

TRANSITION(S) 2050

DECIDE NOW
ACT 4 CLIMATE

Synthesis





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BACKGROUND AND GOALS

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In line with its international commitments under the Paris Agreement (2015), and with the collective goal of stabilising the climate below the +2°C threshold, France has defined two initial National Low Carbon Strategies (SNBC). They have been used to set major greenhouse gas (GHG) reduction targets and carbon budgets for the coming years, which the country must comply with. The trajectory for emission reduction and removal of GHGs must achieve a goal of "carbon neutrality" by 2050, i.e. a balance between annual emission and removal flows (in accordance with the French Energy and Climate Act of 2019).

Starting in the next few years, this implies essential, rapid, profound and systemic transformations to considerably reduce our harmful impacts on the climate and on ecosystems, and to combat pollution. These transformations imply unprecedented action by all members of society, major technical, institutional and social innovations as well as a profound change in individual and collective lifestyles, in production and consumption patterns, in land use planning, development and so forth. **At a time when decisions must be taken to drastically reduce GHG emissions, ADEME is publishing its work ahead of the collective deliberations on the future French Strategy on Energy and Climate (SFEC) and in the run up to the 2022 presidential election.**

The aim of this scenario-building exercise is to contribute to bringing together technical, economic and social knowledge, to stimulate the debate on the possible and desirable options. Collective decisions must be made as much about the sustainable society we wish to build together as about the methods for achieving the profound and systemic transformations that will make it possible. For this reason ADEME is putting forward **four "type" scenarios, each of them intentionally distinct, presenting the economic, technical and societal options to reach carbon neutrality**, without exhausting the range of possible futures that could be chosen. These 4 scenarios are referred to as:

- S1 Frugal Generation
- S2 Regional Cooperation
- S3 Green Technologies
- S4 Restoration Gamble

In addition to the climate issue and the emergency we are facing, other environmental factors are more pressing than ever: quality and availability of water resources, destruction and loss of soil quality, loss of biodiversity, etc. The French strategy chosen will have to be justified with regard to all ecological, social and economic issues.

Compared with past "ADEME Visions" (published in 2012 and updated in 2017), this work has several new features:

- modelling of **several contrasting scenarios** for achieving **carbon neutrality in France by 2050** (with evaluation of the carbon footprint as a second step) and an assessment of the impact on resources (particularly materials, biomass and soils);
- a **multi-criteria comparison of these scenarios**, in particular technical, economic, social and environmental factors, the conditions for achieving them and their consequences;
- a **retrospective, an assessment of the current situation and a trend forecast** up to 2050 to compare the scenarios.

It is to facilitate the move to action that ADEME has carried out this unprecedented forward-looking exercise based on two years' work and the involvement of about a hundred ADEME employees as well as regular discussions with a scientific committee. The assumptions and models were refined and enhanced through in-depth discussions with a hundred or so partners and external service providers, specialists in different fields, as well as two webinars organised in May 2020 and January 2021, each of which brought together nearly 500 participants to discuss the intermediate results.

KEY MESSAGES

01

ADEME presents four pathways that could enable France to achieve carbon neutrality by 2050, each of which is internally consistent. But all of them are difficult to achieve and require that the collective strategy is discussed and decided upon quickly to accelerate the transition: certain choices, in the more or less short term, may be incompatible with the direction of a given scenario. Whatever the pathway chosen, from these four scenarios or other routes leading to carbon neutrality, **the overall consistency of the choices made must be ensured, based on orchestrated planning of changes, involving the State, regions, economic players and citizens.**

02

Achieving neutrality depends on major human or technological gambles in all cases, but they differ according to the scenario: control of demand, changes in behaviour, roll-out of technologies in all sectors, etc. These assumptions of major change are the conditions for creating the scenarios. In particular scenario "S1: Frugal Generation" exhibits rapid social change that generates a risk regarding its acceptance and scenario "S4: Restoration Gamble" involves taking a high risk on carbon capture and storage, BECCS and DACCS¹ technologies, which are not yet highly developed. S1 and S4 thus appear as limit scenarios in this universe of possibilities.

03

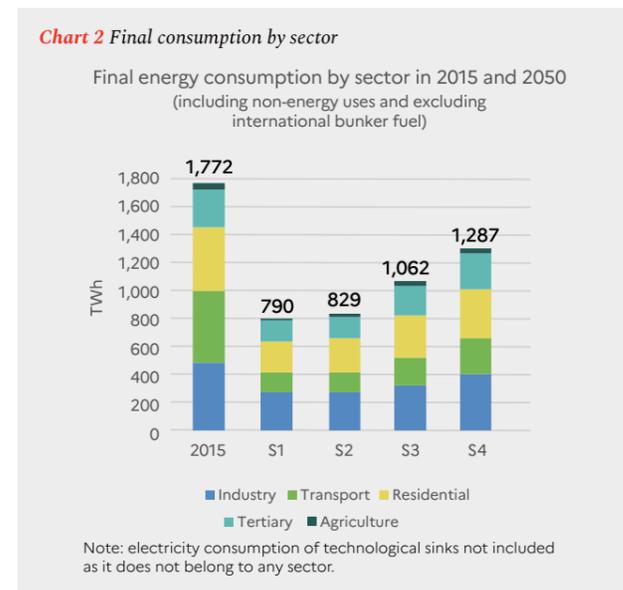
For all scenarios, it is imperative to act quickly. The scale of the socio-technical transformations to be carried out is such that they will take time to produce their effects. This decade, a profound transformation in our methods of consumption, land development, technologies and productive investments must be planned and enacted. For example, all scenarios require an increase in biomethane production capacity of more than 3 TWh/year (i.e. around 150 new digesters/year), as well as very high growth in electrical generating capacity from renewable energies (+5.5 to +8.9 GW/year on average over the period 2020-2050, depending on the scenario). However, these efforts will take time. Thus, scenarios "S3: Green Technologies" and "S4: Restoration Gamble", which above all rely on technological developments, have significantly higher emissions in 2030 than scenarios "S1: Frugal Generation" and "S2: Regional Cooperation", which place increased reliance on the lever of sufficiency and more broadly on controlling demand (Chart 1).

04

Reducing energy demand is the key factor for achieving carbon neutrality: a reduction of 23% (S4) to 55% (S1) in final demand in 2050 compared with 2015, depending on the scenario (Table 4). However, this requires a radical change in housing use and techniques, mobility, and major changes in the agricultural and industrial production system (Chart 2). A greater (S1) or lesser (S4) reduction in natural resource consumption, especially by way of the circular economy, directly contributes to this decrease in energy demand. A further contribution comes from the quantity of waste collected, which increases from S1 to S4. It requires transforming imaginations and consumer practices to engage a virtuous circle of sufficiency.

05

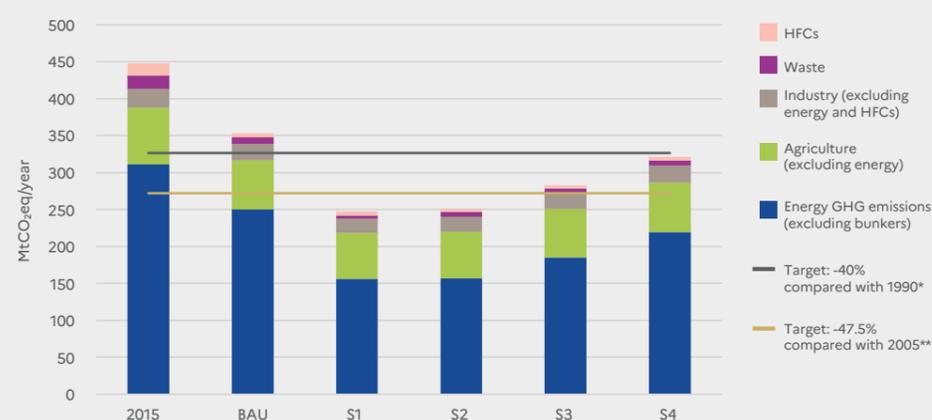
Industry will have to transform itself, not only to adapt to a profound change in demand (reduction in volumes produced, requirement for durability, etc.) but also to decarbonise its production. This will require major investment plans (decarbonisation of the energy mix, energy and materials efficiency, carbon capture and storage or utilisation, etc.), both for widespread introduction of mature technologies and the emergence of breakthrough innovations in industrial processes and for deployment of the necessary infrastructure. The **understanding and participation of the whole society** (citizens, employees) in these transformations will be essential to unite around this "new low-carbon industrial revolution".



06

The biosphere is one of the main assets in this transition. In addition to the value of ecosystems for the preservation of biodiversity and other ecological and land-use functions, their contribution to the decarbonisation of France is based on three specific and interdependent levers: the potential to reduce GHGs, the potential for natural carbon storage and the potential for using renewable biomass to replace fossil fuels. The ADEME scenarios present four possible and contrasting balances between expected services (food, carbon storage, biomass, etc.), the impact of production systems and land use (Table 1).

Chart 1 GHG emissions in 2030



* Target in the Energy Transition for Green Growth Act (LTECV) of 17 August 2015.
 ** The goal for a reduction in French emissions of -47.5% in 2030 compared with 2005 corresponds to a target of -50% compared with 1990. It is planned in the Fit for 55% package for the revision of the Effort Sharing Regulation (ESR).

- 1 In addition to reducing industrial emissions through carbon capture and storage (CCS) technologies, the technological sinks employed are:
- use of CCS on biomass plants (bio-refineries or combined heat and power from wood), BECCS (bioenergy with CCS);
 - use of CCS from the air (direct air carbon capture and storage [DACCS]).

Table 1 Levers activated for the different scenarios

		BAU	S1	S2	S3	S4
Biomass consumption	All biomass	+	++	++	++++	+++
	Lignocellulosic biomass	+	+	++	+++	++
	Agricultural resources	+	++	+	+++	+++
Utilisation of the biomass	Bio-based products	++	+++	+++	++	+
	Anaerobic digestion	+	++	++	+++	+++
	Combustion	++	+++	+++	++	+
	Biofuel	++	+	+	+++	+++
	Pyrogasification				+	

METHOD

How do we imagine the future?

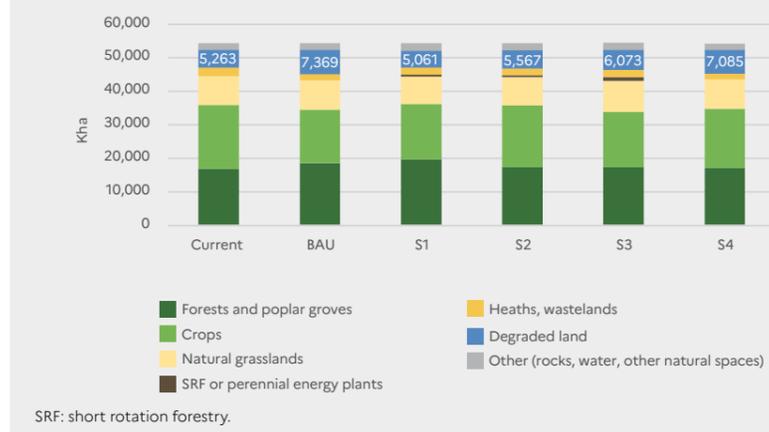
07

Adaptation of forests and agriculture is therefore becoming an absolute priority in combating climate change. All scenarios show the crucial role of preserving carbon sinks and the ability to produce biomass in 2050. The extreme events already observed (megafires, floods, pest attacks) illustrate the catastrophic impact of climate change, which could result in the collapse of certain natural environments and jeopardise the feasibility of all scenarios. In addition to protecting ecosystems for their own value, building resilience is therefore a key priority in combating climate change, particularly to preserve carbon stocks and biomass production capacity.

08

The pressure on natural resources is very different from one scenario to another. This is particularly the case for irrigation water and construction materials, where the volumes consumed vary by a factor of 2 between the scenarios with the lowest and highest consumption. The same is true for land degradation, slightly down from today for S1, but up by 40% for S4² (Chart 3). Moreover, since recycling cannot make up for the materials deficit, it is necessary to save as much material as possible.

Chart 3 Land use in the different scenarios.



09

In all scenarios studied, more than 70% of the energy supply in 2050 is based on renewable energies. Electricity is, in all cases, the main energy carrier (between 42% and 56% depending on the scenario) but its decarbonised production cannot be a pretext for waste, in order to limit the pressure on resources. The mix varies between scenarios, depending on the level of consumption but also technical choices, which are based on a more or less dynamic development of renewable energy and/or new nuclear power (S3 and S4). Gas remains essential in all scenarios, with a level of consumption ranging from 148 TWh (S1) to 371 TWh (S4) and a decarbonisation potential (biogas, syngas) that can be very high in S1, S2 and S3 (about 85%, against 51% for S4).

Table 2 Share of renewable energy in final energy consumption

	2030	2050
BAU	26%	43%
S1	34%	88%
S2	32%	86%
S3	33%	81% to 87%***
S4	29%	70%
LTECV target*	32%	-
LEC 2019 target**	33%	-

* Targets in the Energy Transition for Green Growth Act (LTECV) of 17 August 2015.
 ** Targets in the Energy-Climate Act (LEC) of 8 November 2019.
 *** Values dependent on industrial policy choices for development of the floating wind or nuclear power sectors.

2 This is incompatible with the Climate and Resilience Act 2021, which calls for no net land degradation by 2050.

Four systemic scenarios of society and one Business As Usual (BAU) scenario

The four carbon neutrality scenarios are inspired by the IPCC scenarios (P1 to P4 of the 1.5°C report).³ They are distinguished by their ambition from a scenario based on continuation of current trends (Business As Usual – BAU), which, in the absence of breakthroughs, makes the development pathway incompatible with carbon neutrality (CN). The BAU scenario and the four CN scenarios are modelled on the scale of mainland France. Specific exercises for Overseas France will be conducted at a later date.

The four scenarios are designed to reach a target of carbon neutrality in 2050. This target only makes sense for the climate at a global level. At country level, this target remains conventional to guide the ambition of the national strategy. We therefore use the target as transposed into the French Energy and Climate Act of 2019. This aims, by 2050, for net annual emissions of no more than zero in mainland France as defined by the standards of the emissions

inventory convention of the United Nations Framework Convention on Climate Change (UNFCCC). This assumes that residual emissions in 2050 are at least offset by an equal volume of greenhouse gas removal.

Each scenario is underpinned by a narrative, describing the representation of the world and the societal and political dimensions of the chosen pathway. This qualitative approach is complemented by a quantitative component of technical and economic modelling, with assumptions, sector by sector. Each of the four scenarios is thus made up of a set of interdependent assumptions that ensure the consistency of the energy-resource-region system with the scenario narrative. This work therefore goes far beyond simply modelling the energy system and describes contrasting societal transitions.

Framework assumptions

The following table summarises the major demographic, climate, and economic assumptions on which the scenarios were based.

Table 3 Framework assumptions on demographics, climate and the economy for the ADEME scenarios

	BAU	Frugal Generation S1	Regional Cooperation S2	Green Technologies S3	Restoration Gamble S4
Demographics	65.6 million inhabitants in 2020; 67.4m in 2030; 69.7m in 2050 in mainland France Birth rate: 1.8 births/woman, ageing (a quarter of the population is over 65 in 2050), net migration +70,000/year (source: INSEE, 2017, low fertility scenario, median life expectancy and median migration)				
Climate change	World: +5.4°C in 2100 France: +3.9°C in France in 2100 (IPCC's RCP 8.5)		World: +3.2°C in 2100 France: +2.1°C in 2100 (2070-2100) compared with the baseline 1976-2005 (source: (Météo-France DRIAS 2021 – RCP 4.5 – NDC logic)		
Imported energy prices	72, 88 and 106 EUR/barrel in 2030, 2040 and 2050 (source: European Commission framework, 2020*)				
Economic growth potential	Long-term potential growth (labour force + productivity): 1.3%/year on average over the period (of which 1.1% productivity) (source: SNBC, 2020) Actual economic activity and employment vary by scenario (see macroeconomic analysis)				

3 https://www.ipcc.ch/site/assets/uploads/sites/2/2019/05/SR15_SPM_version_report_LR.pdf.

4 The Commission's baseline scenario price assumptions are on page 33 of the report, which is public: <https://op.europa.eu/en/publication-detail/-/publication/96c2ca82-e85e-11eb-93a8-01aa75ed71a1/language-en/format-PDF/source-219903975>.

VIEW

of the four carbon neutral scenarios

ADEME's BAU scenario corresponds to the continuation of current major trends. It considers that investment plans and programmes currently being implemented will have an impact on emissions: for example, implementation of the multiannual energy programme, the successive Investment Programmes for the Future, etc. On the other hand, it does not pre-suppose that political objectives that have been voted on, but not yet transposed into operational measures, will achieve the desired effects.

In this BAU scenario, energy consumption remains at a high level, simply reduced by about 15% compared with today. GHG emissions are only reduced by a factor of 2, which is largely insufficient for sinks, which are essentially natural, to be able to cancel out these emissions. The net balance thus remains high at +131 MtCO₂eq. Carbon neutrality is not therefore achieved in this scenario of continuation of current trends, which underlines the need to implement breakthrough transformations, as modelled in the other four scenarios.

Adaptation and mitigation, two sides of the same coin

The objective of adapting to climate change is to make our society more robust in the face of the threats it presents, i.e., capable of maintaining its ecological, social, economic or cultural functions while coping with climate hazards.

The climate influences the French environment everywhere (fauna, flora, air quality), available natural resources (water, soil, energy), production conditions

of the primary sector (agriculture, forestry), living conditions and the needs of the population (food, heating, cooling, mobility, protection against bad weather, etc.). Just as, in many cases, it affects the nature of economic activities or the conditions under which they are carried out. In this respect, adapting to climate change is now an essential dimension of the forward-looking exercise.

The ambition to make our scenarios consistent with predicted changes in the climate has led us to identify climate-sensitive hypotheses in the chapters on each industry sector, to evaluate feasibility conditions and to present "snapshots" of possible responses to climate change.

The main impacts in France are relatively well characterised and their expected change to 2050 is still not very differentiated by the climate scenarios. Also, by assumption, all our scenarios experience the same climatic hazards. However, they produce different coping strategies due to:

- methods for looking after nature and biodiversity that will have a different impact on inhabitants and organisations, depending on choices in terms of urbanisation, land use, infrastructure, production methods and consumption patterns;
- differentiated social relationships and collective organisations (themselves the result of risk perception, citizen awareness, etc.), which lead to different adaptation strategies.

In this chapter, the four carbon neutrality scenarios produced by ADEME are introduced by a qualitative account of what society would look like in 2050, following different defining directions, describing lifestyles, the economic model, technological development, governance and the role of the regions. The strategy for adapting to climate change is then described. Following that, the main transformations in the four major systems that structure production

methods and consumption patterns, and are strategic for achieving carbon neutrality, are presented:

- bioeconomy-food-agriculture-forest-soils;
- development of land-buildings-mobility;
- industry-materials-circular economy;
- decarbonised energy systems.

The balance of GHG emissions and their removal by sinks is dealt with at the end.



SCENARIO 1

Frugal Generation

SOCIETY IN 2050

Significant changes in the way we travel, keep warm, eat, buy and use equipment will occur to achieve carbon neutrality without involving carbon capture and storage technologies, which are unproven and uncertain on a large scale. New consumer expectations, but above all new practices, are expressed rapidly in consumption patterns. Growth in energy demand that depletes resources is halted, due to behavioural and organisational changes as much as technological innovation.

The transition is mainly driven by imposed frugality and by sufficiency. The ability of economic players to adapt quickly to changes in demand is sometimes difficult. The constraints will partly come from coercive measures (obligations, prohibitions, quotas), which must be discussed to facilitate their understanding and appropriation. Sufficiency is achieved by voluntarily reducing the demand for energy, materials and resources by consumption of goods and services that is as close as possible to needs: changes in diet, speed limits on the road and restrictions on domestic flights, transformation of vacant buildings and second homes into main residences, etc.

However, restrictive measures and the ability to get everyone on board remain uncertain and run the risk of strong or even violent divisions within society. Therefore, measures are adopted as much as possible by prioritising an egalitarian vision of the transition. Norms and values change, towards an economy of relationships more than of goods, strongly rooted in the regions and their resources. Nature is protected which leads to rational exploitation of natural resources.

The route taken aims to limit negative externalities. By acting at the source, emissions related to uses are rapidly reduced and postponing them or displacing their impact to other countries is avoided.

Links with other regions, especially international dimensions, shrink, in a world where the local and sustainable, as opposed to the global and consumable, is prioritised.

01. Adaptation to climate change

Respect for nature and sufficiency

Nature has been protected, as a whole of which humanity is a part, and it contributes to climate resilience: nature in the city and the re-wilding of spaces not only combats heat islands or intense precipitation, but also helps to maintain ecological continuities and the dynamics of ecosystem adaptation.

Part of the productive system is based on *low-tech* (as opposed to *high-tech*) and small and medium-sized enterprises: technical systems and technologies, simplified and made more robust, are more controllable and repairable by citizens: thus sufficiency in products and services enables direct climatic hazards or their socio-economic impacts to be absorbed more easily.

02. Bioeconomy-food-agriculture-forest-soils

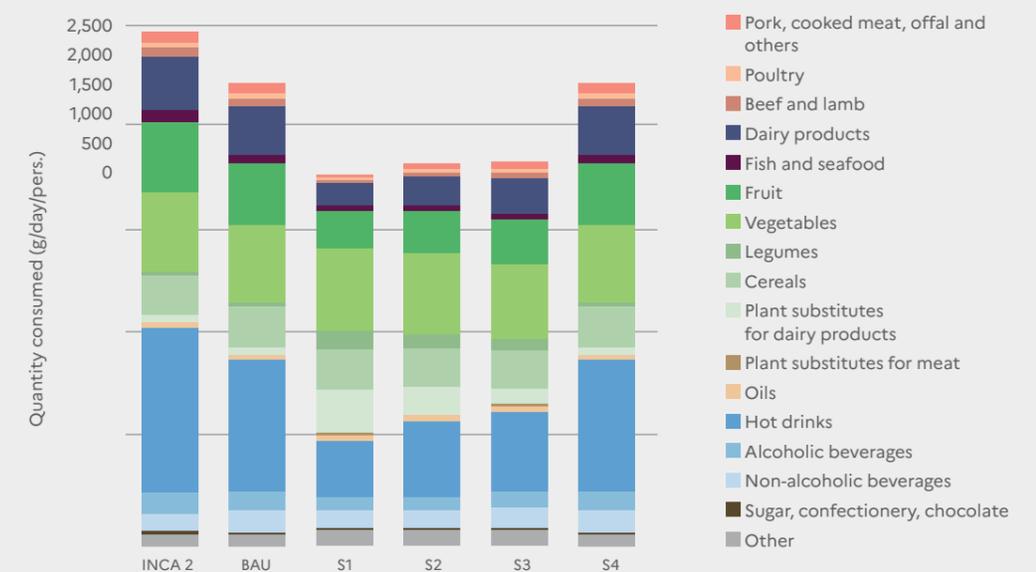
Profound transformation of dietary habits and rational use of forestry resources

The change in agricultural systems (70% of production at very low level of inputs) follows dietary changes, namely a threefold reduction in the quantities of meat consumed and more extensive but less numerous livestock (*Chart 4*). Consumption of exotic products is reduced.

The surface area occupied by non-productive natural spaces therefore increases significantly. Impacts on ecosystems are reduced. Apart from food, anaerobic digestion and combustion are two important ways of utilising biomass, mainly agricultural. Sufficiency in the material uses of wood (sawing, panels and buildings) means that requirements can be met by collecting wood from forests which remains constant.

Finally, the policy of maximum preservation of natural spaces indirectly promotes strong development and a better long-term future for biological carbon sinks in the form of forests.

Chart 4 Composition of the average French diet in each scenario in 2050, represented in quantities consumed per person per day, drinks included, except water (INCA2 represents the current average diet)



Sources: intermediate data from the SISAE project.

03. Development of land-buildings-mobility

Limitation of construction, rapid renovation and large-scale changes in lifestyles

The building stock is massively mobilised and renovated. The existing housing stock is better utilised: 2.1 people per housing unit as opposed to 2 in the trend scenario, second homes fall from 9% to 2.5% of the housing stock. This drastically reduces the number of new builds and therefore consumption of building materials, which generates a reduction in building industry GHG emissions (e.g. cement). Large cities are abandoned in favour of medium-sized cities and rural areas.

Energy renovation is on an unprecedented scale in terms of the proportion of the building stock concerned (80% of housing undergo deep renovation, 80% of tertiary surfaces follow the trajectory provided for in the tertiary decree of 23 July 2019). The use of wood heating is increasing, the use of mains gas is decreasing significantly. The use of bio-based materials is growing.

Daily life in homes is also changing significantly (less use of appliances, sharing of appliances such as washing machines, etc.). Electricity consumption for specific uses (household appliances, electronics, lighting, etc.) is reduced by almost a factor of three from 2015 to 2050.

A significant drop in demand for mobility

The distance travelled falls by 26% by 2050, due to the shift towards more proximity and a decrease in mobility. This favours active modes (walking and cycling) in particular, while cars and aircraft are in sharp decline (half as many trips by car compared with 2015). Cars are progressively becoming electric, covering 90% of all uses, becoming lighter and with lower speeds (e.g. 70 mph on the motorway). At the same time, car-pooling and hitch-hiking are developing in rural areas. Relocalisation of the economy and sufficiency are driving a 45% decline in national freight traffic. Direct GHG emissions from the mobility sector are therefore down by 91%.

04. Industry-materials-circular economy

Reduced industrial production and a market reoriented towards "Made in France"

Material demand is decreasing significantly, in line with major changes in lifestyles: a 30% reduction in the average surface area of housing compared with today, halving of the number of cars produced, a 70% reduction in consumption of synthetic fertiliser per capita, etc.

The durability and repair economy is making significant inroads to extend the life of objects and equipment. Production of waste is reduced by one third in 2050, with a very high recovery rate of 93%.

However, "Made in France" and local products are preferred by end consumers in a desire to control their carbon footprint.

As a result, industrial production is declining in physical volume and activity is being transferred to other sectors. Production of certain industries is relocalised. The production system is decarbonising mainly via biomass, to reach a 53% reduction in energy consumption and a 79% reduction in GHG emissions in 2050.

THE DISTANCE TRAVELLED FALLS BY 26% BY 2050, DUE TO THE SHIFT TOWARDS MORE PROXIMITY AND A DECREASE IN MOBILITY.



05. Decarbonised energy systems

Decline in overall energy demand but doubling in biomass energy consumption

In addition to a drastic reduction in the use of coal (excluding blast furnaces), which has already begun, oil is limited to a few specific uses that are difficult to substitute, particularly for long-distance road and air transport and as a raw material for industry.

Gas follows the same trajectory of a very strong fall in consumption (for example, 3 million homes still heated with gas in 2050 compared with 10 million today). It is almost entirely renewable, without the need for dedicated energy crops.

Hydrogen as a lever for decarbonisation of mains gas

Hydrogen is mainly used in power-to-gas (production of methane from electricity). This will be used to decarbonise gas in a decentralised manner via small-scale units located near anaerobic digestion units to utilise the CO₂ from the purified biogas. To a lesser extent, the production of hydrogen for historical industrial uses (methanol and fertilisers) continues to rely on the current processes of steam reforming of natural gas (88% decarbonised in this scenario). Hydrogen mobility, which would require the development of new technologies, is not developed in this scenario.

The final energy consumption mix⁵ consists of 301 TWh electricity, 265 TWh heat, 110 TWh gas and 70 TWh liquid fuels.

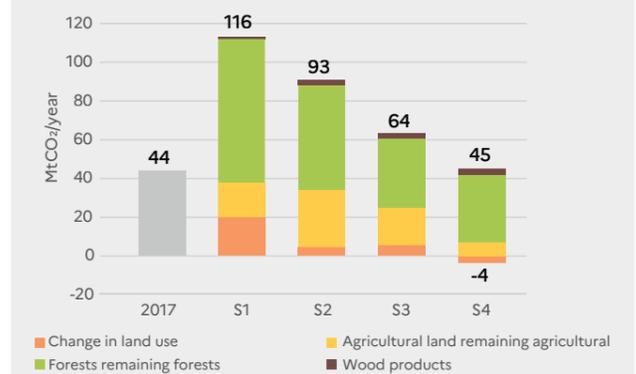
06. GHG and carbon sinks

Emissions controlled using only biological sinks

Wood harvesting is stable and only biological sinks are brought into play (soils, forests, biomass). These are significantly more developed than today (in the order of 80 MtCO₂eq per year for forests alone and 116 MtCO₂eq in total against 44 MtCO₂eq today of total net natural sinks) with modified agricultural practices and, above all, significant growth in maintained forest under extensive management (Chart 5).

The philosophy of this scenario is based on protecting the biosphere and on reducing consumption, which avoids the need for technological sinks, and even to have positive storage as insurance in case of negative impacts from climate change. The net emissions balance is -42 MtCO₂eq.

Chart 5 Natural carbon sinks in 2050 in biomass and soils



Note: the sink value in 2017 is presented as a reference knowing that it was not calculated using the same method as for the scenarios but from national inventory values produced by CITEPA, including carbon sequestration in forest soils and deadwood.

⁵ The final consumption mix does not take into account energy used intermediately to produce other carriers (gas used to produce electricity, electricity used to produce hydrogen, losses, etc.). Therefore, in this scenario, total electricity consumption is 400 TWh and gas consumption is 148 TWh.

SCENARIO 2

Regional Cooperation

SOCIETY IN 2050

Society is transformed within the framework of shared governance and regional cooperation. Non-governmental organisations, public institutions, the private sector and civil society find pragmatic ways to cooperate to maintain the social fabric.

To achieve carbon neutrality, society relies on a progressive but steady change of the economic system towards a sustainable path combining sufficiency and efficiency. Consumption of goods becomes measured and responsible, sharing becomes widespread. Transformations in housing (vacant housing re-occupied, spaces for sharing and community), work habits, diet, travel and consumption are thus less constrained than in S1 but mark a break with recent history. Nature and biodiversity are appreciated for their intrinsic value. Hence, the impacts in France are reduced as well as in the countries from which we import due to strict rules and reduced international trade.

Changes in society's values provide for massive investment in efficiency and renewable energy. As well as investment in the renewal and adaptation of infrastructure and in re-industrialisation policies in targeted industrial sectors. These investments are encouraged by financial incentives, defined by policies and regulations based on social and environmental criteria.

The desire to deal with all the subjects at the same time and to seek the consensus of all stakeholders can slow down the transformation of production systems and lifestyles.

01. Adaptation to climate change

Ecological engineering and the balance between national and local levels

The climate change adaptation strategy is based on balanced governance between national and regional levels: the national level coordinates and pools needs for investment in adapting to climate change from the regional population centres and plans stocks of strategic resources, while the regional or even sub-regional level continuously monitors the pressure on natural resources to adjust public and industry sector policies.

Ecological engineering techniques are developed: ecosystem services are integrated into all infrastructure construction and maintenance programmes, and cities are structured by their ecological framework. Citizens are greening public and private spaces, creating biodiversity corridors. They are collectively preparing to respond to climate shocks.

02. Bioeconomy-food-agriculture-forest-soils

Diversification, re-regionalisation and rational use of plant and forest resources

The food transition is accelerating due to ambitious public policies and increased education on the nutritional and environmental issues surrounding food. It becomes more restrained, more plant based, from sustainable agriculture and strongly relocalised. The environmental impact of the diet is greatly reduced. Meat consumption is down by 50% compared with current consumption, allowing for extensification of production and locally produced feed. Losses and wastage are reduced by half. The local economy becomes the main route to market.

Agricultural resources and lignocellulosic biomass are involved in the transition in a balanced way. The proportion of wood harvested in the forest for material uses is increasing, particularly for the building industry. For energy uses, combustion and anaerobic digestion are prioritised; production of biofuels has developed with the emergence of advanced biofuels that use lignocellulosic resources.

Irrigation remains contained, especially in summer, due to sustainable cultivation practices.

MEAT CONSUMPTION IS DOWN BY 50% COMPARED WITH CURRENT CONSUMPTION, ALLOWING FOR EXTENSIFICATION OF PRODUCTION AND LOCALLY PRODUCED FEED.

03. Development of land-buildings-mobility

Massive renovation, gradual but profound changes in lifestyle

The city is built with a balance between development and integration of natural components. Cities grow upwards in height in a controlled manner. It is a "15-minute city" where everything (or almost everything) is nearby.

Sharing of buildings, rooms or appliances is becoming more widespread. On average, about 150,000 housing units are built each year after optimisation of the use of empty premises. Tertiary surfaces are at a similar ratio to that observed in 1990 (i.e. 12 m² per inhabitant).

Energy renovation is accelerating very seriously: 80% of housing undergo deep renovation, 71% of tertiary surfaces follow the trajectory provided for in the tertiary decree of 23 July 2019. District heating, wood heating and electric heat pumps are developing, as well as bio-based materials.

Transport sustainability at the heart of the ecological transition

Demand for mobility, which is down by 8%, is shifting to a more local approach, with the development of daily trains, cargo bikes, folding bikes, velomobiles, mini-cars, car-pooling and massive electrification, supported by major dedicated investments. This leads to a reduction in vehicle externalities (environmental impacts, congestion, sedentary lifestyles, etc.).

Freight traffic is down 35% in ton-miles due to a reduction in volumes and distances travelled, with the share of rail and waterways more than doubling. Optimising filling and efficiency also reduces energy consumption, which is increasingly diversified and adapted to local resources.

Direct GHG emissions from the mobility sector are thus down by 95%.

RECYCLING IS HIGHLY DEVELOPED, BUT THE TOTAL QUANTITIES TO BE RECYCLED ARE REDUCED DUE TO THE EFFECTIVENESS OF THE CIRCULAR ECONOMY.



04. Industry-materials-circular economy

Re-industrialised and specialised value chains by region, driven by the public authorities

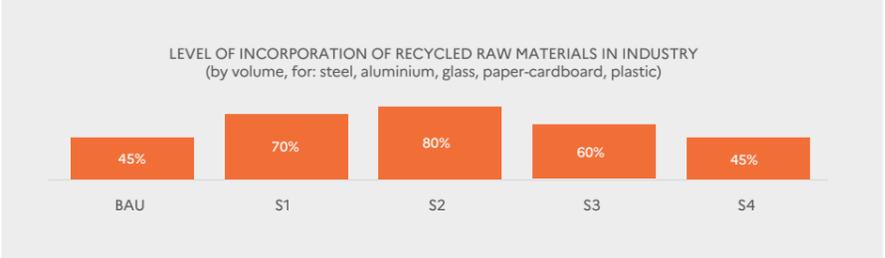
Public planning supports and finances a low-carbon industrial policy towards greater energy and materials efficiency, regional specialisation and a circular economy.

Recycling is highly developed (Chart 6), but the total quantities to be recycled are reduced due to the effectiveness of the circular economy. Demand for recovered raw materials and energy find a balance however, resulting in a high recovery rate (95%) and the virtual disappearance of landfills.

In addition, a major re-industrialisation effort (improving trade balances in terms of physical volumes) is carried out in targeted sectors for which production is decarbonised. Nevertheless, production in physical volume declines in most sectors due to changes in demand.

Overall, a reduction in energy consumption of 47% and GHG emissions of 84% is achieved in 2050 in industry.

Chart 6 Raw material recycling rates in industry



06. GHG and carbon sinks

Maintenance of natural sinks and limited use of carbon capture and storage (CCS)

This scenario is based on changes in agricultural practices to promote carbon storage in the ground. In particular, by planting hedges, agroforestry between plots of agricultural land (the most effective practice in terms of storage) and development of plant cover to preserve soil and fertility. Wood harvesting levels in forests remain moderate, which maintains a significant carbon sink in forests. In total, natural sinks amount to 93 MtCO₂.

Carbon capture and storage is deployed on some processes with emissions that cannot be reduced, such as from cement plants in the north-east of France, to capture and store them in the North Sea, at a volume of 3 MtCO₂ in 2050.

The total GHG emissions of 68 MtCO₂eq are therefore reduced to a net balance of -28 MtCO₂eq, which provides insurance if climate change negatively impacts forests and soils.

05. Decarbonised energy systems

A wide range of direct and indirect uses for hydrogen

The use of decarbonised hydrogen, up to 96 TWh in 2050 exclusively produced by electrolysis, is required in transport, for power-to-methane and in industry for the production of fertilisers, methanol, synthetic liquid fuels and reduction of iron ore.

The energy mix remains dominated by biomass and electricity that is essentially decarbonised.

The sharp drop in gas consumption (158 TWh in 2050) means that the vast majority of demand will be met with decarbonised gas (82%). The anaerobic digestion/power-to-methane industry produces 127 TWh.

The final energy consumption mix⁶ consists of 343 TWh electricity, 260 TWh heat, 126 TWh gas and 42 TWh liquid fuels.

⁶ The final consumption mix does not take into account energy used intermediately to produce other carriers (gas used to produce electricity, electricity used to produce hydrogen, losses, etc.). Therefore in this scenario total electricity consumption is 535 TWh and gas consumption is 158 TWh.

SCENARIO 3

Green Technologies

SOCIETY IN 2050

Technological development provides more of the answers to environmental challenges than changes towards more sufficient consumption patterns. Hence, lifestyles, travel and work are very similar to those of today, but with some differences. For example, the diet is a bit less meat dependent and more balanced. Individual mobility is predominant, but with lighter, electrified vehicles. Industry produces slightly less in volume but is very decarbonised.

Large cities are growing. Technologies and digital technology, which create energy or material efficiency, are in all sectors. The best technologies are widely deployed and widely available to well-off populations. It is a pathway in which the disconnect between wealth creation and environmental impact is still a dividing line. But by focusing on green or decarbonised production, there is a risk that energy and material consumption will not be sufficiently controlled and that the poorest will not have access to basic needs.

The rebound effects can be significant in the absence of policies to counteract them (regulation, pricing, etc.). Dependence on fossil fuels is decreasing slowly, achieving neutrality is based on maximum use of biomass, especially forest biomass, to produce energy and recover CO₂ to store it underground.

The development of natural capital means that nature is better preserved than today: by giving it a price, we hope to find the technical solutions to protect it.

The Government as planner is implementing strong policies to promote decarbonisation of the economy, in a context of international competition and globalisation of trade.

01. Adaptation to climate change

Technology supporting development of resources

Nature is seen as a set of resources to be developed, used and optimised for the benefit of humans, in a relationship of mutual growth between natural ecosystems and intense human activity in all economic areas. In this context, technologies are a means of understanding, monitoring and regulating the impacts of climate change. They also provide new flexibilities and capacities for adapting (precision agriculture, development of seawater desalination, home automation, etc.).



02. Bioeconomy-food-agriculture-forest-soils

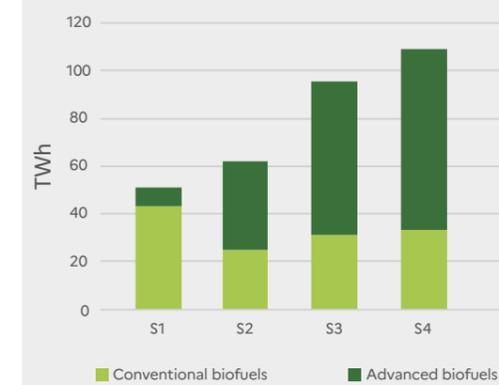
Maximum biomass consumption for multiple uses

Diets are changing significantly as a result of a compromise between health and environmental issues and seeking individual pleasure: -30% in meat consumption, +30% in consumption of organic produce, increase in the consumption of local produce. But this scenario relies above all on the performance of the industrial sectors involved in reducing the environmental footprint of food.

98 TWh of liquid biofuels and electrofuels have to be produced⁷, despite a 76% decrease in demand for liquid fuels in 2050 compared with today. All available renewable liquid fuel production technologies are used, including the most expensive ones. The algae sector contributes to the production of biofuels and those of the third generation represent 12% of total production (Chart 7)

The strong demand for decarbonised energy puts pressure on biomass. This promotes intensification of agriculture with major use of synthetic inputs, an increase in the surface area of energy crops, greater specialisation of the regions and an intensification of forestry for energy needs.

Chart 7 Conventional and advanced biofuel production in each scenario in 2050



⁷ "Electrofuels" or "e-fuels" produced using hydrogen generated by electrolysis with renewable electricity.

03. Development of land-buildings-mobility

Massive renovation and demolition - reconstruction

The interests and activities of the population are focused on large cities. This attractiveness requires physical reconfiguration with a new cycle of "Haussmannian" demolition and reconstruction generating massive consumption of natural resources (Chart 8) and significant demand for transport. Construction methods are evolving towards industrialisation and prefabrication to meet the needs for new flats. The supply of less carbon-intensive building materials and systems is growing.

Technical innovation provides better equipment efficiency. Renovation affects all construction trades but without following a deep renovation pathway (a piecemeal rather than global approach to renovation). In the tertiary sector, energy renovation of the building stock is accelerating. In 2050, 72% of tertiary surfaces present in 2015 follow the trajectory provided for in the tertiary decree of 23 July 2019.

The search for efficiency takes precedence over mobility

Demand for transport is being met across different modes, leading to a 23% increase in the distance travelled by passengers compared with 2015, while freight transport is stable. The modal shift is low and concentrated in the major cities and on the main rail and waterway routes. The main efforts are focused on accelerating decarbonisation of fleets and energy, in particular through electrification of vehicles. The energy mix is more diversified for freight, with electricity for utility vehicles and on electric motorways, but also biogas, hydrogen and biofuels.

Direct GHG emissions from the mobility sector are thus down by 94%.

A PHYSICAL RECONFIGURATION OF LARGE CITIES WITH A NEW CYCLE OF HAUSSMANNIAN DEMOLITION/RECONSTRUCTION.

04. Industry-materials-circular economy

Continuation of trends in consumption enabled by the decarbonisation of the energy mix

Compared with today, industrial production is slightly reduced in volume. However, some sectors, such as aluminium or ammonia, are experiencing an increase in their volumes, due in particular to the dynamics of transport. In addition, while trade is concentrated in the European Union, it is maintained at constant volume.

This production dynamic requires a lot of resources and therefore raw materials from waste. Plastic waste is thus recovered for chemical recycling. Similarly, solid recovered fuels (SRF) are in high demand (18 Mt in 2050), leading to a slight distortion of the waste management hierarchy towards energy rather than recycling.

Decarbonisation of industry is taking place through the electrification of processes and the use of hydrogen. In addition, 11 MtCO₂ of emissions from heavy industrial emitter areas are captured and stored underground in 2050 (north-east, Aquitaine basin).

Overall, a 30% reduction in energy consumption and a 86% reduction in GHG emissions will be achieved in 2050 for industry.

05. Decarbonised energy systems

Innovation for decarbonisation and renewables

The supply of energy must meet demand for goods and services, particularly digital ones, which are highly energy intensive, as well as the need for mobility. For this, biomass is used extensively, in particular waste for anaerobic digestion and wood for energy. Due to the resources available, pyrogasification plays an important role in this scenario (67 TWh). Fossil fuels are still used to a small extent (10%) in transport.

Massive consumption of hydrogen for all end-uses with reliance on imports

The demand for decarbonised hydrogen (94 TWh in 2050) is mainly driven by industrial uses (Chart 9). Approximately half of this demand is met by imports, facilitated by the establishment of hydrogen pipeline transport and storage infrastructure as from 2030.

The final energy consumption mix⁸ consists of 517 TWh electricity, 290 TWh heat, 161 TWh gas and 36 TWh liquid fuels.

06. GHG and carbon sinks

Use of carbon capture and storage (CCS) on biomass units

GHG emissions amount to 85 MtCO₂. To achieve neutrality, the use of natural sinks, mainly agroforestry, plant cover and forests (64 MtCO₂/year) and the use of CCS at industrial plants and waste incinerators (11 MtCO₂/year) is not sufficient.

This scenario provides for greater development of demand for biomass, which explains a higher wood harvest than today and a reduction in forestry sinks. These biomass sources are used for energy (anaerobic digestion, wood energy, biofuels and pyrogasification) and as payments for environmental services (e.g. carbon storage). Development of medium-sized biomass boilers and biorefineries with carbon capture and storage allows offsetting of 21 MtCO₂/year.

Chart 8 Material consumption for new-build construction (residential, care home, shop, hotel, education and office) Cumulative thousands of tonnes between 2015 and 2050

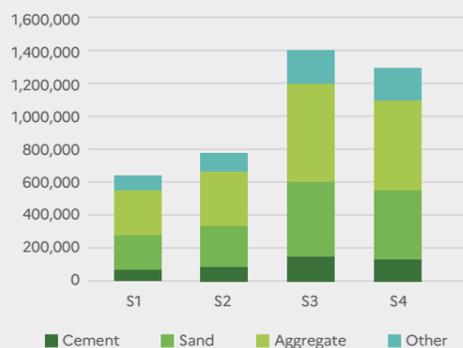
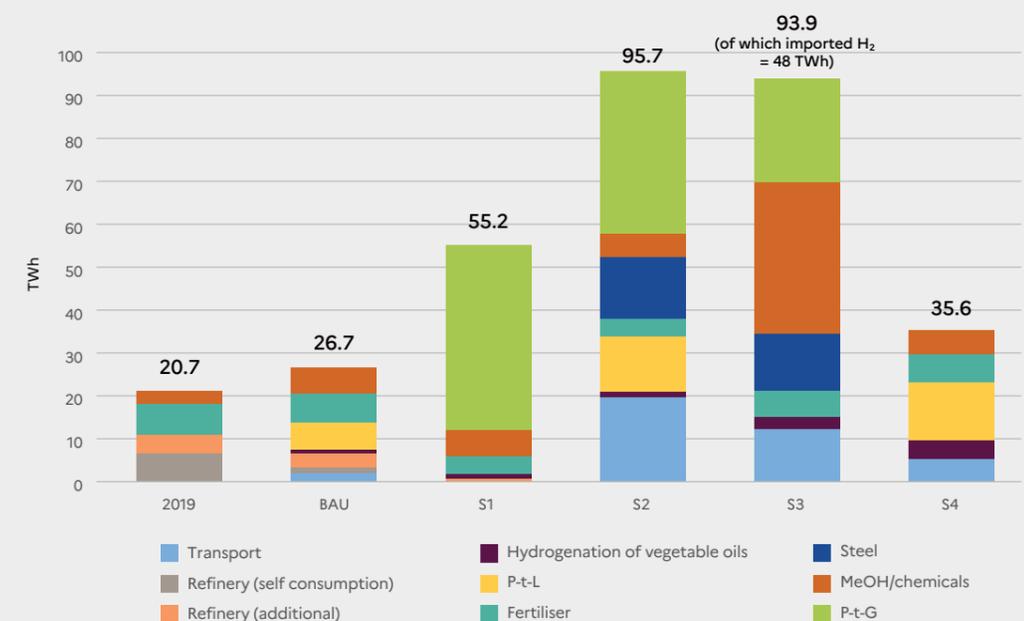


Chart 9 Hydrogen consumption balance in 2050 in TWh for the different scenarios, including self-consumption by refineries



* P-t-G: power-to-gas; ** P-t-L: power-to-liquid.

⁸ The final consumption mix does not take into account energy used intermediately to produce other carriers (gas used to produce electricity, electricity used to produce hydrogen, losses, etc.). Therefore in this scenario, total electricity consumption is 640 TWh and gas consumption is 219 TWh.

SCENARIO 4

Restoration Gamble

SOCIETY IN 2050

The lifestyles of the early 21st century are safeguarded. Appliances are very popular in the home for cooking, warming, controlling (light, energy) and security. Applications are very developed particularly for eating (healthily) or moving (efficiently). But this proliferation of devices consumes a lot of energy and materials with a potentially high environmental impact.

Global ecological issues are perceived as a quid pro quo for economic and technological progress: society places its trust in its ability to manage and even repair social and ecological systems with more material and financial resources to maintain a liveable world. This leads to the questioning of a certain number of objectives currently enshrined in law (halving energy consumption, zero net land degradation, etc.). Local ecological issues (resources, pollution, noise, biodiversity) are addressed through technical solutions. But this exclusive focus on technologies is a gamble, to the extent that some of these technologies are not mature. This is the case for carbon capture and storage from the air, which are at an experimental stage in 2021 and for which there is no study to determine if they can be deployed at acceptable costs and impacts and in a timely manner.

Globalisation is accelerating, with improved aid for the most disadvantaged countries.

The logic of this scenario corresponds to the development of two recent dynamics that represent an unprecedented break with past trends:

- the emergence of a global middle class that could contribute to robust growth in production and consumption;
- the digital revolution that makes life easier for citizens and businesses. Present everywhere and for all activities, digital is also a major energy consumer despite technical advances to make it more efficient.

01. Adaptation to climate change

A national strategy guided by security policies

The adaptation strategy relies in particular on national governance and strategic stocks to deal with more frequent climate hazards. Technical control of nature by mankind becomes a goal of resilience. Ecological challenges are managed by targeted and technocentric solutions. The uncertainty of climatic events is contributing to the creation of a gigantic insurance market for individual protection against the consequences of climate change.



02. Bioeconomy-food-agriculture-forest-soil

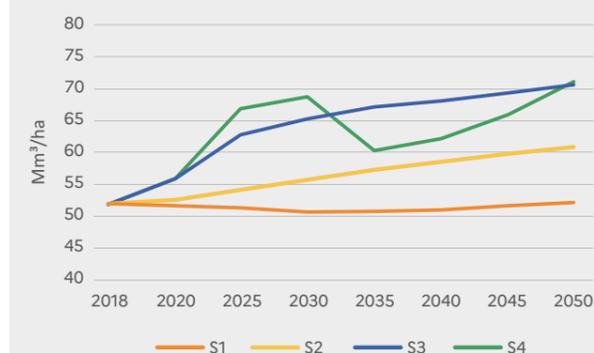
Technological levers to support productive and specialised sectors

The agriculture and agri-food industries are highly specialised and competitive. The main change in diets is based on the inclusion, still low, of alternative proteins such as synthetic meat or insects. In fact, livestock and intensive farming systems, dominated by conventional systems (70% of farms), are in the majority. Agriculture uses all technologies to optimise its production and limit its impacts but consumes about 65% more irrigation water than today.

The use of lignocellulosic biomass and wood waste for energy is promoted. The anaerobic digestion and biofuel sectors represent the majority of biomass consumption (more than 75% of the biomass used for energy purposes). But *power-to-liquid* technology and the algal biofuel industry are also developed, although to a lesser extent.

The forestry landscape will be profoundly modified, with massive felling before 2030 followed by reforestation with softwoods (Chart 10).

Chart 10 Harvesting of forest wood in the different scenarios



03. Development of land-buildings-mobility

Energy efficiency and technical innovation

Large cities and land degradation are growing in connection with the search for ever more comfort and safety. Technology is being used in the industrialisation of building renovation, energy efficiency of equipment, as well as in mobility. In particular, by allowing citizens to choose their mode of transport at any time or to be driven by their vehicle.

In the building industry, renovation is carried out at two speeds. Housing where architecture is such that industrialised renovation can be carried out (via prefabrication) undergo deep renovation. The rest of the housing stock pursues renovation in piecemeal fashion, without following a set pathway to improve performance. Performance of household appliances is improved and supports the appearance of new highly efficient technologies, in particular thermal equipment for the renovated housing stock. The tertiary sector is growing, reaching 1,133 million m² of heated surface area in 2050, a quarter of which are buildings built after 2015. The tertiary surface area represents a ratio of 16 m² per inhabitant in 2050, compared with 15 m² in 2015.

Technology finds its way into the drivers and management of mobility

The distance travelled increases by 39% due to an increase in long-distance travel, particularly by air, and a constant search for speed. The individual car retains its central position, despite the rise of shared self-driving vehicles. Driven by the rise of e-commerce, logistics is increasingly connected, just-in-time and focused on speed of delivery. This supports the dominance of sea and road transport, while the fragmentation of shipments multiplies deliveries in light commercial vehicles. Technological advances facilitate electrification, the use of biogas increases, but decarbonisation is limited by available resources. Direct GHG emissions from the mobility sector are thus reduced by 90%.

THIS STRONG ENERGY DEMAND REQUIRES THE USE OF SEVERAL DECARBONISATION LEVERS: BIOMASS, IN PARTICULAR FORESTRY, RENEWABLE ENERGIES, BIOGAS AND BIOFUELS. BUT THAT IS NOT SUFFICIENT.

04. Industry-materials-circular economy

Decarbonisation of industry is focused on carbon capture and storage, in a world where consumption and globalisation are intensifying.

With globalisation promoting trade in materials, and consumption growing faster than production, markets rely more on imports. These are supplemented by national production, for which decarbonisation is focused on carbon capture and storage (CCS) as well as increased electrification.

To supply this production, the resource requirements are immense. They are met by exploiting natural resources, but also with recycling pushed to its limits due to advanced technologies.

Overall, the energy consumption of industry will only be reduced by 19% in 2050, leading to a 54% reduction in GHG emissions before capture.

05. Decarbonised energy systems

Strong electrification and massive use of imports

Despite relatively efficient systems in industry, construction and transport, energy demand is high. This requires the use of several decarbonisation levers: biomass, in particular forestry, renewable energies, biogas and biofuels. But that is not sufficient.

The scenario also relies on some foreign countries specialising in the production of decarbonised or renewable gas, which enables France to import (44 TWh of renewable or decarbonised gas) and to increase the overall level of gas decarbonisation to 51%.

Competition from other technologies compromises the position of hydrogen

Development of hydrogen is limited, given competition with other technologies: technological advances on batteries in mobility, strong deployment of carbon capture and storage (CCS) in the chemical industry and from the air (DACCS) to the detriment of power-to-methane.

The final energy consumption mix⁹ consists of 709 TWh electricity, 271 TWh heat, 270 TWh gas and 73 TWh liquid fuels.



06. GHG and carbon sinks

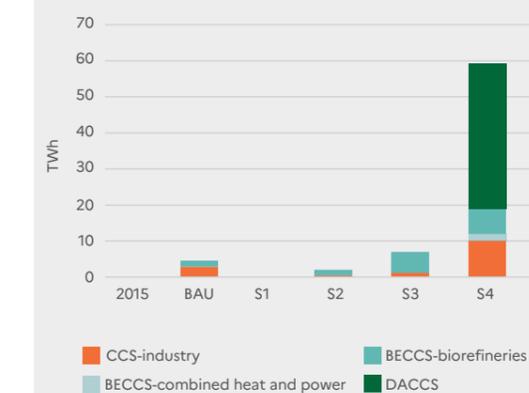
Necessary development of technological sinks

This scenario has the highest level of emissions (135 MtCO₂/year) and the lowest natural carbon sinks (41 MtCO₂/year). The pace of land degradation is maintained at current levels, the trend of converting grassland to cereals continues.

To compensate, the use of CCS and technological sinks is the most important here:

- strong development of CCS in industry (41 MtCO₂/year) throughout the country due to the development of the necessary infrastructure: transport pipelines and geological storage sites for CO₂, about half of which are in the North Sea and half in France, on the first demonstration storage sites in the identified areas (Paris Basin, Aquitaine Basin, etc.);
- extensive use of bioenergy with carbon capture and storage (BECCS) (29 MtCO₂/year);
- implementation of Direct Air Carbon Capture and Storage (DACCS) at 27 MtCO₂/year. This is reflected in very high energy consumption of 59 TWh/year, i.e. 6% of electricity consumption (Chart 11).

Chart 11 Electricity consumption associated with CCS and carbon sinks in 2050 for each scenario



⁹ The final consumption mix does not take into account energy used intermediately to produce other carriers (gas used to produce electricity, electricity used to produce hydrogen, losses, etc.). Therefore in this scenario, total electricity consumption is 810 TWh and total gas consumption is 371 TWh.



S1 FRUGAL GENERATION



S2 REGIONAL COOPERATION



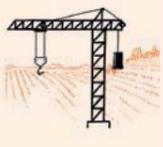
S3 GREEN TECHNOLOGIES



S4 RESTORATION GAMBLE

LIFESTYLES

LIFESTYLES

	S1 FRUGAL GENERATION	S2 REGIONAL COOPERATION	S3 GREEN TECHNOLOGIES	S4 RESTORATION GAMBLE	
LIFESTYLES	Society <ul style="list-style-type: none"> Search for meaning Frugality chosen but also imposed Preference for local sourcing Nature protected 	<ul style="list-style-type: none"> Sustainable changes in lifestyles Sharing economy Fairness Preservation of nature enshrined in law 	<ul style="list-style-type: none"> New technologies rather than reduced consumption "Green" consumerism for the benefit of well-off populations, connected society Services provided by Nature are optimised 	<ul style="list-style-type: none"> Mass consumption lifestyles safeguarded Nature is a resource to be exploited Confidence in the ability to repair damage to ecosystems 	Society
	Food <ul style="list-style-type: none"> Meat consumption reduced by a factor of 3 Share of organic: 70% 	<ul style="list-style-type: none"> Meat consumption halved Share of organic: 50% 	<ul style="list-style-type: none"> 30% reduction in meat consumption Share of organic: 30% 	<ul style="list-style-type: none"> Meat consumption almost stable (10% decrease), supplemented by alternative synthetic or plant proteins 	Food
	Housing <ul style="list-style-type: none"> Massive and rapid renovation Strong limits on new construction (conversion of vacant housing and second homes into primary residences) 	<ul style="list-style-type: none"> Massive renovation, gradual but profound changes in lifestyle (growth in cohabitation and the size of housing adapted to household size) 	<ul style="list-style-type: none"> Large-scale demolition and rebuilding of housing All homes renovated but not efficiently: only half undergo deep renovation 	<ul style="list-style-type: none"> New construction maintained Only half of the housing stock renovated. When renovated, houses undergo deep renovation Appliances multiply, combining technological innovation and energy efficiency 	Housing
	Personal mobility <ul style="list-style-type: none"> Strong reduction in mobility Distance travelled per person reduced by one-third Half of all journeys on foot or by bicycle 	<ul style="list-style-type: none"> Managed mobility Distance travelled per person reduced by 17% Nearly half of all journeys on foot or by bicycle 	<ul style="list-style-type: none"> Mobility managed with State support: infrastructure, widespread teleworking, car-pooling +13% in distance travelled per person 30% of journeys on foot or by bicycle 	<ul style="list-style-type: none"> Strong increase in mobility +28% in distance travelled per person People prioritise speed 20% of journeys on foot or by bicycle 	Personal mobility
ECONOMY	Technical Relationship to progress, digital, R&D <ul style="list-style-type: none"> Organisational and technical innovation Prevalence of low-tech, reuse and repair Digital collaboration Stable data centre consumption due to stabilisation of flows 	<ul style="list-style-type: none"> Massive investment (energy efficiency, renewable energy and infrastructure) Digital technology in support of regional development Stable data centre consumption due to stabilisation of flows 	<ul style="list-style-type: none"> Targeting of the most competitive technologies to decarbonise Digital technology in support of optimisation Data centres consume 10 times more energy than in 2020 	<ul style="list-style-type: none"> Innovation on all fronts Capture, storage or use of captured carbon essential Pervasive presence of the Internet of Things and Artificial Intelligence: data centres consume 15 times more energy than in 2020 	Technical Relationship to progress, digital, R&D
	Governance Decision-making ladders, international cooperation <ul style="list-style-type: none"> Local decision-making, little international cooperation Regulation, prohibition and rationing via quotas 	<ul style="list-style-type: none"> Shared governance Environmental taxation and redistribution National decisions and European cooperation 	<ul style="list-style-type: none"> Minimum regulatory framework for the private sector Government as planner Targeted carbon tax 	<ul style="list-style-type: none"> Supply-side support Strong and targeted international cooperation in a few key sectors Centralised planning of the energy system 	Governance Decision-making ladders, international cooperation
	Region Rural-urban mix – land degradation <ul style="list-style-type: none"> Important role for the region in terms of resources and taking action "De-urbanisation" in favour of medium-sized cities and rural areas 	<ul style="list-style-type: none"> Demographic recovery of medium-sized cities Cooperation between regions Regional energy planning and land policies 	<ul style="list-style-type: none"> Urbanisation, competition between regions, functional cities 	<ul style="list-style-type: none"> Low involvement by regions, urban sprawl, intensive agriculture 	Region Rural-urban mix – land degradation
	Macro-economy <ul style="list-style-type: none"> New prosperity indicators (income gaps, quality of life, etc.) Contraction in international trade 	<ul style="list-style-type: none"> Qualitative growth, "re-industrialisation" of key sectors in conjunction with the regions Regulated international trade 	<ul style="list-style-type: none"> Green growth, innovation driven by technology Regional specialisation International competition and globalisation of trade 	<ul style="list-style-type: none"> Carbon-based economic growth Minimal and targeted carbon tax Globalisation of the economy 	Macro-economy
Industry <ul style="list-style-type: none"> Production as close as possible to needs 70% of steel, aluminium, glass, paper, cardboard and plastic sourced from recycled materials 	<ul style="list-style-type: none"> Production of value rather than volume Dynamic local markets 80% of steel, aluminium, glass, paper, cardboard and plastic sourced from recycled materials 	<ul style="list-style-type: none"> Energy decarbonisation 60% of steel, aluminium, glass, paper, cardboard and plastic sourced from recycled materials 	<ul style="list-style-type: none"> Decarbonisation of industry relying on carbon capture and storage 45% of steel, aluminium, glass, paper, cardboard and plastic sourced from recycled materials 	Industry	

OVERVIEW

of the 4 scenarios

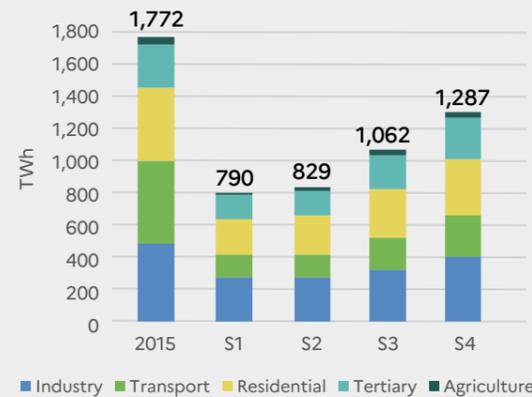
S1 Frugal Generation | S2 Regional Cooperation | S3 Green Technologies | S4 Restoration Gamble

ENERGY

4 different energy mixes for 2020

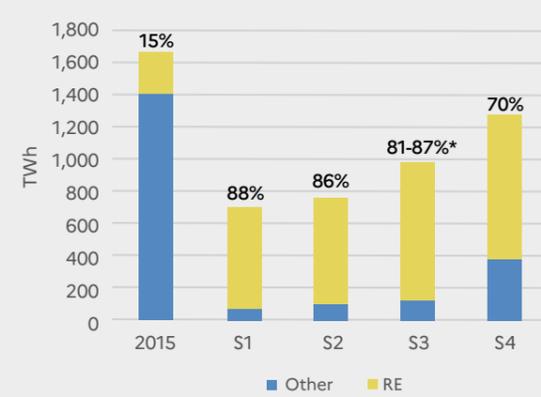
REDUCED ENERGY DEMAND

Final energy consumption by sector in 2015 and 2050 (including non-energy uses and excluding international bunker fuel)



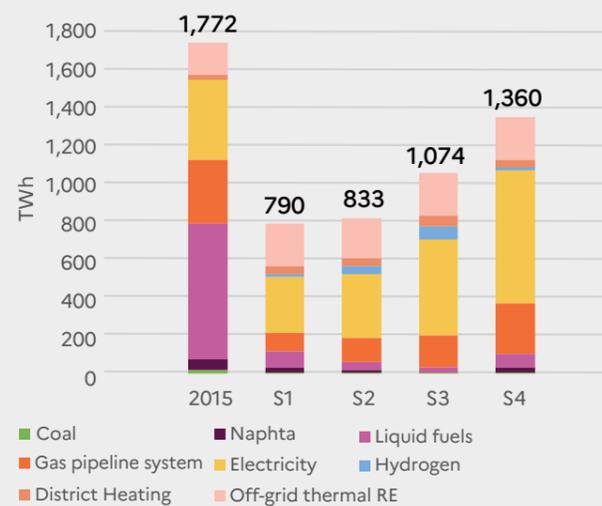
MORE THAN 70% RENEWABLE ENERGY IN ALL SCENARIOS

Energy consumption and share of RE of gross final energy consumption in 2015 and 2050



* Values dependent on industrial policy choices for development of floating wind or nuclear power.

Final energy demand by vector in 2015 and 2050 (with non-energy uses and excluding international bunker fuel)



A GROWING SHARE FOR ELECTRICITY

VIRTUAL DISAPPEARANCE OF FOSSIL-FUEL ENERGIES

SOME RESIDUAL GAS CONSUMPTION REMAINS

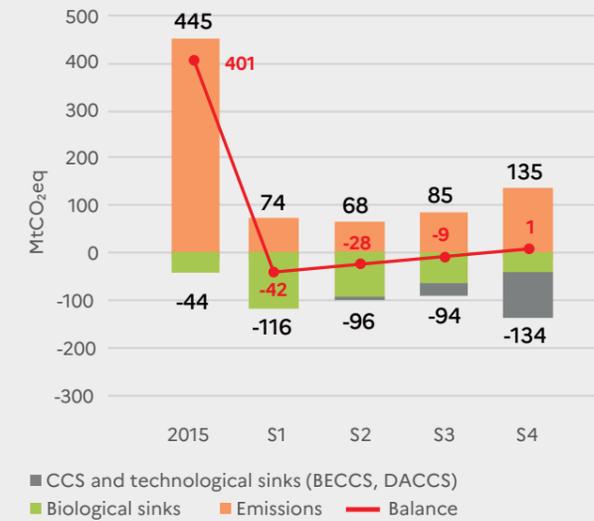
Note: final energy consumption does not take into account energy used as an intermediate in the manufacture of other energy or non-energy carriers such as hydrogen. By way of illustration, the electricity consumption (not shown in this graph) used to manufacture hydrogen for energy use is 62 TWh, 135 TWh, 65 TWh and 33 TWh respectively in S1, S2, S3 and S4. The difference between consumption demand and the graph of energy demand by sector is due to consumption by technological carbon sinks, which is not allocated to a specific sector. The difference with gross final energy consumption results from consumption for non-energy uses.

CLIMATE

The major role of biological sinks for achieving neutrality in 2050

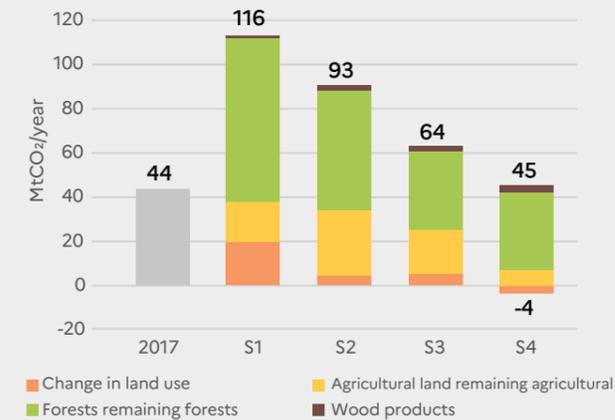
FOUR NEUTRAL SCENARIOS IN 2050, WITH VARYING DEGREES OF RELIANCE ON CARBON SINKS

Balance of CO₂ emissions and sinks in 2015 and 2050



GROWTH OF BIOLOGICAL SINKS IN S1 AND S2 DUE TO GROWTH OF FORESTS AND CHANGING AGRICULTURAL PRACTICES

Natural carbon sinks in biomass and soils in 2017 and 2050



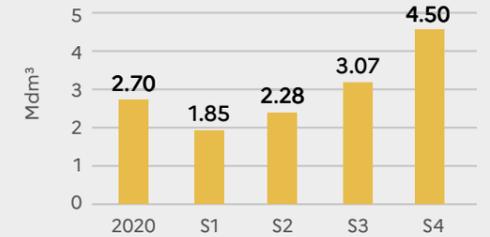
Note: the 2017 sink value is given as the benchmark, though it was not calculated in the same way as for the scenarios: it used values from the national inventory carried out by CITEPA, adding carbon sequestration to forest soils and forest deadwood.

RESOURCES

Differing pressure on resources

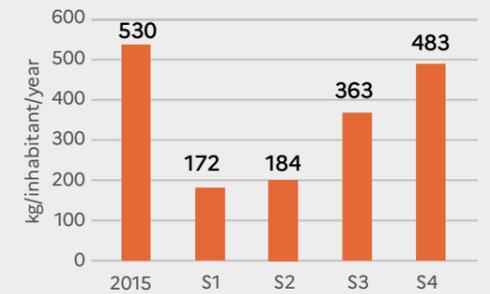
2 SCENARIOS LIMITING THE USE OF IRRIGATION

Water requirements for irrigation in 2020 and 2050



LESS HOUSEHOLD AND SIMILAR WASTE

Household and similar waste collected in 2015 and 2050



USE OF BIOMASS DOUBLED OR MORE

Use of biomass for non-food uses in 2017 and 2050



Main indicators

Table 4 Values of some indicators in 2015 and 2050

Indicators		2015	S1	S2	S3	S4
ENERGY	Final energy consumption, with non-energy uses, including technological carbon sink consumption (TWh)	1,772	790	833	1,074	1,360
	Reduction in primary consumption of fossil fuels compared with 2012	-7%	-89%	-94%	-96%	-79%
	Share of renewables in energy consumption	15%	88%	86%	81%	70%
	Share of electricity in final energy consumption (excluding bunkers and non-energy uses)	27%	42%	44%	52%	56%
CLIMATE	Quantities of GHG emitted Mainland France excluding LULUCF* (MtCO ₂ eq)	445	74	68	85	135
	Emissions reduction compared with 1990	-16%	-86%	-87%	-84%	-75%
	Quantities of carbon sequestered in natural sinks - net balance** (MtCO ₂ eq)	-44	-116	-93	-64	-41
	Quantities of GHG stored from CCS on industrial units (MtCO ₂ eq)	0	0	-2	-9	-37
	Quantities of GHGs stored using BECCS (MtCO ₂ eq)	0	0	-1	-21	-29
	Quantities of GHGs stored using DACCS (MtCO ₂ eq)	0	0	0	0	-27
	Net GHG balance** (MtCO ₂ eq)	401	-42	-28	-9	1
RESOURCES	Quantities of waste collected excluding public works (Mt)	141	60	65	104	93
	Waste in non-hazardous and non-inert landfill (Mt/year)	18.4	1.1	0.6	1.5	3.2
	Quantities of building materials needed (Mt, annual average 2015-2050)	51	18	22	40	37
	Quantity of construction materials re-used (thousands of tonnes)	550	3,925	3,666	3,719	12,018
	Water consumption in agriculture for irrigation (billion m ³)	3.3	1.8	2.3	3.1	4.5
	Quantity of biomass used as materials (MtDM)***	10.3 (2017)	12.7	12.9	13.5	13.9
	Quantity of biomass used for energy purposes (MtDM)	34 (2017)	90.5	91.5	115.2	109.6
	Land take by area (thousand ha) ¹⁰	5,263 (2020)	5,061	5,567	6,073	7,085
	Agricultural land (thousand ha)	28,778	25,636	27,712	27,164	26,695
	Surface area of forests and poplar farms in mainland France (thousand ha)	16,914 (2020)	19,769	17,515	17,564	17,264

* Land use, land-use change and forestry.

**Includes an estimate of the amount sequestered in forest soil and deadwood (-9 MtCO₂eq) in addition to the official LULUCF inventory for France (-35 MtCO₂eq).

*** Million tonnes dry matter.

¹⁰ Indicator derived from work on modelling agricultural production; base data: surface area from the TERUTI-LUCAS study. It will be completed for the areas of housing, public services, industrial, commercial, tertiary, logistics and agricultural activities, mobility infrastructure and energy production in the publication dedicated to land use and soil quality to be published in the first quarter of 2022.

Energy balance

Taking into account different degrees of implementation of measures that reduce final consumption (sufficiency, efficiency) or increase it (relocalisation of industry in S1 and S2), energy consumption is reduced by 23% (in S4) to 55% (in S1) compared with 2015, including non-energy uses and excluding international bunkers. The intensity of this decrease is the largest for the transport sector (-73% in S1 and S2 compared with 2015). It results both from restrained usage in S1 and S2, but also from the efficiency of electric motors in all scenarios. In the case of construction, reductions in consumption are greater than 45% in S1 and S2, whereas they are only about 16% in S4 (Chart 12).

Demand by energy carrier changes significantly in all scenarios:

- liquid fossil fuels disappear almost entirely in all scenarios, in favour of grid energies (electricity, gas and heat);
- renewable energy distributed off-grid (wood energy, biofuel, renewable heat from heat pumps and geothermal energy) increases by 32% to 45% in all scenarios compared with 2015;
- the share of electricity in final energy consumption increases in all scenarios compared with today (27%): it represents between 42% (S1) and 56% (S4) of final consumption for energy uses in 2050. But this increase in relative share does not necessarily mean an increase in total electricity consumption in absolute terms in 2050, including electricity used

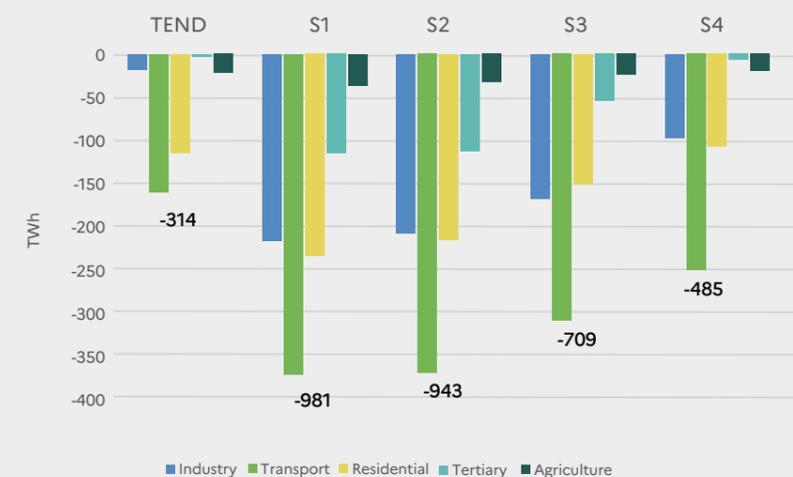
to manufacture other final energy carriers such as hydrogen. Compared with 2015, the amount of electricity to be generated (including losses) decreases by 20% in S1, is relatively stable in S2 (+6%), increases by almost 30% in S3, and by 65% in S4.

The share of mains gas decreases in all scenarios, reaching a residual consumption of about 150 TWh in S1 and S2 (i.e. a decrease of more than 65% compared with 2015), which can mostly be produced from renewable energies. The decrease in demand of only 15% in S4 requires maintaining a significant share of imported natural gas (about 50%), with the GHG impact offset by development of DACCS.

District heating systems develop in all scenarios (up to a 2.3-fold increase in heat delivered in S3), except in S1 due to less urban development.

In the scenarios, renewable energy becomes the major source of energy supply. Renewable energy, which covers about 15% of gross final energy consumption today, will cover 70% (S4) to 88% (S1) in 2050.

Chart 12 Difference in final energy consumption of sectors in 2050 compared with 2015 (with non-energy uses excluding technological sinks and international bunkers)



FINDINGS

by sector

GHG balance

The balance of GHG emissions and sequestration shows that in all four scenarios, net annual emissions are cancelled out in 2050 by drastic reductions and a combination of natural and technological sinks. All scenarios also present residual emissions until 2050, which corresponds to certain uses where consumption of carbon containing energy cannot be avoided, but especially process emissions (industrial and enteric fermentation).

The scenarios differ in the composition and level of the residual emissions left in 2050, as well as in the composition and degree of GHG sequestration sources. The lower pressure on land and biomass resources in S1 and S2 allows biological sinks (forestry and agriculture) to contribute more to sequestration, greater than 90 MtCO₂ per year. On the other hand, the greater exploitation of forests and lesser degree of change in diet and agricultural production in S3

and S4, combined with high demand, limit the capacity of biological sinks to ~60 and ~40 MtCO₂ respectively, and require rapid development of technological solutions for CO₂ capture:

- in all scenarios except S1, by industrial emissions reductions using CCS technologies;
- in S2 (very slightly), S3 and S4, by use of CCS on biomass plants (biorefinery or combined heat and power from wood, BECCS);
- in S4 by the necessary use of Direct Air Carbon Capture and Storage (DACCS) (Chart 13).



Adaptation to climate change

In addition to technical and economic issues, constraints, implementation conditions and climate-sensitive assumptions are additional but unavoidable difficulties in the construction of alternative futures. These questions, which are included in the sectoral chapters, require further knowledge to be developed on impacts to account for the complexity of the phenomena involved. Overall, climate change is

intrinsically linked to preservation of biodiversity. Treating the two issues separately risks compromising our ability to successfully stop climate change while preserving ecosystems. The issue can be broken down into different areas: combating land degradation, water management, development, lifestyles, etc., but it is ultimately our relationship with nature that is being questioned.



Regional development and urban planning

For regional development and urban planning, the sequence “Avoid, Reduce and Compensate” will be used to rethink the city and the region with restrained and sustainable management of resources, in particular soils. With the exception of scenario S4,

nature has an unequivocal place in these scenarios for the co-benefits it can bring in terms of well-being, biodiversity and combating climate change, both in terms of mitigation and adaptation (carbon sequestration, effect on urban cooling, etc.).



Residential and tertiary buildings

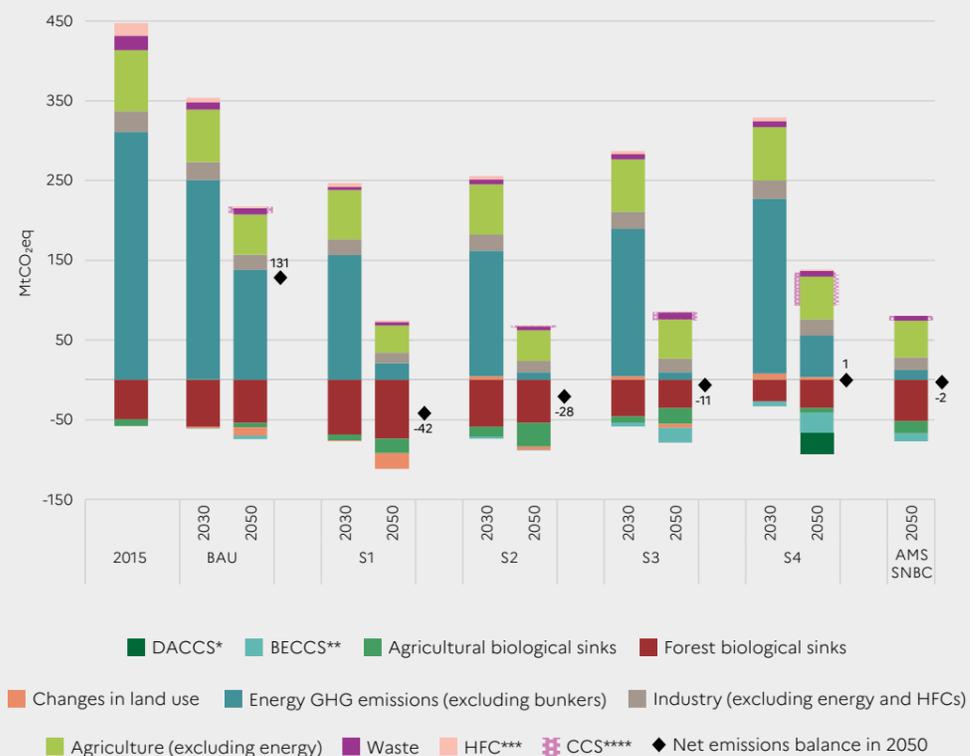
The transition of buildings must be accelerated right now. Scenario S1 relies on widespread thermal renovation and sufficiency in building use to reduce their climate footprint. Scenarios S2 and S3 lead to similar emissions, but with two different strategies: insulating buildings as a priority in S2, and decarbonisation of heating methods as a priority in S3. By placing less emphasis on improving the insulation of buildings, scenarios S3 and S4 shift the responsibility for decarbonisation of the building sector to other sectors (development of low-emission energies for S3, carbon capture and storage for S4).

must be subject to specific measures to accompany the change in social norms (limiting the housing surface area per person, use of fewer appliances); consumption linked to **new uses** (air-conditioning, data centres) must be controlled; finally, **efficiency measures at housing stock level** (reuse of existing buildings, increase in the intensity of use to build less) constitute an opportunity for sufficiency: they reduce the number of main residences in S1 and S2 by 2 million in comparison with the other scenarios.

The buildings transition requires that no lever is neglected: **energy renovation** is essential (especially in S1, S2 and S3 which lead in 2050 to a housing stock where **about 90% of accommodation existing in 2015 has been renovated**) (Chart 14, next page); **daily life**

Scenarios S3 and S4 generate the highest consumption of materials: between 1300 and 1400 million tonnes cumulatively over the period 2015-2050. This is more than double the consumption of S1. In all scenarios, the residential sector consumes the most materials.

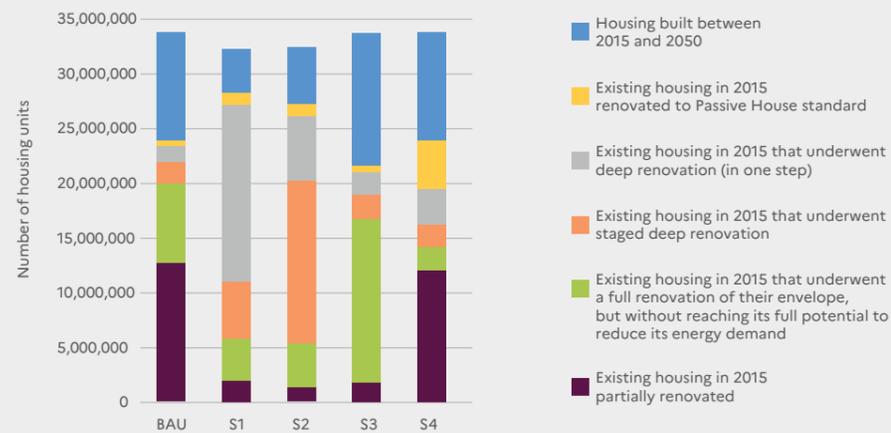
Chart 13 Balance of GHG emissions and capture in 2030 and 2050



Note: emissions are shown as positive and sinks as negative below the horizontal axis. But the contribution of CCS technologies to the balance is considered as a reduction in emissions, not a sink. It is shown as negative in the upper part of the chart. Non-energy emissions from agriculture are CH₄, N₂O and CO₂. Other emissions are GHGs from industrial processes, incineration and waste storage.

* DACCS: direct air carbon capture and storage.
 ** BECCS: bioenergy with carbon capture and storage.
 *** HFC: hydrofluorocarbons (refrigerant gases).
 **** CCS: carbon capture and storage.

Chart 14 Main housing stock in 2050 - Breakdown by energy performance level in all scenarios (number of housing units)



Passenger mobility and freight transport

Five levers have been identified to reduce emissions from mobility of people and goods: moderation of transport demand, modal shift, filling vehicles, vehicle energy efficiency and energy decarbonisation. Partly due to land use plans that are more focused on the local economy, S1 and S2 can act more strongly on the first three levers and on certain efficiency levers that are more related to sufficiency, while S3 and S4 act more strongly on the last two, more technological levers. The four scenarios therefore explore a wide range of possible futures: for example, in terms of passenger mobility needs, which evolve from -26% (S1) to +39% (S4) compared with 2015.

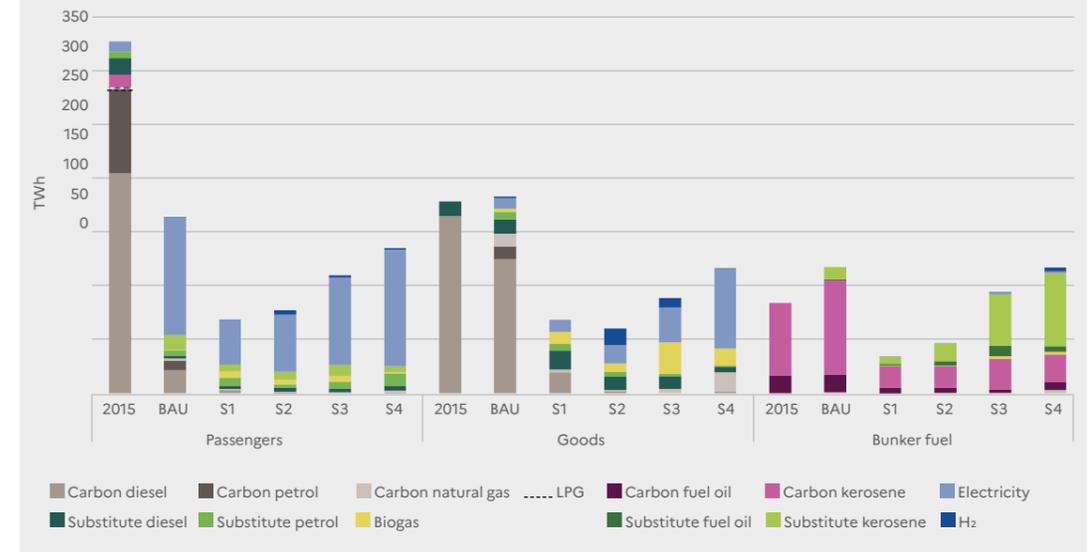
Sufficiency levers reduce energy requirements by a factor of more than two compared with the current trend scenario and reduce several environmental pressures related to mobility. **Efficiency and decarbonisation** levers are essential in all scenarios.

In particular, **electrification is essential** for light road vehicles. **Biomass** (biofuels and biogas) completes the mix of heavy goods vehicles, shipping and air transport modes, which are more difficult to decarbonise. **Hydrogen** is used additionally in certain scenarios (**Chart 15**)

Thus:

- for passenger transport, 80 to 87% of energy demand in 2050, including long-distance air transport, will be met by fossil free energy carriers (electricity, hydrogen, liquid and gaseous biofuels and synthetic fuels);
- for freight transport, decarbonisation is slower and the energy carriers are more diversified, particularly for heavy goods vehicles and international shipping. Depending on the scenario, fossil-free carriers meet 65% to 91% of energy demand in 2050.

Chart 15 Energy demand for transport in 2050 by energy carrier and scenario (for passenger transport, cargo and bunkers [international transport])



I Food

Three main levers can drastically reduce the environmental impact of food, **to build win-win strategies between climate impact and health impact**:

- a change in diet towards healthier and **less meat based diets**, particularly by reducing meat consumption by a factor of three (S1) or two (S2) or by 30% (S3) compared with today;
- the demand for products with high environmental value (**low level of inputs**), which become the majority in S1 and S2;
- **reduction in losses and waste**, which reaches 50% in all the scenarios, via levers that are more behavioural in S1 and S2 and more technological and digital in S4.

Thus, S1 and S2 are based on a high degree of sufficiency for individuals, companies and communities and a strengthened social role for healthy and sustainable food. S3, and S4 to an even greater extent,

rely more on technological innovation. Efficiency gains are driven in particular by artificial intelligence or digital technology, with a lesser effect on changing diets and the environmental quality of products, requiring a shift in efforts to other sectors. The latter two scenarios benefit less from health gains than S1 and S2.

Considering only the impact of lower meat consumption on agricultural emissions (the main item in the current diet), the scenarios result in a carbon emission reduction of about 40% for S1 compared with current emissions, against only 6% for S4. Impacts of the same order of magnitude are estimated on the land use footprint.

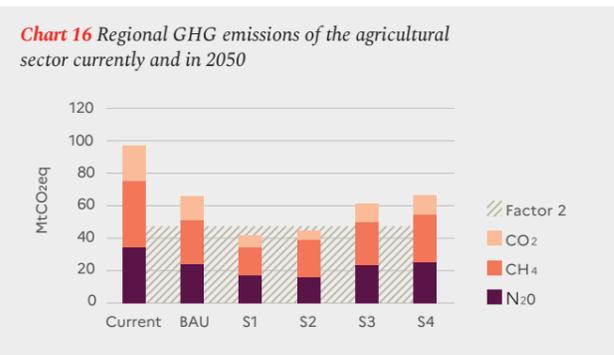
Agricultural production

By 2050, the agricultural sector will be at the crossroads of multiple challenges. It must meet both food and non-food demands, provide various essential ecosystem services (carbon storage, but also biodiversity reservoirs, soil and water quality conservation, etc.) and adapt to climate change, while contributing to France's carbon neutrality objectives. Depending on the scenario, different interdependent levers are activated, such as: agroecology, reduction of livestock and a shift to more extensive systems, reduced irrigation needs, production of biomass for energy.

The simulations carried out show that halving GHG emissions from the agricultural sector is only possible in S1 and S2 through greater sufficiency and a better consideration of the essential role of the living world in maintaining our production capacities (Chart 16). All stakeholders in the sector must make a transition, in particular through the change in diet. To be successful, this major transition must be supported.

Beyond the GHG emissions aspect, the more extensive scenarios S1 and S2 also reduce irrigation water consumption (halved compared with today in S1), as well as the use of crop-protection products (reduced by a factor of five in S2 compared with today) and synthetic fertilisers (mineral nitrogen) in favour of biological nitrogen inputs or development of legumes, which provide symbiotic nitrogen fixation.

On the other hand, S3 and S4 favour more intensive systems, but technically optimised to reduce their impacts (compared with current systems and those extrapolated from current trends). The contribution of the agricultural sector to biogas and biofuel production is highest in S3.



Forestry production

The search for a balance between carbon storage in ecosystems and increased harvesting to replace non-renewable materials and energy sources governs the forestry production scenarios. Therefore, by varying the rate of wood removal from the biological growth of forests (which falls from 59% in 2018 to about 55% in S1, and increases up to 82% for S4 in 2050), forestry sinks are greatly reduced in S3 and S4 and the availability of wood for the wood materials and energy sectors differs depending on the scenario: stability for S1 until 2050, +9 Mm³/year in S2 and +19 Mm³/year in S3 and S4 compared with today.

In all cases, it is essential to stop clearing forests, to manage them sustainably and to restore damaged stocks, to promote their resilience and adaptation to the impacts of climate change while protecting biodiversity and carbon storage. Directing wood harvesting to uses that have a long service life by promoting the recycled use of wood in cascade¹¹ is also an effective mitigation lever.

¹¹ Principle according to which wood is used in the following order of priority: 1) wood-based products, 2) extension of their life, 3) reuse, 4) recycling, 5) bioenergy and 6) disposal.

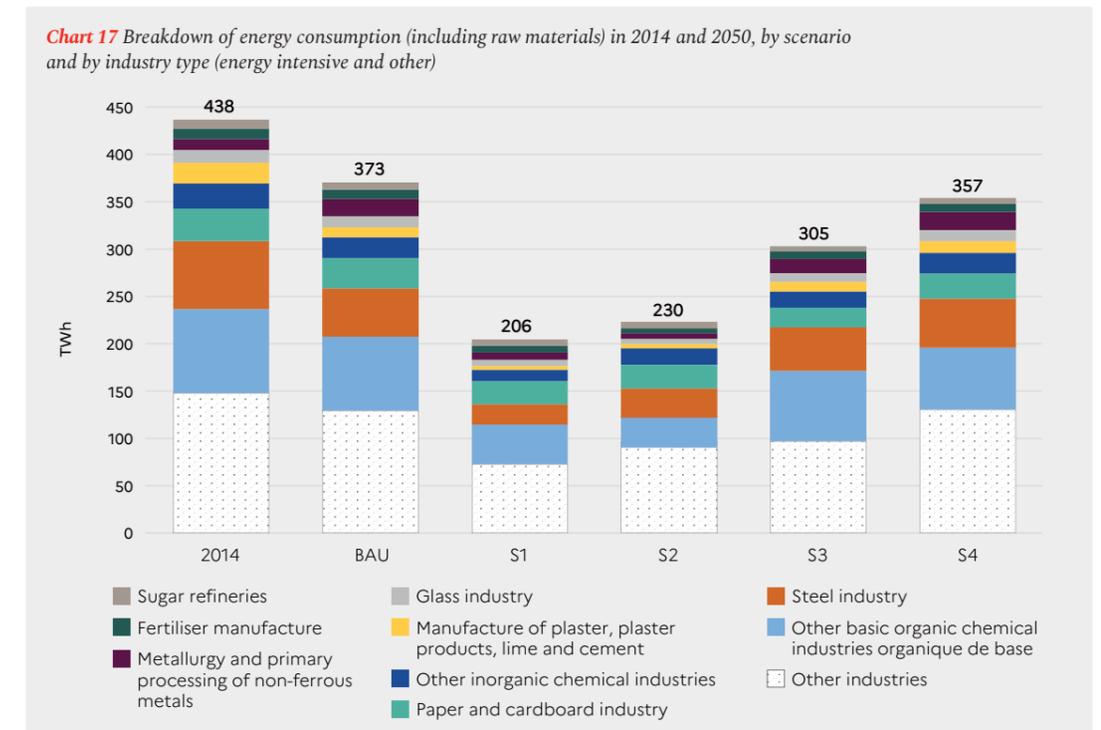
Industrial production

Scenarios S2 and S3 achieve a strong reduction in industrial emissions: 84% and 86% respectively (including CCS). In S2, this is essentially due to major efforts in terms of sufficiency and efficiency coupled with strong re-industrialisation, and in S3, by strong decarbonisation of the energy mix. This reduction is lower (79%) in S1 because it is mainly driven by consumer sufficiency favouring local industrial production, without recourse to CCS. Finally, while S4 will only reduce emissions by 54%, the technical gamble on CCS deployed on a large scale is liable to abate emissions by 96% compared with 2014 levels. Scenarios S1 and S2 also limit the risk of "carbon leakage", avoiding the off-shoring of heavy industry to countries with lower carbon taxes.

This major decarbonisation of industry is based, first of all, on a decline in physical demand for industrial products: a decrease in production of primary materials¹² is observed in all scenarios (by 38%, 26%, 14% and 2% respectively in S1, S2, S3 and S4). This decline is the result of developments in downstream sectors (decline in new construction in the building sector, decline in plastics and fertilisers for the chemical industry, etc.), improvements in material efficiency and recycling, and changes in trade balances. This decline in volume is part of a new industrial model that promotes quality over quantity and is based on

a circular economy with quality products that are more expensive but durable, eco-designed, repairable, reusable and recyclable (S1 and S2). For S3 and S4 the model is more quantitative, but with decarbonised processes and energy.

This industry transition requires anticipating and supporting new business models and positioning the French low-carbon industry in international trade. It also involves large-scale low-carbon investment plans (decarbonisation of the energy mix, energy and material efficiency, carbon capture, utilisation and storage [CCUS], etc.), both for mass market use of mature technologies and for disruptive innovations in industrial processes as well as for deployment of the necessary infrastructure. To achieve this, the visibility and security of low-carbon markets, as well as public support in terms of incentives and land-use planning, will be key. Finally, it implies above all a change in the structure of jobs in the sector and therefore the need for a proactive policy on the part of public and private stakeholders in terms of employment and skills. Understanding and participation by all of society (citizens, employees) in these transformations will be essential to unite society around this "new low-carbon industrial revolution" (Chart 17).



¹² On average over the 70 industrial sub-sectors considered (categories 12 to 38 of the Nomenclature of Economic Activities for the study of energy deliveries and consumption).



Gas and hydrogen mix

The development potential for renewable gas production by 2050 is very significant compared with today at between 130 TWh_{LHV} and 185 TWh_{LHV}, i.e. 30% to 43% of current fossil gas consumption. Whatever the scenario, anaerobic digestion is the mainstay of gas decarbonisation (Chart 18). The second pathway is based on coupling anaerobic digestion with power-to-methane, which uses the biogenic CO₂ emitted by anaerobic digestion. Depending on available resources, pyrogasification can be an additional route. Major decarbonisation of gas is possible (82 to 88%), provided that demand for gas decreases significantly compared with today (by -50% to -70%). Otherwise, the situation requires imports of renewable or decarbonised gas¹³ and the use of technology sinks to offset the remaining emissions from natural gas.

Hydrogen consumption is higher than today in all scenarios (up to 4.5 times higher) and electrolysis technology is proving essential to replace the hydrogen currently produced from fossil gas. Hydrogen production in France reaches a maximum of 96 TWh in 2050 in the S2 scenario for various uses (power-to-gas and mobility) to which more centralised industrial uses are added such as fertiliser and methanol production, liquid fuels synthesis and reduction of iron ore. Only scenario S3 also relies on hydrogen imports (48 TWh).

The decade 2020-2030 is crucial to put the country on the right track for developing electrolysis capacity. At the same time, new hydrogen-consuming sectors will emerge before 2030: heavy mobility using hydrogen directly or indirectly, power-to-gas, methanol production and the steel industry.



Electricity generation mix

Electricity generation mix scenarios vary in two main ways. On the one hand, very different levels in electricity demand (from 400 TWh in S1 to 800 TWh in S4, including all uses of electricity, such as production of hydrogen or other end-use carriers and to power technological carbon capture). And on the other hand, the differing planning, public involvement or public governance policies underlying the four scenarios. Therefore S1 and S2 are based solely on the installation of new renewable energy capacities, but with two different approaches: for S1, small-scale facilities and widespread distribution over France to promote appropriation by citizens and local authorities; in S2, large-scale facilities and

cost minimisation. S3 and S4 follow the same policy of cost minimisation as S2, but the increase in demand for electricity requires a strong role for the State, which enables the industrial and massive deployment of technologies such as EPRs or offshore wind turbines.

Whatever the technological choices, all scenarios involve the massive development of renewable energies (solar, onshore and offshore wind).

The results on the electricity mix will be detailed in a later publication.



Heat and cooling distributed via urban and off-grid systems (including biomass energy)

Today, heating needs represent about 50% of final energy consumption in France, mainly for space heating and industrial processes. This heat can be distributed via urban systems or produced in a decentralised way ("off-grid heat").

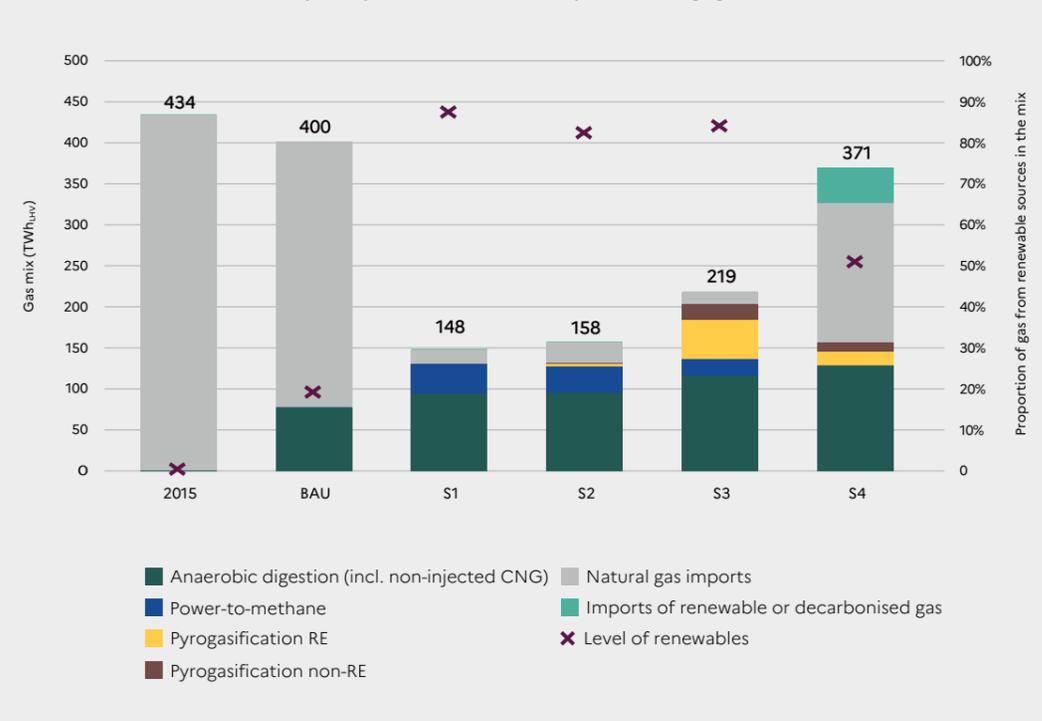
In all scenarios, heat demand decreases compared with 2015 (700 TWh), quite significantly in S1 (351 TWh), S2 (358 TWh) and S3 (440 TWh) and to a lesser extent in S4 (612 TWh) with the disappearance or near disappearance of fuel oil and coal. Gas is maintained, but at low levels: between 11% and 32% off-grid (45% in 2015) and between 10% and 12% in urban systems (39% in 2015) depending on the scenario, with more than 80% decarbonised gas in S1, S2 and S3 and 32% in S4. In grids, they increase greatly in all scenarios, from 50% in 2015 to

about 90%. Overall, and for all scenarios, the distribution of heat production between grid and off-grid supply shows an increase in the share of grid supply in 2050, from 3% in 2015 to 8% in S1, 10% in S2 and S3 and 6% in S4.

Supply of cooling is low in S1 (6.4 TWh) and S2 (6.5 TWh), but more significant in S3 (25.2 TWh) and S4 (28.4 TWh), due to decentralised technologies such as heat pumps.

For residential wood heating, current trends continue in S1 of steady national consumption of wood and an increase in the number of households heating with wood. The other scenarios, on the other hand, show lower consumption, which can be explained by significant energy sufficiency (S2), widespread use of electrically powered heating in homes (S3) or a social requirement for automation that leaves little room for wood heating systems, especially logs (S4). Finally, a common trend in each of the scenarios is the significant increase in biomass in systems between now and 2050.

Chart 18 Gas mix in 2015 and 2050 for the five ADEME scenarios (reference and high gas variant)



¹³ Production by oil-producing countries, for example, which may want to maintain their business models by producing fuels or synthesis gas using their abundant sunlight.

Liquid fuels

In all scenarios, despite a sharp decline in demand for liquid fuels, the supply of biofuels, even if supplemented by synthetic fuels, does not meet demand from the transport sector. In S1 and S2, the supply of liquid fuels comes mainly from conventional biofuels (produced from agricultural resources), currently the only mature biofuel production pathway: this varies from 25 TWh in S2 to 43 TWh in S1. Its development depends on changes in food demand. In S3 and S4, on the other hand, the production of advanced biofuels is developing in addition to conventional biofuels through diversification of resources, especially lignocellulosic ones.

However, development is limited by availability of resources. It depends on forest management policies and production of waste, which determine the total biomass and non-recyclable carbon waste resources. It also depends on other uses of these inputs for the manufacture of materials, direct combustion or gas production. Therefore in S1, the advanced biofuels

sector is only marginally developed because of demands on the resource and to promote carbon storage in ecosystems. On the other hand, scenarios S3 and S4 use biomass to a large extent, which leads to major development of the sector, which varies between 8 TWh and 76 TWh depending on the scenario.

Faced with the limits of biomass resources, electro-fuels can complement renewable liquid fuels. However, their development is constrained by the amounts of electricity required and may compete with direct uses of hydrogen or power-to-gas (production of methane from hydrogen and CO₂), hence the minor development of e-fuels in S2, S3 and S4.

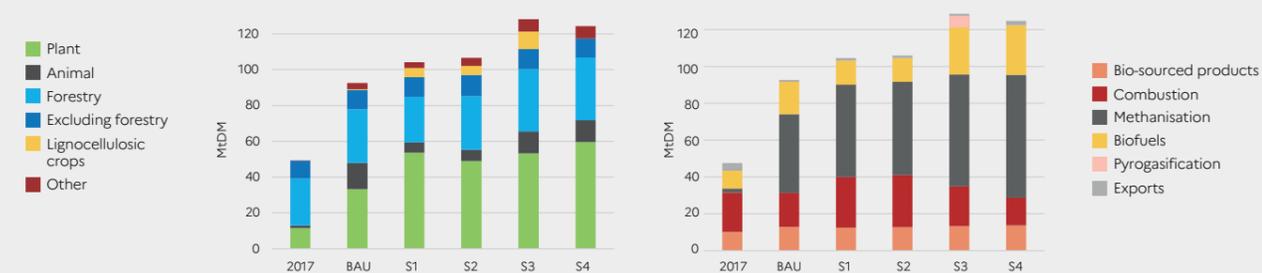
Biomass resources and non-food uses

For all scenarios, biomass consumption for non-food use is more than doubled compared with 2017, but with different strategies in terms of resources mobilised, while respecting the physical limits of all the uses considered (Chart 19).

The volume of biomass used exceeds 100 million tonnes of dry matter (MtDM) in 2050 and even reaches 120 MtDM in S3 and S4. This makes the resource an essential "mainstay" in all scenarios. In all scenarios, plant biomass of agricultural origin represents the strongest lever for growth and increases from 11 MtDM in 2017 to at least 50 MtDM in 2050. Scenarios differ, however, in the total volume of biomass

and the distribution between the resources used: forestry, agricultural crops, effluent. The intended uses (bio-based product, combustion, anaerobic digestion, biofuel) also vary from one scenario to another. Combustion, which today represents almost half of uses, barely grows in absolute value: in all scenarios, it represents less than 30% of uses (in tonnage). Conversely, anaerobic digestion uses at least half of the biomass tonnage - agricultural, lignocellulosic and waste.

Chart 19 Biomass resources and non-food uses in million tonnes dry matter (MtDM)



Plants: intermediate crops, crop residues, surplus grassland;
Animals: livestock manure;
Excluding forestry: wood;
Lignocellulosic crops: short rotation forestry, miscanthus;

Other: waste (wood, industries), household waste (bio-waste), sludge, silo residues, co-products and by-products of the agri-food industries;
Bio-based products: non-energy and non-food uses of biomass (e.g. building materials).

Waste

The scenarios studied correspond to a decrease of about 30% in the amount of waste in S1 and S2 compared with 2015, while the level of waste production is maintained in S3 and S4 (between 90,000 and 100,000 kt/year), notably due to higher production of building waste, itself generated by the "Haussmannian" scenario of demolition and reconstruction. Scenarios S1, S2 and S3 meet the target of a 50% reduction in the quantity of waste sent to landfill by 2025 (by 2026 for S1). S4 meets this target only in 2028.

The exercise shows that, whatever the scenario, the demand for recycling raw materials and energy leads

to a virtual disappearance of final waste storage. In S3, the demand for solid recovered fuels is such that the waste management hierarchy is turned upside down: priority is given to energy recovery to the detriment of some material recovery. In all scenarios, either as a matter of principle or necessity, **the circular use of material, including organic material**, is a central element of the economic model and waste management policy. Moreover, waste production depends on industrial production and therefore on final demand. This is why it is essential to take **as much action on final demand as on intermediate consumption**, to limit the impact on the downstream part of the supply chain.

Carbon sinks

Protection of existing carbon stocks and sinks in ecosystems, as well as development of additional sequestration, are two essential levers for achieving carbon neutrality. The development of additional sequestration can be based on both natural and technological sinks. This means that all scenarios show an increase in sinks by a factor of 2 to 3 compared with 2017. For the first two scenarios, this increase is mainly based on natural sinks (forests, agricultural land) while it is mainly based on technological sinks (BECCS, DACCS¹⁴) in scenarios S3 and S4.

In addition to their role in biodiversity, natural ecosystems are already major carbon stocks and sinks. In all scenarios, "natural" sinks play a role in achieving carbon neutrality by 2050 on a national scale. A crucial issue is therefore to **avoid degradation** that is practically irreversible on human time scales (e.g. soil loss, deforestation or forest degradation) and to en-

sure sustainable agricultural practices and forestry management that guarantee that ecosystems can function properly and that promote their resilience in the face of climate change.

Technological carbon sinks are currently barely developed or not developed at all. Depending on the scenarios and time horizons considered, they do not all have the same potential and, above all, they do not all have the same impact. BECCS will be able to build on the **deployment of CCS, which is a necessary technology for industry to reduce its incompressible emissions, by substitution of fossil resources with biomass**. DACCS, deployed only in S4 and characterised by high energy and resource consumption, may not be operational soon enough to help achieve carbon neutrality in 2050 and may prove to be very costly in energy (6% of electricity consumption).

¹⁴ BECCS: bioenergy with carbon capture and storage; DACCS: direct air carbon capture and storage.

LIMITATIONS

and prospects

This exercise incorporates analytical advances in a number of areas that have been little or poorly studied in climate forecasts. It also contains limitations, for each sector (detailed in the dedicated chapters) and across the whole exercise.

- **Modelling that is by necessity theoretical:** any model is by definition a simplification of reality. The models used in this exercise have varying degrees of accuracy, without it being possible to quantify the margins of uncertainty associated with the modelling results. The results presented here should therefore be considered as orders of magnitude. ADEME proposes several archetypal scenarios, each of them intentionally distinct, presenting the economic, technical and societal options to reach carbon neutrality, without exhausting the range of possible futures that could be chosen.
- **Absence of formal modelling of crises and breakthroughs,** whether economic, environmental or systemic. Major changes in social systems could occur more easily in the context of a crisis or following a major crisis, which would thus play the role of a catalyst for change.
- **Environmental footprint.** In accordance with the French national low-carbon strategy (SNBC), the neutrality targeted in this exercise is defined at the scale of mainland France and on direct emissions, which excludes the impact of imported products. Two documents will soon complement this publication, one dedicated to metals of the ecological transition and the other to the GHG footprint of materials in the scenarios.
- **Multi-criteria optimisation.** We have chosen to build the scenarios only on the two criteria of energy and GHG emissions. While other impacts are documented, the scenarios are not designed to be optimised from a multi-criteria perspective, including consideration of the economic cost of the transition. However, such an approach could lead to a review of certain pathways.
- **Adaptation to climate change.** The impacts of climate change are thoroughly considered in changes in needs (for example in air conditioning). Concerning the specific issues of adaptation, a first estimate has been carried out within the framework of this exercise, in particular for forestry, but for other sectors the approach is more qualitative, or even non-existent, depending on the state of knowledge of each sector.
- **Biodiversity and ecosystems.** No accurate figures on impacts on biodiversity and ecosystems could be produced, in particular due to the lack of geographical localisation of the scenarios. Discussions are ongoing with the French Office for Biodiversity to document the assessment of these impacts.
- **Water resources.** The question of water use and impacts on water resources and aquatic environments could not be studied in depth. Nevertheless, discussions have been initiated with the water agencies to further explore this strategic issue.
- **Regionalisation of scenarios.** The interest is obvious, especially in terms of facilitating a coherent transition to action aligned with the constraints inherent to each region. The time available has not allowed this objective to be achieved so far, but work has already begun.
- **A society made of diversity.** The levers explored in the scenarios express averages for all of the people of France. However, there is a need to explore, beyond these averages, how different social groups, characterised by different norms, practices and resources, can make use of these levers. The same is true for social and fairness aspects of the transition. Particularly on the issues of wealth distribution and inequalities, or on the role or attractiveness of the regions in the transition.
- **Still imperfect knowledge of the sufficiency and technological sink levers.** The juxtaposition of scenarios built on very different driving forces may suggest that the various levers considered (sufficiency, energy efficiency, new technologies, etc.) benefited from the same level of expertise and feedback. However, whether in the field of sufficiency or carbon sinks, knowledge is much less developed than in energy efficiency or renewable energy, which have been studied and researched for several decades.

Next steps in this work

This work is just the first part of a series of publications that will be published during 2022. Most of these publications will be put into perspective during the *Grand Défi Écologique* (the “Great Environmental Challenge”), an event organised by ADEME on 29 and 30 March 2022 in Angers.

This series of publications will cover the following subjects:

Analysis of the electricity generation mix

Materials for the Energy Transition

Macroeconomic assessments including employment and investment

Analysis of changes in lifestyle, conducted through a qualitative study of views and perceptions of the scenario narratives by 31 French people from different backgrounds

Footprint of materials, greenhouse gases, resources and consumer goods

Soil

Adaptation to climate change

Analysis of the impact on some key sectors, in particular: “New construction”, “Gas and liquid fuels”, “Proteins” and “Last mile logistics”

Robustness and vulnerability to shocks

Air quality

Regions (in the form of a guide to help regions with forward planning)

Digital

SYNTHESIS TRANSITION(S) 2050

“Transition(s) 2050. Decide now. Act 4 climate” is a forward-looking exercise describing four consistent and contrasting pathways to carbon neutrality in France in 2050. The pathways aim to link the technical and economic aspects with consideration of the societal transformations that they assume or provoke.

The following sectors are considered in detail: those related to consumption (land development, building, mobility and food); those forming the production system (agriculture, forestry and industry), those forming the energy supply (gas, cooling and heating, biomass, liquid fuels and hydrogen); those that constitute resources (biomass and waste) and carbon sinks. Wherever possible, these sectors are also analysed for their impact on water, soils, materials and air quality.

This publication is the result of more than two years’ work by ADEME, in interaction with external partners, to inform decision-making in the coming years. For the aim is not to propose a political project or “the” right pathway, but rather to bring together technical, economic and environmental knowledge to raise awareness of the implications of the societal and technical choices that the chosen paths will entail.

This document is published by ADEME.

Find the ADEME scenarios

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Illustrations: Stéphane Kiehl

Editorial and graphic design: bearideas

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