means accounting for imports and excluding exports). Finally, international transport was not listed in the French emissions. Besides, other greenhouse gases are outside the scope of this study.

This scenario therefore focuses on only 69%²⁹ of the overall French domestic emissions (share of CO₂ within the total French production related emissions). If consumption-related emissions from

production outside the French borders are added, the scenario presented here only accounts for 44% of the French emissions.

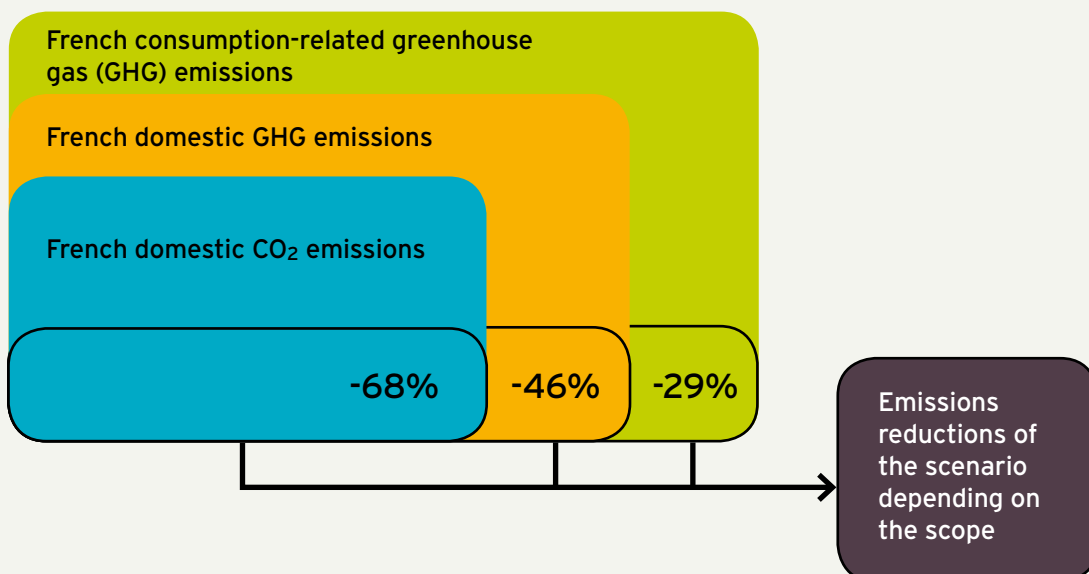
A 68% emissions reduction in 2050 represents a 46% reduction of the total French GHG emissions and of only 29% of the total consumption-related French GHG emissions³⁰. In conjunction with the uncertainties surrounding the energy transition, this prospect emphasizes the importance of at least insuring a Factor Four in France to fight climate change.

As a result, the following section first delves into uncertainties. Then, it presents additional measures and their impact on the energy consumption, emissions reduction, investment and price development. These measures were not considered to be acceptable by at least half of the stakeholders. Finally, a combination of measures reaching the Factor Four is explored.*

²⁹- CITEPA (2011) "Inventaire des émissions en France".

³⁰- Edgar G. Hertwich / Glen P. Peters (2009) "Carbon Footprint of Nations: A Global, Trade-Linked Analysis", *Environmental science & technology*, 43 (16).

Emissions reduction scope (compared to 1990)

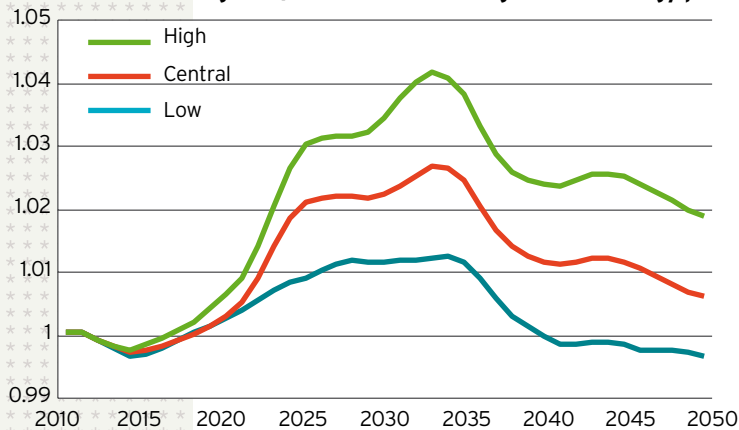


4

Reconciling stakeholders' acceptance and ambitious climate objectives

After studying the acceptability of policy measures in the previous section, we now focus on other types of determinants which could significantly impact the CO₂ emissions trajectory, namely the uncertainties around fossil energy prices, a border tax adjustment and a change of the development styles. The uncertainty surrounding these scenario variants is of a completely different nature compared to the issue of stakeholders' acceptability.

50 - GDP Mitigation/Reference according to fossil energy prices



³¹- The "industry" denomination refers to energy-intensive industry.

³²- The "tertiary" aggregates services and the manufacture that is not intensive in energy.

I. The role of fossil energy prices

In the previous section, the mitigation scenario was based on fossil energy prices from the World Energy Outlook (IEA, 2011). To show the impact of energy prices assumptions on mitigation scenarios, we investigate two other scenarios: one with fossil energy prices 30% less expensive, and one with fossil energy prices 30% more expensive.

Unsurprisingly, higher (respectively lower) energy prices lead to higher (respectively lower) emission reductions. Nevertheless, emission reductions in 2020, compared to 1990 are always higher than 25%. In the long term, only high energy prices are consistent with a Factor Four. In the low prices scenario, emissions increase in the short term,

because relative energy prices between 2010 and 2020 favor a substitution from oil, coal and electricity towards gas. In the long term, total CO₂ emissions only decrease by 57% compared to 2010.

The main sectoral impact compared to the central energy prices scenario is on the renovation of the existing buildings stock. With low energy prices, economic incentives for refurbishment are not high enough to induce a significant transition to lower energy classes.

In the scenario with lower fossil fuel prices, the decarbonization of the power sector is complete because electricity prices remain higher than gas prices during the whole period, therefore electricity demand is reduced compared to other scenarios. With a lower demand it is less challenging to decarbonize the power production.

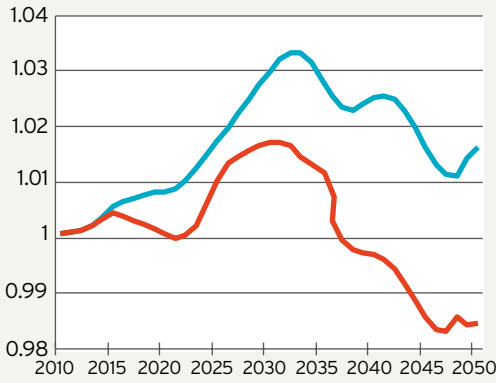
The scenario with higher energy prices has a higher decarbonization rate on the long term but for other reasons: as the overall costs are higher, the CCS technology becomes competitive and reduces the emissions of the fossil power production.

Whatever the assumptions with regards to fossil energy prices, GDP growth in mitigation scenarios is always higher than in the corresponding reference scenario. This result underlines the importance of the implementation of mitigation policies to reduce the vulnerability regarding the evolution of fossil energy prices.★

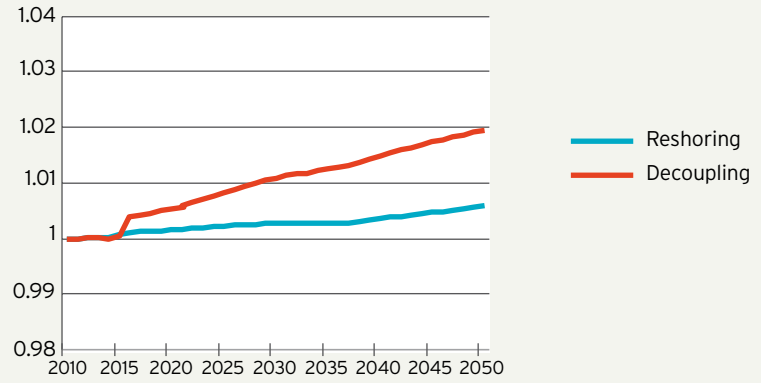
Total and sectoral emissions reduction compared to 2010 according to the fossil energy prices

	2020			2030			2040			2050		
	Low	Central	High	Low	Central	High	Low	Central	High	Low	Central	High
Industry³¹	-33%	-33%	-33%	-38%	-37%	-53%	-48%	-59%	-67%	-57%	-57%	-77%
Tertiary³²	-34%	-36%	-38%	-40%	-39%	-59%	-44%	-49%	-64%	-47%	-49%	-67%
Agriculture	-19%	-24%	-20%	-26%	-30%	-48%	-30%	-42%	-58%	-33%	-40%	-61%
Transport	-8%	-19%	-19%	-22%	-35%	-37%	-38%	-55%	-57%	-54%	-60%	-65%
Residential	-28%	-44%	-37%	-43%	-62%	-61%	-54%	-72%	-74%	-65%	-75%	-79%
Electricity	-61%	49%	-53%	-34%	-68%	-43%	-99%	-100%	-100%	-100%	-86%	-99%
Total	-18%	-15%	-24%	-26%	-39%	-43%	-45%	-59%	-64%	-57%	-60%	-71%
Total /1990	-25%	-31%	-31%	-33%	-50%	-48%	-50%	-67%	-67%	-60%	-68%	-74%

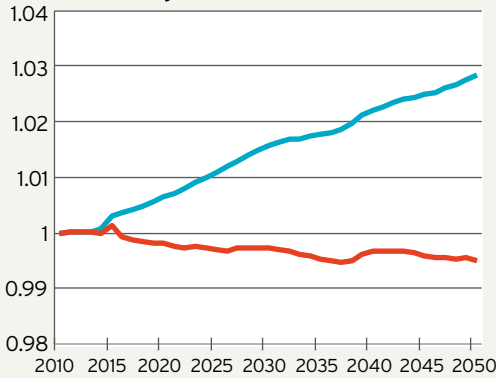
51 - CO₂ emissions (/mitigation scenario)



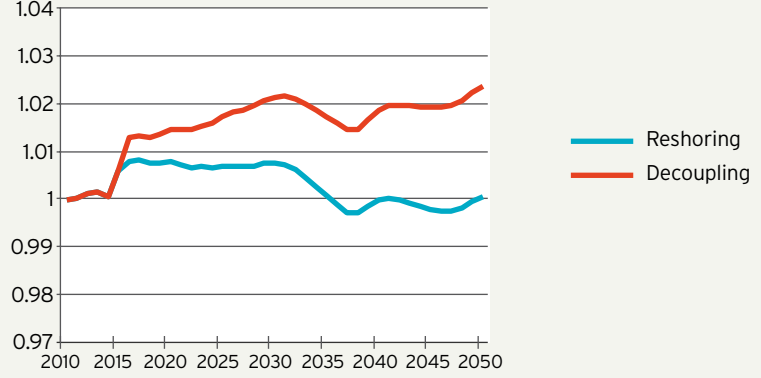
52 - GDP (/mitigation scenario)



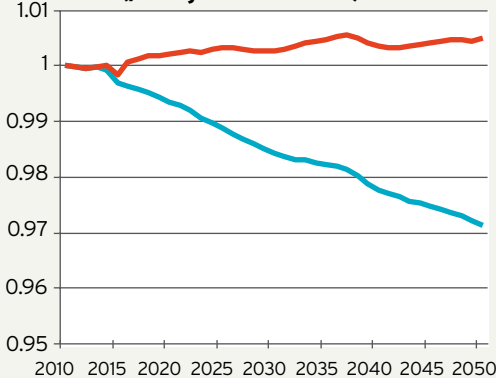
53 - Consumption price index (/mitigation scenario)



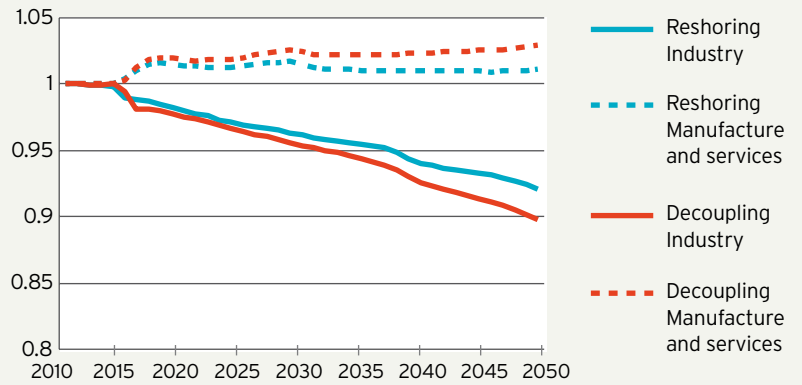
54 - Final consumption (/mitigation scenario)



55 - Competitiveness index (/mitigation scenario)



56 - Production index (/mitigation scenario)



II. The impact of the development style

Two variants refer to the evolution of values and standards:

- * The decoupling³³ of consumption styles: French households are considered to change their consumption patterns and to consume less material goods and more services.
- * The reshoring³⁴ of production capacities back to France: French consumers and producers prefer to consume French products instead of importing.

In the reshoring scenario, households agree to pay higher prices for goods if these goods are produced

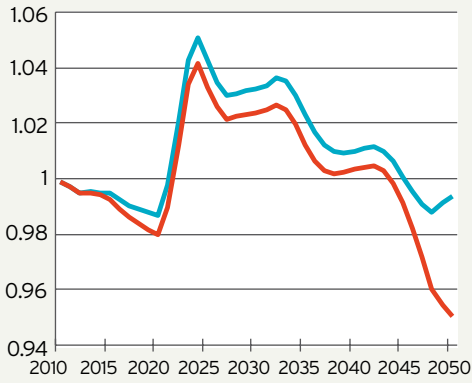
in France. Logically, this raises consumption prices (+3% in 2050). The combined effect of higher prices and reshoring on final consumption levels is almost neutral. On the one hand, industrial production decreases, and on the other hand, services and manufacture production increases. GDP is 0.6% higher in 2050, and CO₂ emissions are between 1 and 3% higher compared to the acceptable scenario in 2050. Overall competitiveness decreases, but more of the French consumption is produced in France.

In the decoupling scenario, policies and measures are implemented in a French economic context with a 30% decrease of the industrial and material content of consumption in 2050. The decrease

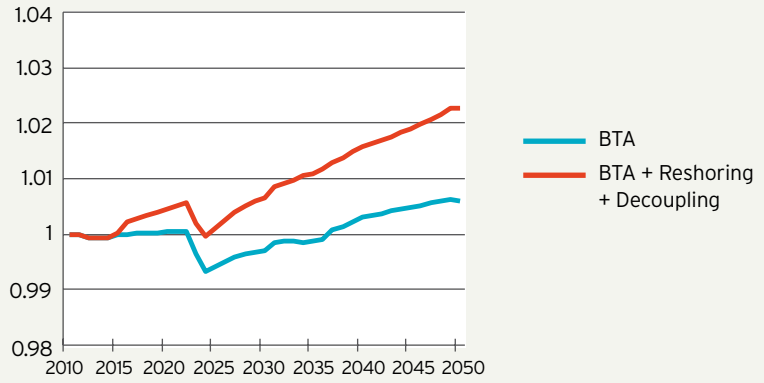
³³- The ability of an economy to grow without corresponding increases in environmental pressure, particularly in terms of the use of natural resources, is referred to as decoupling or eco-economic decoupling.

³⁴- Reshoring is defined as the relocation of activities from foreign countries back to France, as opposed to offshoring. For instance, relocation of activities from France to China is called offshoring whereas bringing back the activities in France is called reshoring.

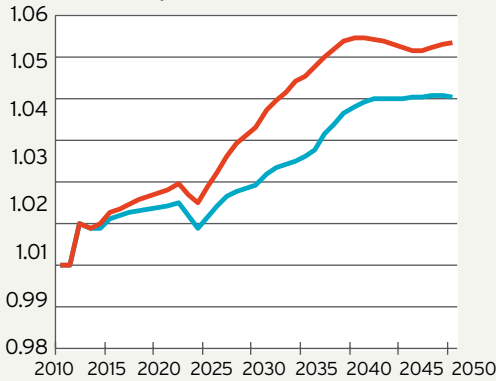
57 - CO₂ emissions (/mitigation scenario)



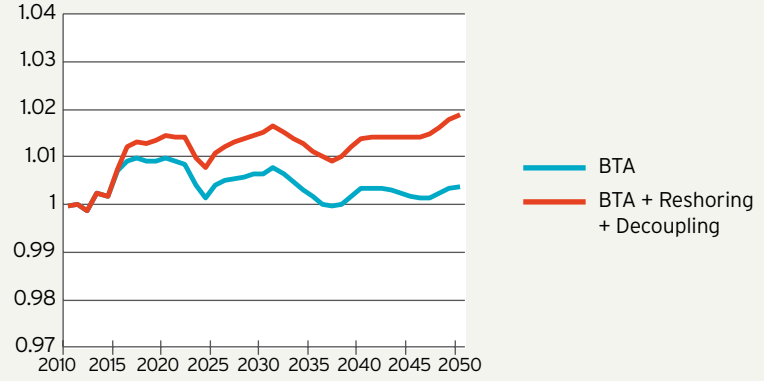
58 - GDP (/mitigation scenario)



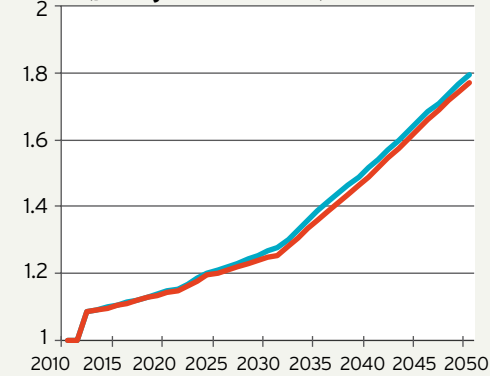
59 - Consumption Price index (/mitigation scenario)



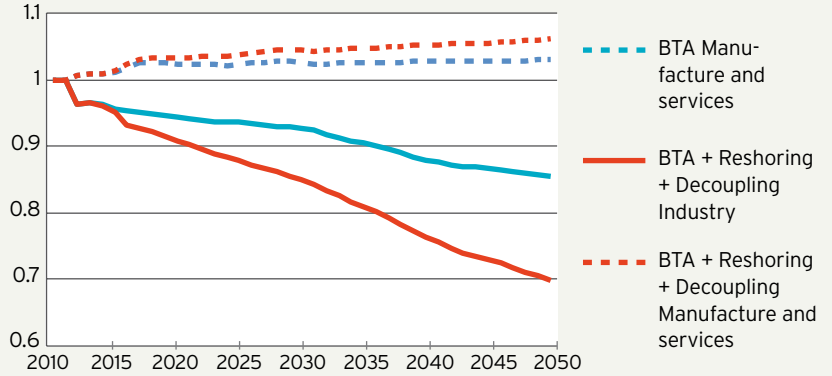
60 - Final consumption (/mitigation scenario)



61 - Competitiveness index (/mitigation scenario)



62 - Production index (/mitigation scenario)



of the material consumption is partly compensated by more consumption of services. Overall final consumption is higher by 2.5% in 2050. The consequence on the economy is a 2% GDP increase compared to the acceptable scenario in 2050, and a nearly 2% decrease in CO₂ emissions. The consumption price index slightly decreases because of the diminution of the weight of energy expenditures on the economy. For the same reason, the price competitiveness index mildly increases.

If both these variant exhibit an increased GDP, the results in terms of emissions and economic activity are different. Relocation increases CO₂ emissions as well as the consumer price index. However, the economic decoupling allows a higher level of activity without a raise in CO₂ emissions.*

III. Do we need a border tax adjustment?

A number of policies have been suggested to address concerns over competitive losses due to one country introducing a carbon tax while another country does not. In this variant, the impact of the implementation of a border tax adjustment (BTA) at the EU27 level was analyzed. The role of a BTA is to address the competitiveness losses which stems from the price distortion induced by the carbon taxation. This BTA taxes imported goods in the manufacturing sector. Highly energy-intensive industrial goods are not subject to the BTA, as we consider that European imports mainly consist of manufactured goods. The level of taxation is subject to the additional carbon content compared to EU average carbon content. This additional measure is computed alone in a first scenario, and

a second scenario gathers the BTA and previous assumptions related to decoupling and reshoring.

Logically, the direct impacts of the BTA are a reinforced international competitiveness, but also an increase of consumer prices. As the BTA is applied only for the manufactured goods (and not on industry), manufacturing increases, but the energy-intensive industry production decreases. Due to the relative weights of these sectors in the French economy, the global outcome on the longer term is a slightly increased economic growth, with a more significant emissions decrease.

If assumptions related to reshoring and decoupling are added, economic and environmental outcomes of the implementation of the BTA are significantly improved. In this variant, CO₂ emissions drop by an additional 5% in 2050, GDP and final consumption levels increase by 2%, while competitiveness increases. The only drawback would be the 5% increase of the consumer price index.★

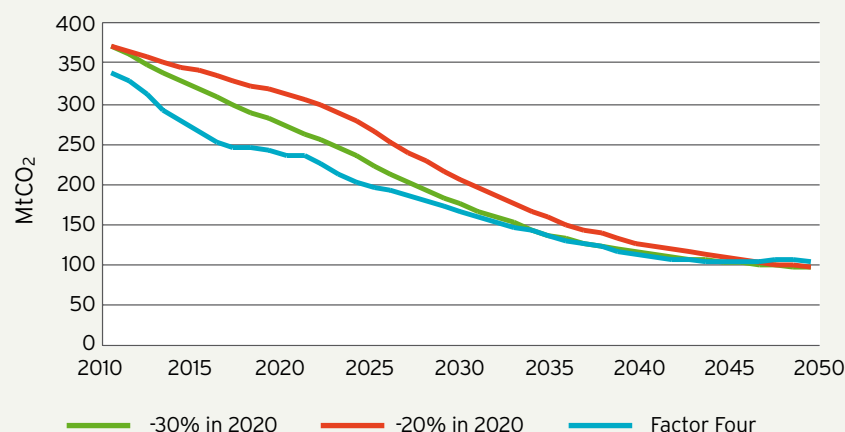
IV. How to reach the Factor Four?

Additional measures that were considered as acceptable by about 50% of stakeholders are implemented to further CO₂ emissions reductions:

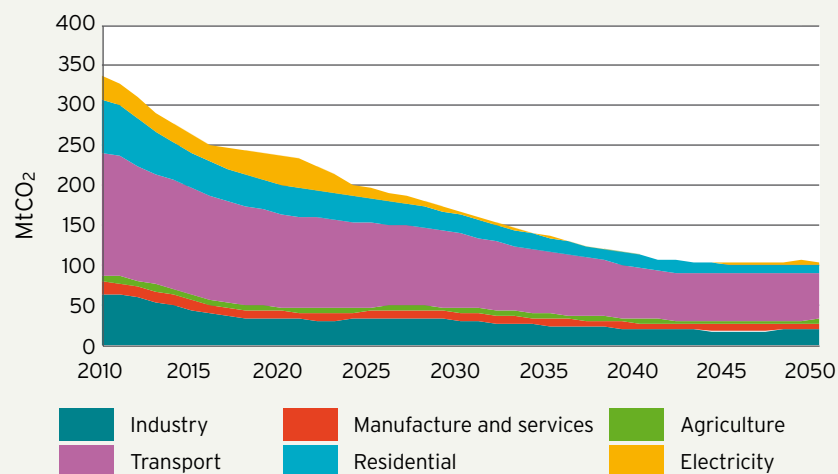
A carbon-energy tax (CET): the carbon tax is replaced by a carbon-energy tax to give a further incentive to reduce energy consumption. It taxes the energy content and the carbon content of the energy and is applied to all the forms of energy (coal, gas, oil, nuclear) except renewable energies. So electricity is also taxed. The tax rate corresponding to the carbon content is still the same as in section 3. The tax rate concerning the energy content is calibrated in 2012 in order the total income from the energy part of the CET equals the total income from the carbon content.

This CET is calibrated in order to align the energy part of the tax with the amount of the carbon part of the tax on average. The CET induces a tax level corresponding to a doubling on average of the previous carbon tax for fossil fuels. For carbon-free energy, the CET adds a tax valued as the energy part of the CET on fossil fuels. The CET aims at introducing more sufficiency in households' behaviors, particularly concerning specific electri-

63 - Comparison of the Additional Measures Scenario emission trajectory to Scenario with additional measures trajectories



64 - Sectoral CO₂ emissions in the Additional Measure Scenario



city consumption, and more energy efficiency in industry and in the tertiary sector.

A refurbishment obligation is applied to the building stock. The planning of the obligation is organized following the type of building (individual houses, collective dwellings and social houses) and the energy label of the building, beginning with the less energy-efficient classes. The refurbishment aims at reaching label B (80 kWh/m²/year). The obligation is first applied to social houses because this type of housing is best suited to implement such a measure and because of fuel poverty considerations, due to its existing centralized ownership structure. Implementation dates are given in the following table. Refurbishments are calibrated in

Sectoral emissions reductions / 2010				
	2020	2030	2040	2050
Industry	-41%	-43%	-57%	-63%
Manufacture and services	-51%	-55%	-70%	-75%
Agriculture	-32%	-37%	-52%	-58%
Transport	-23%	-40%	-57%	-63%
Residential	-48%	-67%	-81%	-85%
Electricity	-20%	-90%	-100%	-85%
Total	-43%	-48%	-65%	-69%
Total compared to 1990	-36%	-59%	-73%	-75%

order to leave enough time for the firms in the construction sector for restructuring and training to be able to face this vast national action plan.

Dates for the refurbishment obligation

	G	F	E	D	C
Social housing	2016	2016	2016	2020	2020
Collective dwellings	2020	2024	2024	2028	2032
Individual houses	2018	2022	2026	2030	2034

The total number of refurbishments remains below 200.000 until 2020. After 2020, this number gradually increases until 2040 with 900.000 renovations a year. Thereafter, the number of annual renovations declines. At the end of the period, 16.1 million of buildings are retrofitted.

With these additional measures, emissions reductions reach the Factor Four.

With the additional measures, the emissions reduction pathway is lower than both Factor Four pathways (-20% in 2020 or -30% in 2020). This precocious abatement to achieve Factor Four pleads for early action as way to ensure that emissions reductions at the end of the period follow the prescribed pathway. In addition, this leads to lower cumulated emissions, which results in a slightly lighter environmental impact.

Sectoral emissions reach a very low level. The residential sector reaches a division by 6.6, thanks to the refurbishment obligation. Transport and

production sectors reduce their emissions by two thirds. The power sector is totally decarbonized in 2040, but emissions increase again until 2050 because gas is used to fill the gap between the electricity demand and the development of renewable energies and residual nuclear production. We find results similar to those of chapter 3 with respect to the sectors with the highest emission reductions and the sector that represent challenges to decarbonize.

From a macroeconomic point of view, the average economic growth in the Additional Measures Scenario (AMS) is slightly inferior to the reference scenario whatever the option for the CET recycling. Nevertheless, until 2030, additional measures have positive economic impacts particularly because of energy efficiency measures which reduce the necessary energy expenditures of households.

These GDP trends are directly linked to the evolution of the unemployment rate (compared to the reference scenario). Whatever the tax recycling option, the impact on unemployment is positive compared to the reference scenario. The maximum reduction of the unemployment rate occurs around 2030, but the unemployment rate decreases as soon as 2020. The recycling of the CET for lowering payroll taxes has the most positive impact on employment over the whole period.

In this AMS scenario, the analysis of the households' energy expenditures can prove very interesting. Overall households' energy expenditures decrease slightly (-1%) as soon as 2020 compared to the reference scenario. The decrease reaches 5% in 2030 and the households' energy expenditures display a very important decrease between 2030 and 2050, stabilizing at a level 28% inferior to the reference. The share of the mentioned costs (total energy budget share for households) is 18.4% in 2010, 15.8% in 2050 in the reference and 11.3% in 2050 in the Factor Four scenario.

Conflicting trends are hidden behind this apparent regular decrease in expenditures. Gasoline expenditures decrease throughout the period, accounting for improvements in cars energy efficiency and modal switch towards public transportation, with a transition speed much faster than in the reference. The share of other transport modes in the energy expenditures increases by 20% in 2030 to fall back to an identical level in 2050. Regarding residential energy, most of the effort is done between 2020 and 2030 where the share drops much faster than in the reference. As a result of the refurbishment obligation the share of construction and refurbishment in 2030 soars compared to the reference, as to be multiplied by 2.7. As said previously, these opposing tendencies still result in a very important decrease, which seems to be a precondition to a very ambitious mitigation plan.★

		Average annual GDP growth rate			
		2010-2020	2020-2030	2030-2050	2010-2050
Reference scenario		1.19	1.29	1.23	1.24
Additional measures scenario	Transfer to households	1.27	1.41	1.06	1.20
	Payroll taxes	1.29	1.41	1.06	1.21
	Energy Efficiency And renewables	1.27	1.41	1.06	1.20
		Unemployment rate/Ref. Sc.			
		2020	2030	2040	
Additional measures scenario	Transfer to households	-0.2%	-1.9%	-1.0%	
	Payroll taxes	-1.3%	-3.1%	-2.4%	
	Energy Efficiency And renewables	-0.2%	-1.9%	-1.0%	
Expenditure share / Reference scenario		2020	2030	2050	
Construction and refurbishment		156%	262%	67%	
Gasoline		-17%	-32%	-49%	
Residential energy		-15%	-32%	-36%	
Other transports		10%	19%	1%	
Total energy budget share		-1%	-5%	-28%	

Sensitivity analysis

1 - Sensitivity analysis parameters and nomenclature

	Scenario name	CCS in the power sector	Nuclear (EPR) investment cost (€/kW)	Cost of nuclear plant lifetime extension (€/kW)	Biofuels - 1 st and 2 nd generation	Renewables cost decrease between 2010 and 2050
Default settings	Acceptable scenario	available	2900	700	available	- X%
	AMS scenario	available	2900	700	available	- X%
Alternatives	No CCS	unavailable	2900	700	available	- X%
	Expensive nuke	available	4500	700	available	- X%
	Expensive extension	available	2900	1400	available	- X%
	No biofuels	available	2900	700	unavailable	- X%
	Expensive RNE	available	2900	700	available	- X/2%
	Adverse scenario	unavailable	4500	1400	unavailable	- X/2%

I. Sensitivity analysis description

Emission reductions in the scenario implementing the measures considered as acceptable by stakeholders depend on many assumptions, particularly concerning technological change as well as the availability and acceptance of technologies.

Therefore, we undertake a sensitivity analysis on several parameters. We tested several parameters as described in table 1, namely the availability of carbon capture and storage, investment costs of new nuclear plants, the extension of existing nuclear plants lifetime, investment costs of renewable electricity plants, and the availability of biofuels. We considered here a “no biofuels” alternative scenario in which second generation biofuels never achieve economic and technical viability and first generation biofuels are banned because of their weak environmental performances and their impact on land use change. We considered here the “expensive RNE” alternative scenario where the pace of cost decrease for renewables is half the pace of cost decrease assumed in chapter 3 (meaning that it takes twice as long in the “expensive RNE” scenario to reach the same cost as in the original scenario).

For each of these five parameters, we tested the acceptable scenario with the most pessimistic

option for that parameter. Moreover, an adverse scenario was tested where all the five parameters are set to the pessimistic case at the same time. In addition, an adverse scenario was tested based on the “Additional Measures Scenario” from the previous section.

Table 1 presents the content of the modified parameters for the seven resulting scenarios, as well as the scenario nomenclature used in this section.★

II. Sensitivity analysis for the “acceptable scenario”

Table 2 presents the emissions impacts for the sensitivity analysis. The impossibility to rely on biofuels is the variant with the largest impact on emission reductions in the short-term as well as in the long-term. Other parameters taken one by one have only a limited impact on emission reductions.

Nevertheless, when these parameters are combined all together, long-term emissions reductions are significantly reduced as they reach only -53% in 2050 compared to 1990, thus exceeding the aimed “Factor Four”. It is noteworthy that short-term reductions (i.e. in 2020) do not fall below the “No Biofuels” scenario. Indeed, all the other parameters of the “Adverse Scenario” mainly

2 - Sensitivity analysis for the "acceptable scenario" described in chapter 3 Emissions, electricity prices and macroeconomics impacts

	Emission reductions compared to 1990		Electricity price (€/MWh)		GDP (/Mitigation)		Unemployment rate (/Mitigation)		Household energy related expenditures (/Mitigation)	
	2020	2050	2030	2050	2020	2050	2020	2050	2020	2050
Acceptable scenario	-31%	-68%	1081	1100	-	-	-	-	-	-
No CCS	-32%	-67%	1110	1077	0.0%	0.2%	0.0%	-0.1%	0.0%	-0.3%
Expensive Nuke	-33%	-65%	1151	1217	0.1%	-1.1%	-0.1%	0.8%	-0.4%	2.7%
Expensive Extension	-31%	-67%	1090	1153	0.0%	-0.2%	0.0%	0.2%	0.0%	0.6%
No Biofuels	-28%	-61%	1109	1087	-0.2%	-1.2%	0.3%	1.2%	0.3%	0.4%
Expensive RNE	-31%	-66%	1085	1163	0.0%	-0.2%	0.0%	0.3%	0.0%	0.9%
Adverse scenario	-28%	-53%	1169	1332	-0.2%	-2.3%	0.2%	2.4%	0.4%	4.3%

impact the power sector, where the transition really starts after 2020 when the first nuclear reactors are decommissioned and the share of intermittent renewables becomes significant. In this case, the measures considered as acceptable by stakeholders are not ambitious enough, even if emission reductions are significant in 2020.

Electricity prices increase in the short-term in all scenarios. The most influential parameter is the cost of new nuclear power plants. Indeed, increasing the investment costs by 55% leads to a 6% increase of electricity prices in the short term and to an increase of 11% in the long term compared to the "acceptable scenario". The unavailability of CCS, as well as the unavailability of biofuels, induces a 3% increase in prices in the short term because these technologies reduce emissions, but slightly decrease the price in the long-run as they avoid a lock-in in carbon-emitting technologies. The pessimistic case for renewables investment cost (respectively the extension of nuclear power plants) has no effect in the short run and induce a 5% (respectively 6%) price increase in the long run. Finally, the "Adverse Scenario" leads to an increase of the electricity prices 8% in the short term and 21% in the long run, compared to the acceptable scenario presented in section 3.

Macroeconomic impacts such as economic growth, unemployment and energy related expenditures for households are limited, but negative (see table 2). The most influential parameters are the unavailability of biofuels and the increase in investment costs for new nuclear power plants. However, short-term impacts are

very limited in the "Adverse Scenario" which is the most pessimistic one (inferior to 1% in 2020 compared to the acceptable scenario). In the long run, the increase in the electricity price leads to a 4.3% increase in energy-related expenditures for households in the "Adverse Scenario".

The impact on investments in the power sector is however very contrasted. Higher costs of new nuclear plants are considerably decreasing their share in the energy mix. They are being replaced mainly by gas power plants. With the low level of carbon tax at the beginning of the period, only half of the additional investment is with CCS. On the contrary, the unavailability of CCS technologies induces a shift towards new nuclear and gas without CCS. It is interesting to note that most scenarios rely on gas without CCS to a certain extent, at least as a transition technology.

The impacts of the other investigated sources of uncertainties are much more limited. The total amount of capacity is almost stable, showing that electricity becomes increasingly important as an energy carrier. However, any of the pessimistic assumptions leads to an increase in price (at least temporary) compared to the acceptable scenario, inducing a lower demand for electricity, which decreases the profitability of investment, hence reducing actual investments (even if by a small amount).

In the "Adverse Scenario", the high cost of nuclear and the unavailability of CCS induce a massive shift toward gas power plants without CCS. However, only 10.4 GW of gas power plants are built against the missing 18.6 GW of nuclear

3 - Sensitivity analysis for the "acceptable scenario" on investment in the power sector Cumulated investment between 2010 and 2050 (GW)

	Emission reductions compared to 1990		Electricity price (€/MWh)		GDP (/Mitigation)		Unemployment rate (/Mitigation)		Household energy related expenditures (/Mitigation)	
	2020	2050	2030	2050	2020	2050	2020	2050	2020	2050
Acceptable scenario	-31%	-68%	1081	1100	-	-	-	-	-	-
No CCS	-32%	-67%	1110	1077	0.0%	0.2%	0.0%	-0.1%	0.0%	-0.3%
Expensive Nuke	-33%	-65%	1151	1217	0.1%	-1.1%	-0.1%	0.8%	-0.4%	2.7%
Expensive Extension	-31%	-67%	1090	1153	0.0%	-0.2%	0.0%	0.2%	0.0%	0.6%
No Biofuels	-28%	-61%	1109	1087	-0.2%	-1.2%	0.3%	1.2%	0.3%	0.4%
Expensive RNE	-31%	-66%	1085	1163	0.0%	-0.2%	0.0%	0.3%	0.0%	0.9%
Adverse scenario	-28%	-53%	1169	1332	-0.2%	-2.3%	0.2%	2.4%	0.4%	4.3%

4 - Sensitivity analysis for the « additional measures scenario » - Emissions, electricity prices and macroeconomics impacts

	Emission reductions compared to 1990		Electricity price (€/MWh)		GDP (/AMS)		Unemployment rate (/AMS)		Household energy related expenditures (/AMS)	
	2020	2050	2030	2050	2020	2050	2020	2050	2020	2050
AMS	-44%	-75%	1179	1600	-	-	-	-	-	-
Adverse AMS scenario	-40%	-68%	1192	1503	-0.2%	-1.6%	0.3%	1.5%	0.3%	-0.1%

5 - Sensitivity analysis for the "additional measures scenario" on investment in the power sector - cumulated investment between 2010 and 2050 (GW)

	Gas without CCS	Gas with CCS	New Nuclear	Coal	Oil	Total
AMS	14.4	2.4	0	0	2.4	19.2
Adverse AMS scenario	14.4	2.4	0	0	4.8	21.6

and gas with CCS. Indeed, another impact is the decrease in cumulated investments in the power sector (-16%) because of the electricity price increase in this scenario.

III. Sensitivity analysis for the Additional Measures Scenario

We also explore the aggregated impact of these parameters on the additional measures scenario (described in section 4).

The impact on emissions reductions is significant but smaller compared to the impact on the "acceptable" scenario (7 points of emissions reductions compared to 13 points in the previous

sensitivity analysis). It is thus important to keep in mind that the implementation of additional measures leads to reduce by 50% the impact of uncertainties surrounding technology development and their impact on emissions reductions. Macroeconomic impacts linked to unemployment, GDP growth and to household energy related expenditures are also smaller than for the "acceptable" scenario. This is partly explained by the smaller impact of uncertainties on investments in the power sector in the Additional Measures Scenario due to the reduced need for additional investments in electricity production capacities, with the exception of renewable energy.

The Additional Measure Scenario is thus more robust to uncertainties. ✪

6

Conclusion

The outcome of this collaborative scenario creation attempt is threefold. First, we designed and introduced a methodology for collaborative scenario creation. Second, we successfully applied this methodology to design a scenario which integrates the visions and contributions of a variety of stakeholders. Finally, the analysis of the energy scenario resulting from this process opened up a fruitful discussion on the transition and necessary steps to face the urging climate challenge.

The emissions reductions following the implementation of all the measures that were judged acceptable by at least half of the stakeholders come close but fail in reaching the Factor Four target. In 2020, the mitigation scenario leads to CO₂ emissions 33% lower than 1990, which is more ambitious than the 20% European objective. However, the package of measures leads to a 68% CO₂ emissions reduction only in 2050 compared to 1990. Nonetheless, the Factor Four is reached in the residential sector as well as the power sector. The crucial issues lie with the contributions of the transport sector and the productive sectors to tackle emissions. In the transport sector, the evolution of emissions will heavily depend on mobility, strongly driven by urban sprawl. The predominance of road for transportation and the yearning for more mobility, intertwined with the transformation of urban patterns in France will determine the shape of the energy transition. Besides, the emissions level in the productive sectors will be contingent upon the relative prices of gas and electricity and the speed of technical change. This mutation might significantly affect economic performance, calling for a national debate on the role of globalization.

This scenario does not represent a paradigm shift in the development pattern. Indeed, GDP per capita is projected to increase by 41% between 2010 and 2050, and consumption is not reduced but redirected towards less energy-intensive products and services. Climate policy measures, especially

through higher fossil energy prices, promote the development of low-carbon technologies and energy demand reduction, which contribute to reducing the overall energy bill and the energy budget of households. In addition, these policy measures alleviate the economic detrimental consequences of the rise of fossil fuels prices. Also investing in energy efficiency drives GDP growth and reduces unemployment. The trigger for this evolution is the implementation of a carbon tax to redirect investments towards less carbon-intensive options by increasing the cost of fossil fuels. A low carbon transition cannot be initiated without this crucial leverage, which is supported by a majority of the contributing stakeholders.

This project has revealed elements of consensus regarding climate mitigation policies but also some cleavages. Two measures that were not consensual among stakeholders appear crucial in actually reaching the Factor Four objective: the refurbishment obligation for the existing building stock and the energy-carbon tax (instead of a carbon tax only). This report reveals the need for a strong political commitment to leverage the decarbonization of the energy system. The responsibility lies with the stakeholders and the government to decide on a hierarchy of values and actions fed by scientific evidence and public concerns. The question of the precedence of long-term interests (e.g. protecting the needs of future generations) over short-term considerations is an ethical issue, which should be subjected to public scrutiny. In any case, scientific evidence shows today that urgent and far-reaching action is necessary. This project shows that a consensus about the acceptability of ambitious measures cannot be easily found among stakeholders, especially if their activity is directly impacted. However, it is the responsibility of the government to act as a mediator to implement the measures that are needed to achieve climate objectives and to define the required compensations to overcome the identified cleavages. ★

Summary tables of the acceptable mitigation scenario



Policies and measures financial balance (mitigation scenario) in bn €

	2010	2020	2030	2040	2050
TRANSPORT					
Heavy trucks eco-tax	0	1.3	1.1	1.1	1.2
Kerosene tax	0	1.6	1.1	1.4	1.3
Impact on domestic consumption tax on petroleum products	23.8	21.4	17.9	13.4	12.9
INFRASTRUCTURE INVESTMENTS					
Urban transports	+3 billion € each year from 2012 until 2030			-	-
Railways	+3 billion € each year from 2012 until 2030			-	-
Road transports	-6 billion € each year from 2012 until 2030			-	-
ELECTRICITY					
CSPE Income = feed-in tariffs expense	2.9	1.9	7.2	17.8	12.7
RESIDENTIAL SECTOR					
Tax credit	-	-3.3	-2.5	-0.8	-0.5
Eco-loan	-	-3.3	-1.9	-0.6	-0.4
Construction	-	-9.5	-9.4	-7.7	-6.3
Refurbishment	-	-14.9	-10.3	-3	-1.8
OVERALL MEASURES					
Carbon tax	0	13.7	18.1	23.9	34.8
BILAN	26,7	8,9	21,3	45,5	53,9

CO₂ sectoral emissions compared to 2010 (mitigation scenario)

	2020	2030	2040	2050
Industry	-33%	-37%	-59%	-57%
Manufacture and services	-36%	-39%	-49%	-49%
Agriculture	-24%	-30%	-42%	-40%
Transport	-19%	-35%	-55%	-60%
Residential	-44%	-62%	-72%	-75%
Electricity	49%	-68%	-100%	-86%
Total	-15%	-39%	-59%	-60%
Total (compared to 1990)	-31%	-50%	-67%	-68%

Acceptable policy measures in the mitigation scenario

Residential sector	Tax credits: The purchase of refurbishment elements is eligible to income tax credits. Increased rates and an extended eligibility base are modeled from 2009 until 2050 through a uniform tax rebate of 30% of the investment.
	Zero-interest loans for retrofitting actions: 0% interest rates apply for retrofit packages with a maximum amount at 30,000€ per dwelling. The credit duration period is about 10 -15 years.
	Thermal regulation for new buildings: From 2012 maximum primary energy consumption level: 50 kWh/m ² /year of primary energy. After 2020: new buildings have to be net producers of energy.
	Implicit representation of obligatory renovation funds for jointly-owned buildings availability of third-party financing which reduces the risk aversion of the agents.
	Biogas: The biogas penetrates gradually between 2012 and 2050. Its share reaches 17% in the gas in 2050.
	Urban planning: Economic incentives and regulations slow down urban sprawl until 2030. After 2030 urban density increases again.
	Urban transports investment program: Investments in urban transports (buses, tramways) are doubled during 15 years from 2012.
	Teleworking: one day of work out of ten.
	Vehicles occupation rate: increase of the cars occupation rate for urban transport from 1.25 to 1.5.
	Kerosene tax: A tax on kerosene consumption for air transport is introduced in 2012. It represents 400€/toe.
	Heavy truck environmental tax: an eco-tax on the liquid fuel consumption of heavy trucks is introduced in 2012. It is calibrated to bring in 1.2 billion € in 2012.
	Rail investment program: Investments in road infrastructures are limited to maintenance of infrastructures. Investments are shifted from road to rail for 20 years.
All collective transports investments are deducted to the road infrastructures investments .	
Bonus-malus: is extended until 2050. A positive annual financial balance for the government budget or at least close to 0 is obtained.	
Logistics: annual decoupling of freight transport needs of 1% for all sectors.	
Infrastructures: the modal share of rail transport in freight reaches only 20% in 2030 (exogenous assumption).	
Biofuels: Biofuels penetrate following the biofuel development scenario in the "World Energy Outlook 2006". Production is about 5 Mtoe in 2020 and 16 Mtoe in 2050 (respectively 9% and 39% of total refined petroleum products).	
Electricity	Expectations: The electricity sector is assumed to receive clear carbon tax signals and expects the exact value of the carbon tax for the whole period.
	Existing nuclear plants lifetime extensions: 40 GW out of 63 GW have their lifetime extended for 0.7 bn€/GW.
	Feed-in tariffs: Feed-in tariffs for renewable energies are economic incentives to facilitate the market penetration of these technologies to accelerate the learning effect. Feed-in tariffs are normally decreasing over time and end when the technologies achieve price competitiveness with other technologies.
	Demand side management: implicit measures (interruptible contracts, smart metering) are used to flatten the load demand curve.
	Interdiction of electric heating: Electric heating is not globally banned but the implementation of the thermal regulation up from 2012 is de facto excluding electric heating (exception heat pumps).
	Grid construction: The construction of renewables triggers additional grid investments, thus increasing the electricity price for 3€/MWh in the mitigation scenario.
Overall policy measures	Carbon tax: 32€/tCO ₂ in 2012, 56€/tCO ₂ in 2020, 100€/tCO ₂ in 2030, to 200€/tCO ₂ in 2040 and to 300€/tCO ₂ in 2050.
	Progressive tariff: For all households, any consumption above 60 kWh/m ² is more expensive: 5% after 2014 and of 10% after 2030.
	Carbon tax recycling: The carbon tax income is recycled in a lump sum towards households (each person receives an equal share of the total perceived amount).

Primary and final energy in the mitigation scenario (Mtoe)

	2010	2030	2050
PRIMARY ENERGY MIX			
Total primary energy	234	178	166
Biogas	-	2	3
Biofuel	-	8	16
Coal	11	6	6
Electricity - nuclear	91	71	58
Electricity - renewables	10	18	28
Gas	40	23	15
Oil	82	50	40
Wood	-	3	3
FINAL ENERGY MIX			
Final energy	152	130	126
Biogas	-	2	3
Biofuel	-	8	16
Coal	6	4	3
Electricity	46	46	52
Gas	34	15	11
Oil	66	50	39
Wood	-	3	3

Note: in this table, primary energy for biomass (biogas, biofuels and wood) equals final energy since the Imaclim-R model does not represent the energy transformation for these energies (but only the economic flows).

