DDP DEEP DECARBONIZATION PATHWAYS

DEEP DECARBONIZATION PATHWAYS **of freight transport**

IN FRANCE

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DEEP DECARBONIZATION PATHWAYS (DDP) INITIATIVE

The DDP initiative is an initiative of the Institute for Sustainable Development and International Relations (IDDRI). It aims to demonstrate how countries can transform their economies by 2050 to reduce their greenhouse gas emissions in a deep and coherent way, with the aim of reaching carbon neutrality as soon as possible in the second half of the 20th century. The DDP initiative is based on the Deep Decarbonization Pathways Project (DDPP), which analysed the deep decarbonisation of energy systems in 16 countries prior to COP 21 (deepdecarbonization.org). Both projects share key principles. Analyses are carried out at the national scale, by national research teams, working independently from their governments. These analyses adopt a long-term time horizon to 2050 to reveal the necessary short-term conditions and actions consistent with the achievement of long-term climate and development objectives. Finally, national research teams openly share their methods, modelling tools, data and the results of their analyses to share knowledge between partners in a very collaborative manner and to facilitate engagement with sectoral experts and decision-makers. The development of long-term deep decarbonisation sectoral trajectories in different countries, in this case with freight transport in France, is part of this broader initiative.

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DEEP DECARBONIZATION PATHWAYS

OF FREIGHT TRANSPORT

IN FRANCE

DESCRIPTIVE REPORT, DECEMBER 2019

This document is a “descriptive report” of scenarios of deep decarbonisation of freight transport in France by 2050. It targets various societal actors with an interest in exploring two coherent stories of the main transformations (societal, organisational, technological and political) leading to the decarbonisation of this sector as well as their consequences on a set of dimensions, such as the number of tonnes transported, the proportion of rail, the circulation of road vehicles, the final energy demand, and the place of different energy carriers. This document will soon be supplemented by a “technical report” describing the underlying assumptions considered.

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Method and scenario choice

Philosophy

In 2015, France adopted a first reference document that defined a scenario to decarbonise the national economy: the National Low Carbon Strategy (SNBC). This document was revised for the first time in 2019, setting the objective of "carbon neutrality". This revision calls for the level of annual greenhouse gas emissions from the passenger and goods transport sector to be reduced to 4 $MtCO_2e$ by 2050, a figure that currently stands at around 137 $MtCO_2e$, with fossil fuel consumption by domestic air transport being responsible for this residual amount of national emissions in 2050. This high level of ambition therefore represents a huge challenge for goods transportation by road, rail or river (subject of this study): the total decarbonisation.

A specific focus on the freight sector is essential given its importance in current total national GHG emissions (around 7 to 9% in 2015 according to national emission inventories), particularly when the sector's emissions have only stabilised over the last ten years, while other sectors, such as the residential or productive sector, have achieved reductions. During the subprime mortgage crisis (2007-2009), emissions from the transport of goods fell sharply to reach a level comparable to that of 1990, mainly due to a decrease in demand.

A brief overview of previous freight decarbonisation studies reveals that certain key aspects of the changes undergone in the sector have rarely been subject to analysis or investigation, even though they constitute important factors of the sector's emissions and may constitute crucial levers for considering ambitious mitigation policies. For example, aspects related to the possible future of freight demand and the future of multimodal transport systems for freight, as well as how these aspects would link to technological transformations. Furthermore, public documents on SNBC's proposed pathway for freight transport do not provide sufficient details on the factors and conditions associated with these transformations to understand the transformation trajectory, the scope of the necessary changes, and the actions that must be undertaken today by the various actors (shippers, carriers, authorities, consumers). The explicit formulation of these variables could also enable the construction of a comparative analysis of all possibilities and their related uncertainties, which would facilitate a comparison between these possibilities and the level of ambition required by the "carbon neutrality" objective.

Transport economics and the environment

To better understand the impacts of our scenarios on the future of the freight sector in France and on its decarbonisation, a review of its functioning and interactions with logistics chains is beneficial.

Goods transportation, which is never an end in itself, depends on the context in which it takes place and conditions the functioning of logistics chains, which serve to provide customers with a level of service corresponding to their preferences, at an acceptable cost. The level of service is multidimensional: delivery speed, reliability of schedules, place of delivery, etc. Industrial constraints, regulations, the availability of natural resources and infrastructure, the rationale underlying the location of facilities influence the morphology of logistics chains and the demands of shippers in terms of transport. Technological (e.g. automation), organisational (e.g. just-in-time), commercial (e.g. omni-channel logistics) and digital (e.g. e-commerce) transformations can therefore have profound effects on these sectors.

Goods transportation also involves a variety of modes, vehicles, networks, and businesses. This diversity reflects the plurality of logistical needs and the heterogeneity of geographic contexts. A coexistence of practices therefore exists, ranging from the delivery of hot food by bicycle in less than an hour, to the intercontinental transport of refrigerated containers by sea, which takes several weeks. In addition, networks and services are configured to allow, as much as possible, the pooling of transport resources, particularly for palletised goods or parcels.

The use of environmentally friendly transport modes raises significant challenges for the supply chain. For example, the use of freight trains will only be economically preferable for a shipper if it can accumulate sufficient quantities of goods to be shipped, so that the high fixed costs of rail become lower unit costs than for road, and that too much time will not be wasted in modal transfers. This means that a substantial critical mass must be reached, which is only possible if a freight company can allow goods to be held in transit for long periods of time, which is not always the case. In addition, the uneven structure of the rail network contributes to making it competitive only beyond certain distances; and the distribution of industries across territories complicates the pooling of flows, that would in theory increase the critical mass mentioned above. This simplified representation ignores the intricacies related to transport timetables, operating constraints, interactions with passenger transport, etc. It is nevertheless sufficient to show that modal choices result from a complex interaction between logistics chains and freight characteristics.

This complexity is not specific to rail transport. It is general and has several consequences. Firstly, assessing the performance of the goods transportation system is by no means straightforward. Errors can be easily made by ignoring operational constraints and reaching the conclusion that the system is suboptimal (a fill rate in tonnage is an unsuitable indicator if volume is the constraining factor; the same is true if the constraint is the maximum duration of delivery rounds, such as in urban logistics). Secondly, supply chain developments and goods transportation are not guided by a single variable. Thus, it is often considered that accelerating turnaround times in industry, particularly the development of just-in-time logistics, is responsible for the increasing domination of road transport for goods. In reality, the underlying trends also concern flow dispersal, product diversification, and supply channels; which explains why adaptation has been easier for road freight transport through its ability to offer both a wide range of services, but also by developing many synergies between actors so that costs can be controlled. The diversity of logistical constraints therefore remains great, and some shippers will favour speed, others will seek high reliability, others will aim for minimum costs.

In the context of a foresight exercise focused on decarbonisation and the energy transition, these observations have several consequences. Firstly, the behavioural changes, particularly regarding modal choices, that our narratives imply can only be understood through the combined modification of several factors (distances, multimodal connectivity, price and speed of options, requirements of shipping companies and customers, etc.). Secondly, it is difficult to predict the future environmental impacts of freight transport. The use of a heavy mode, which is virtuous in principle, can only be effective if this mode is used in good conditions (for example with a sufficient filling rate). Lastly, the development of political and regulatory strategies that will be essential to achieve decarbonisation objectives must take this complexity into account, and adapt to it, failing which such strategies will be ineffective.

Goals

Based on this observation, and following up on its 2017 work on passenger transport, the Deep Decarbonisation Pathways (DDP) working group (composed of the University Gustave Eiffel, Cired, EDF R&D and Iddri) decided to carry out a study on the decarbonisation of goods transport in France, with two objectives:

- Provide a framework for developing, comparing and analysing decarbonisation scenarios for freight transport by 2050, describing all of the determinants of the transition and linking them to a set of quantified indicators. This framework should enable the building of transformation narratives that are as close to reality as possible, capable of supporting and informing a transparent dialogue on coherent strategies of socio-economic, technical and organisational transformations. To achieve this, an analytical framework was designed to create transparency and consistency between the mobilisation of the various socio-technical factors involved, and their quantified impacts on the decarbonisation of the sector.
- Start to explore the range of possibilities for the decarbonisation of the freight transport sector in France by mobilising this framework for scenario construction and analysis. To gain the most from this exercise, we created two scenarios based on contrasting rationales of change in the economic and social macrostructure, for the purposes of analysing the transformations in the transport, logistics and energy systems that would be necessary to achieve decarbonisation of freight transport by 2050 in each of these worlds. In practical terms, this study has enabled the comparison of a conventional narrative implying the continuation of

the current production-consumption-distribution structures, compared to a rupture scenario that on the contrary considers fundamental changes that affect the structure of the economy and the freight transport demand. A particular focus was placed on understanding and exploring an alternative future for transported goods, and its consequences on the organisation of the transport and logistics system as a whole, themes that receive little attention in the field of freight decarbonisation scenarios.

The methodological and analytical work presented in this report has an instructive and exploratory aim, rather than a prescriptive one. The intention is to encourage dialogue among all of the actors involved in the sector's transition and to create methodological conditions to ensure that such discussions can better inform decision-making regarding the measures to be implemented, from today onwards, to reach the long-term 2050 objectives.

Method

The fundamental methodological principles in common with the general approach of the DDP initiative are, notably: a national scale analysis, based on the specificities of the country, the long-term analysis by 2050 to inform short-term decisions, transparency and granularity of the hypotheses and the presentation of results that facilitates the sharing of knowledge and encourages discussions with different actor groups. The principles of this approach and the way in which they are integrated into the pathway construction framework is described in Waisman et al., 2019.[1]

This project aims to apply these general principles to the freight transport and logistics sector. The starting point was the development of scenarios and an analysis of the sector's decarbonisation, taking into account all of the transformation levers ("storylines"). Beyond the classic focus on technological improvements and solutions based on fuel substitution, this involves a systemic analysis of all of the sector's transformation determinants, particularly changes in behaviour, lifestyles, infrastructure, space organisation and logistics strategies. The analytical framework is built around five information families - the chapters of the storylines - which break down the essential main elements to enable the definition of a complete and coherent account of low carbon transformations:

- Economic and social macrostructure: systems of production, consumption and trade of goods
- Transport and storage infrastructure and its management
- Logistics operations and service provision
- Goods transport vehicles
- Production and distribution of low carbon fuels

The DDP method addresses the challenges involved with translating the actual relationships and implications of the narratives in terms of the quantified changes in various key indicators ("dashboard") that characterise the mobility patterns described. These key indicators include parameters such as changes in the goods being transported, modal shares, rail/road analysis of transport time, distance and cost. They are grouped in the "dashboard" into five main groups:

- Goods and mobility
- Modal structure
- Logistics indicators
- Road freight transport
- Energy consumption and emissions

Compared to other foresight studies which use complex quantitative models, our approach is enriched from the perspective of the qualitative description of the transformation stories, while also seeking to provide a coherent quantitative vision. Complementarity between the two approaches is essential. Quantitative models are capable of taking large numbers of interdependent phenomena into account, but their precision should not be overestimated in the context of a prospective analysis, along with their capacity to represent real world complexity. Indeed, their implementation requires the definition of many assumptions and, since the quality of the model's output is only as good as the quality of the original hypotheses, it is difficult to control them when they relate to a very distant time horizon, such as 2050. More importantly, various parameters in complex quantitative models assume, implicitly or explicitly, that certain aspects will remain stable during the study's time horizon. However, this foresight exercise pushes quantitative models to their limits, since they are required to simulate a world that is very different from the one in which they were conceived and parameterised. A more qualitative approach enables us to explore different visions of the future, to include fundamental

1 Waisman et al (2019) *"A pathways design framework for national low greenhouse gas emission development strategies" Nature Climate Change 9.4 (2019): 261-268*

breakthroughs resulting from current trends, and to link future technologies with more structural or socio-economic aspects that are difficult to integrate into a pure modelling exercise

In practice, our methodological approach requires the best possible information about the current reality of freight transport in France. We thus carried out a vast data collection project to describe the structure of the sector in very fine detail for the year 2010, the starting point of the analysis, by combining several factors: all tonnes loaded and/or unloaded (segmented by major product categories), total and average distance travelled (in ranges of kilometres), modal structure and composition of vehicle fleets (in terms of capacities, engines and unit consumption), logistics performance indicators (load rate and empty running, road speed and/or total speed), etc. Based on our narratives and the world views they describe, we then make hypotheses on the developments (joined or isolated) of these different indicators up to 2050, allowing us to link the changes in freight transport with its CO_2 emissions.

"Method" - see Annex 1
For more information about the foresight approach of the Deep Decarbonization Pathways initiative.

"Data segmentation" - see Annex 2
For more detail on the information described in this study, for example details on the segmentation of goods categories: G1 - G6.

Carbon emissions

The following analyses take the sources of territorial emissions into account, derived only from land transport modes (rail, road and river), i.e. emissions emitted by any vehicle under the French or foreign flag circulating on the national territory, including transits. The emissions considered correspond to the direct emissions of vehicles with engines and are expressed in millions of tonnes of CO_2 equivalent. An additional analysis of the indirect emissions related to energy production was also conducted, with the aim to observe the shift of emissions from the transport sector to the energy production sector. However, a complete study of the Life Cycle Analysis (LCA) scenario was not carried out, so as to allow the integration of other emissions linked to infrastructure development and vehicle renewal. Emissions from land use change were not taken into account.

This work integrates the challenges of transforming the sector towards carbon neutrality into other sustainable development issues, such as health issues (local pollution, accidents), social and economic issues (jobs, wages, services), and other sustainability issues (time, space management, noise and visual pollution). Certain emissions are excluded from this analysis, including those from: foreign light commercial vehicles, French overseas departments, regions and communities (DROM-COM) included in the scope of Kyoto, domestic air travel and those from maritime transport.

"Scope of emissions" - see Annex 3
For more information about the exact delimitation of the emissions considered.

Storylines

The narrative of the transformations by 2050

This section presents all the changes of the different determinants of the sector's transformations. Following a summary of the two scenarios, we present the story of the main framing hypotheses on the transformation of the economic and social macrostructure and of the production, consumption and commodity trading systems that define these two worlds, as well as their interactions with the changes in the transport and energy systems.

Qualitative summary of the two scenarios

Scenario 1: *Continued structural trends mean that the sector's decarbonisation is dependent on road sector transformation, and on the high demand for biofuels*
There is a continuation of the current societal trends in the development of production, consumption and trading systems, without integrating the constraints that this model imposes on the development choices of the transport and energy system. Trade flows remain intense and are still accelerating. Following the last decades' significant increases is a stabilisation of the structure of activities, and therefore of average transport distances. Meanwhile, demand for transport continues to increase, mainly in terms of the quantity of tons transported. Road transport continues to develop in all transport segments (national, import, export and transit) supported by investments in road transport, which have been engaged to reduce congestion problems and alleviate wear and tear on the roads. Multimodality and intermodality struggle to develop due to increasingly constraining time expectations and lack of investments in other modal infrastructures and multimodal logistic platforms. The decarbonisation of land freight transport primarily relies on the transformation of the road vehicle fleet, including light commercial vehicles (LCVs) and heavy goods vehicles (HGVs), which raises mattering technological challenges for those HGVs that require a range of over 500 km. This business segment also pushes for the use of significant quantities of liquid and gaseous agrofuels, which puts notable pressure on the food and energy system.

Scenario 2: *Strategic changes in the macroeconomic structure involving numerous behavioural and organisational transformations allow to distribute the decarbonisation effort across several drivers*
Society carries out the feasible transformations in production, consumption and trading systems. It implements a set of instruments to develop the circular economy, which empowers producers and consumers. Society regains control over time and eases the challenging time constraints on the transportation system. Eventually, the system is relocated around regional ecosystems. The reduction in tonnage quantities and in average transport distances allows freight transport demand to be monitored. As the relocation of trade reduces the need for long-distance, it supports the conversion of a major proportion of the road vehicle fleet. Associated with road transport circulation, an awareness of the social challenges leads to the implementation of a set of measures, including strategic investments in rail infrastructure and the construction of a group of interconnected national multimodal platforms; the latter being implemented in order to create an efficient long distance rail transport model, that is combined with regional road transport. This new organisation enables greater improvements in the application of intermodality and loading levels. The development of rail freight and the service it offers, plays a significant role in lowering the energy requirement in liquid and gaseous biofuels, which is compatible with the agroecological transformation of the agri-food system.

Main framing hypotheses on the economic and social macrostructure, and the transformation of the production, consumption and goods trading system

Assumptions common to both scenarios

Population. The French population grows by around 9 million between 2010 and 2050. It thus reaches 74 million inhabitants by 2050. Population ageing means that those over 65 represent more than a quarter of the population in 2050. In addition, the increasing number of step-families and single-parent families, older couples and singlehood decreases the average number of inhabitants per household from 2.2 to 2.0 in 2050.

Economy. Gross domestic product (GDP) and added valued (AV) continue to grow at an average annual growth rate (AAGR) of 1.8% to doubling in euros over the period 2010-2050. This growth is mainly driven by the market service sector. The economy is increasingly tertiary, with market and non-market services growing from 78% of AV in 2010 to 83% in 2050. This study does not attempt to quantitatively measure the impact of social, economic and organisational changes on GDP, but instead only includes qualitative analyses on the nature of this impact.

EU trade. European social integration is accelerating to avoid a democratic crisis. Social, fiscal and environmental harmonisation aligns production costs in most sectors and harmonises rules between different countries.

Energy system. The renewable energy transition leads to an almost complete elimination of fossil fuel uses: coal, oil and natural gas. The use of refined liquid petroleum for fuel falls dramatically in a low-carbon world, while coke and refined products are generally less used. Regulations are implemented to limit the environmental impact of plastic production, and the use of wood, paper and glass undergoes a renaissance for many applications. French commitments to the Paris Agreement and the national low-carbon strategy (SNBC) result in a full decarbonisation of energy carriers by 2050 for goods transport via road, rail and river.

Technologies. The development of digital applications continues to accelerate and their use in the freight transport sector multiplies. Moreover, electric heavy goods vehicles (HGVs) are developing with lower ranges than today's internal combustion engine vehicles; only hybrid or gas HGVs can guarantee the same autonomy for long distances. Electric light commercial vehicles (LCVs) can deliver ranges of more than 300 km, which is more than sufficient for the vast majority of activities. Numerous technological innovations reduce the traction energy consumption of vehicles.

In addition, France is not isolated on the international scale because all countries commit to adhering to the Paris Agreement and reducing their emissions.

Transformations specific to Scenario 1

Economy. Industrial production gradually specialises in high AV production (for industries such as aeronautics, robotics, information technology, etc.), and France is more competitive for these kinds of goods on international markets. This means that French industries' production and exports of high AV products and imports of low AV products simultaneously increase.

Non-EU trade. International trade occupies an increasingly prominent position in the French economy, even though nowadays the pace of this process is slowing down. In view of the economic, environmental, social and wage disparities throughout the world, and given the certain economies of scale that have already been achieved by certain countries, international competition will for some time continue to provide products at lower prices than those manufactured entirely in France. Despite a number of national initiatives (such as "Made in France", regional production clusters, short food circuits), production will largely remain international, while the economy will continue to be highly embedded in globalised value chains.

EU trade. European socioeconomic integration is followed by a strategy to keep a very low transport cost of goods. Thus, a reduction of production cost gaps between territories is insufficient to fundamentally transform intra-EU logistic chains.

Urbanisation. The metropolisation of the French population continues. The main urban centers therefore carry on attracting the majority of the population and sprawling across larger areas, with a particularly rapid development of peri-urban zones. Economic activities are also increasingly concentrated around these cities where higher education and research ecosystems can be found.

Agri-food system. The agri-food system generally retains the same structures as today, with for example a high dependence on chemical inputs and the transport of food products over long distances. Food consumption per person increases, although only moderately for animal products. Food waste is managed more properly but it remains concerning. Transport still represents a reasonably low proportion of the selling price of agri-food products, and thus enables agricultural products to be carried over long distances. Short food circuits are not particularly favored by public initiatives and therefore remain a niche market.

Construction system. This system generally retains the same structure. Despite a decrease in built space economic activity intensity due to the tertiarisation of the economy, there is a demand for more built space per person. This is particularly due to both the growth of peri-urban areas—where built space is cheaper than in city centres—and single-parent families. In addition, more materials are required per built square meter in order to better insulate buildings and decrease the energy demand.

Production-consumption system of manufactured goods. The production system generally retains the same structure. On the producer side and at a national scale, a limited number of proactive measures are taken to enable the transition of sectors to more sustainable production. Developments take place on a voluntary basis, remaining marginal and uneconomical in terms of raw materials. The repair economy remains a niche segment. Therefore, even if they could be repaired, many products with minor defects are frequently discarded.. On the consumer side, no measures are taken to regulate sales practices (LCA, advertising, marketing, etc.) or transform consumer's behaviour. Thus, there is no increase in goods sharing between households. There could even be a decrease as the phenomenon becomes limited to the intra-household pooling of goods. In parallel, the industry moves towards the decarbonisation of production and the electrification of its requirements. Electricity will cover up to 40% of industrial energy needs.

Energy system. The decarbonisation of the industrial sector is complex, but the level of electrification has considerably improved and reached around 78% by 2050. This sector is a priority for the use of gaseous biofuels.

Temporal trading system. Trading systems also generally retain the same temporal structures. A significant proportion of industries, carriers and consumers continue to demand "just-in-time" deliveries from their suppliers to react quickly to changes in demand and reduce fixed stocks. This time constraint is particularly structural because the national economy has developed an emphasis on high AV products, which has a major impact on the choice of transport modes and vehicles by carriers and logisticians, and more generally on the organisation of logistics chains. The development of "e-commerce" and so-called "free" deliveries fuel this frenzy of fast exchange.

Transformations specific to Scenario 2

Economy. The transformations at work in this scenario lead to the development of a more employment-intensive economy through the development of production activities at national and regional levels, along with new service activities such as those related to repair or eco-design. The creation of value involves the strengthening and revaluation of work, for example in activities related to caring or the maintenance of territory and heritage.

Non-EU trade. The European Union (EU) opts to redefine the regulation of international trade and manages to make it a vector for the deployment of global sustainable development. The EU thus embarks on the renegotiation of all its trade treaties to include an incentive system vis-à-vis the Sustainable Development Goals. This system aims to integrate, among other things, the negative externalities from pollutant emissions derived from the production and transport of imported products, but also all of the deleterious consequences of international trade on community well-being (with social standards applied to low salaries and pension levels, population health and biodiversity protection). Many conditions must be met to achieve this transformation, such as the reinforcement of product traceability, tools to better control imports at EU borders and compliance with revised treaties, as well as the development of innovative economic supports: broadening of the carbon market to include non-EU countries and development of "green bonds" dedicated to the relocation of trade and freight or joint agreements with major European companies and industrial branches to guarantee the choice of subcontractors and business partners.

EU trade. European integration is followed by an increase in the transport costs of goods, which questions the organisation of current supply chains, with locations close to major consumer markets becoming increasingly attractive. The EU thus experiences the creation of a proximity economy with the relocation of a certain amount of production at a regional level and therefore a shortening of trading distances. The products that are affected the most are those with low AV. Indeed, the value of work and transport are proportionally higher in their final price. Many measures can accompany this transition. They include tax incentives for companies (revision of the corporate tax at the European level to integrate emissions related to their transport and production activities), commitments by carriers to promote local supply and consumer incentives (real delivery pricing, depending on distances and modes used, development of ecolabelling for products through life cycle analysis tools).

Urbanisation. Since French households wish to live near employment opportunities, the trend towards greater trade regionalisation influences their location choice. Notably due to the creation of such regional production consumption ecosystems, secondary French cities experience a new boom and see population increases. The development of these cities will be based on a model of densification and more collective housing to limit urban sprawl and generate economies of scale for indivisible goods - public transport, housing, hospitals and educational establishments for example.

Agri-food system. Breaking away from the current situation, agroecology develops in France and throughout Europe to achieve the commitments on biodiversity protection and food health improvements, and to reach carbon neutrality by 2050. This transition concerns both production methods (elimination of crop protection products, reduction of chemical inputs, agroforestry, livestock-arable integration, etc.) and household dietary (evolution towards a more balanced, sustainable and local food).

Construction system. Breaking away from the current situation, the construction sector undergoes major transformations. The low-carbon transition in the construction and renovation sector foster uses of materials with lower environmental footprints. Urbanisation oriented towards a model of controlled densification will also reduce the need for materials per household. Conversely, the need for infrastructure investment for the energy transition will tend to increase the need for materials in the short and medium terms. A sectoral approach specific to this field is necessary to develop and mainstream improved internal recycling techniques in this area (between demolition and construction).

Production-consumption system of manufactured goods. Breaking away from the current situation, the low-carbon transition of French society also involves the transformation of the production and consumption of various manufactured goods, such as clothing, electronic devices or cars. The market economy of manufactured goods will be transformed by integrating eco-design upstream of production, and developing a repair and recycling economy, which is intensive in terms of employment, downstream of a product's first life cycle. This circular economy will be based on a strong trend towards the use and sharing of goods, as opposed to the exclusive, individual possession of objects. This results in limiting their number. This transformation requires the linkage of a number of measures to transform both production regulations and those of consumption and trade.

Producers and sectors thus become responsible for their products until they are recycled and a number of measures may aim to guarantee their end-of-life recovery or to offer recovery schemes to valorise second-hand products. Many additional measures could accompany this transformation towards eco-design and the repair society: strengthening minimum lifespan criteria for certain products, and the banning of planned obsolescence; reinforcing criteria on modularity and repairability; upgrading repair and collection activities; reinforcing the use of resistant and recyclable materials; revising rules on waste pricing; revising the pricing of spare parts to incentivise repairs rather than new purchases; supporting the development of technological innovations that could benefit the repair economy, such as 3D printing and "open source" product design, etc.

Life cycle analysis (LCA) indicators on all products become widespread, while marketing and advertising practices are regulated to encourage the shift from a society centred on consumption and possession, towards another one centred on responsible usage and sharing. Additional measures can accompany this transformation towards a sharing and functionality society: education and awareness-raising campaigns that start at school, to put the issue of usage at the core of individual thinking on consumption and possession; supporting the development of new communal public services such as public libraries for objects, organising guarantee systems and enabling these activities to emerge; bridging the generational gap, creating a link between young and old, particularly in terms of sharing certain fixed equipment; health campaigns and investment in meeting places to encourage the use of active modes of transport over short distances, but also to encourage car-sharing.

Energy system. The decarbonisation of industry is complex and the level of electrification does not accelerate dramatically, reaching around 33% by 2050. This sector is a priority for the use of gaseous biofuels.

Temporal trading system. Breaking away from the current situation, delivery conditions move towards a system where expansion of "just-in-time" services is limited, and where delivery is clearly shown as a component of the final price. This transformation requires the linkage of a certain number of measures to transform both the delivery rules and choices in terms of consumption and delivery.

Delivery times and locations in towns are regulated, constraining the leeway for shippers and carriers. On the vendor's side, minimum times for the transport of non-perishable products could, for example, be discussed to fix limits to the ever greater compression of transport times. To avoid the continued expansion of traffic and the effects of congestion in urban areas, home delivery could for example be better regulated from urban distribution centres (UDCs) to reception points and semi-centralised storage areas that will be developed; the use of home delivery becoming subject to criteria regarding access to mobility, or very specific product types, such as heavy and bulky goods.

Combining certain measures relating to consumer awareness, information and economic incentives may also change consumer behaviour over time. In general, consumer awareness should support a move towards a less "impatient" society. Moreover, there must be transparency in informing consumers about delivery prices, while the mention of "free" delivery will be banned. Furthermore, the system of product pricing will explicitly differentiate between the proportion of the cost linked to the production of a product and its transport to a UDC, and the proportion attributable to last-mile delivery. The latter could be regulated so as to minimise "instant" deliveries, particularly for non-perishable goods. Finally, to systematically encourage the buyer to favour longer delivery times, which therefore allow more flexible logistics, regulations will frame pricing according to delivery times and by proposing the introduction of progressive price scales.

Transport and energy systems in both scenarios

These transformations in the production, consumption and trade system contribute to the transformation of the freight transport demand, both in terms of quantities transported and also in terms of distances travelled (see "Goods and mobility" section of the Dashboard). Scenario 1 is thus characterised by significant growth in tonnes transported and the quasi-stability, compared to the situation today, of average transport distances, therefore maintaining a link between transport demand and GDP growth. Conversely, scenario 2 shows a slight decrease in tonnes transported and a reduction in average transport distances compared to today, signifying a decoupling of freight demand from GDP. The structure of these two visions enables the emergence of very different transport and logistic chain systems.

Transport and logistics infrastructure

Non-EU external trade can lead to different needs for the development of port capacity and their interconnections with "hinterlands".

In scenario 1, non-EU trade continues to develop and occupy a prominent place in the French economy, creating strong needs for the extension and reinforcement of major port infrastructures. Conversely, in scenario 2, the radical changes in terms of the integration of the sustainable development objectives into free trade treaties do not lead to the same need for strengthening these infrastructures. In scenario 1, the development of major maritime ports is crucial to guarantee the proper integration of the French economy into globalisation. To accommodate the increase in non-EU trade, ports will be equipped with better multimodal platforms, particularly for rail transport, to be able to serve a larger proportion of the transport demand to and from ports. In the same vein, the development of the Seine-Nord river project, enabling in particular the linking of the port of Le Havre with Paris through inland waterways, makes it possible to develop the capacity of this route for the benefit of this major international port and the north of the country, which is interconnected with other major seaports in northern Europe.

Alleviation of time constraints is necessary to promote the renewal of multimodality and intermodality at the national level.

In scenario 1, the continuation of time constraints on logistics favours a road-dominated system, since it is the most flexible mode of transport, which among other things creates a decrease in the interest in the development of major railway infrastructures or large multimodal platforms. Conversely, the easing of time constraints in scenario 2 is a key element in encouraging the development of rail infrastructures and multimodal platforms, and enabling the major deployment of multimodality and intermodality.

In scenario 1, road infrastructures remain at the core of infrastructure development strategies. Several major road network expansion projects are implemented, particularly outside of cities, especially on regional main roads and ring roads, to absorb increases in passenger and freight traffic. The rail network is maintained to guarantee its proper functioning as part of the main routes, and to address the demand associated with major maritime ports.

In scenario 2, the development of a networked multimodal transport system is possible, but it requires different investment choices. Each of the 12 regions of mainland France has at least two main "upstream" multimodal platforms, that are interconnected with each other and linked to the various land transport networks (rail, road, river where applicable), which ensures a network of platforms throughout the territory, every 200 to 300 km. In addition, multimodal platforms will be developed or reinforced at every international interconnection on land, but also for maritime and air interconnections. The development of European transport corridors should guarantee the interoperability of rail transport at borders. These "upstream" platforms will be completed and linked to a set of "downstream" multimodal platforms, such as UDCs, to allow goods to be transported by road, rail or river to the peripheries of large consumer centres (for example, at least one near each of the 89 largest mainland departmental cities).

Furthermore, rail infrastructures in particular will have to be strengthened, for example by: the development of freight-dedicated routes, or the doubling of rail tracks in areas where passenger transport dominates the service, such as in the vicinity of large cities; the development of new rolling highways on the South Atlantic route to Hendaye and the West Atlantic route to Brittany; networking between multimodal platforms, the development of capillary networks and rail-connected terminals near to relevant major commercial activity zones. This work could be based on the territorial expertise developed by local rail operators. Similarly, river infrastructures development must be supported where relevant. These significant investments over the next 20 years, in both the rail network and in efficient multimodal sorting, consolidation, de-consolidation and storage platforms, are an additional necessity for the relaxation of time constraints to enable intermodality to play a major role in the sector's decarbonisation. Moreover, this will also encourage the massification of flows of goods and a reduction in the related spatial footprint, loading optimisation, improvement to rail commercial speeds, and a reduction in offloading between modes.

Rules to access major infrastructures are structural elements to define the place of the different modes in the transport system

In scenario 1, the development of rail and its infrastructures is not encouraged by massive public investments and the alleviation of time constraints. This trend penalises the choice of non-road modes. Moreover, the absence of efficient modal alternatives makes it difficult to implement strategies for the internalisation of the social costs of roads and its political and social acceptability. This scenario does not therefore kickstart a revision of the rules on accessing the rail system to rebalance the French model between freight and passengers transport. Conversely, scenario 2 leads to the development of a high quality system of rail and multimodal logistics infrastructures, making the modification of access rules to the rail and road networks more relevant.

In scenario 2, railway management for the transport of passengers and goods thus evolves to achieve a re-prioritisation of freight transport in the overall rail traffic balance, facilitating access to rail for freight. This transformation requires a revision of the rules applied by infrastructures' managers, particularly regarding the reservation and allocation system for train paths. These infrastructural and managerial transformations will enable an increase in the rail service offers, the increase of train running speeds by 10 to 20% depending on routes, and the reduction of offloading times for rail, up to 10% per tkm, due in particular to links with multimodal logistics platforms. In parallel, this scenario makes it possible to implement a toll aimed at internalising a set of environmental and social externalities for road transport, such as the wear and tear of infrastructures, congestion, and health costs related to accidents. This pricing per mile applies to all vehicles with variations according to vehicle types and the distances travelled throughout the territory. However, it will in fact have a much stronger effect on trips of over 500 kilometres, mainly transit, imports and exports, which will favour the development of intermodality and long-distance rail, as well as the development of local and European regional ecosystems. The additional revenues linked to this pricing will be recycled into the improvement of the transportation system and infrastructures. Moreover, the alleviation of time constraints will also make it possible to reduce the circulation speeds of HGVs and LCVs over 2.5 tonnes GVWR on motorways, for reasons of safety, pollution and traffic flow.

Last-mile delivery conditions and urbanisation models provide different options for traffic and urban infrastructures development.

In scenario 1, the search for ever shorter delivery times remains a structuring constraint in the search to fulfil the demands of ever more impatient consumers, which does not encourage vehicle filling and increases road traffic. In parallel, there is no improvement in delivery pricing transparency, giving the impression that transport can sometimes be "free", which does not encourage change in consumer behaviour. This scenario also extends urbanisation trend following the urban sprawl model to varying extents. Conversely, scenario 2 involves the complete transformation of the trading system, reducing the expectation for rapid delivery times, and generating greater transparency on the real costs of last-mile transport. This scenario also entails the strengthening of new urban centres with the creation of local production-consumption ecosystems and controlled urbanisation, focused on the densification of secondary cities.

In scenario 1, the trading system and the urbanisation model continue to encourage rapid transport modes, especially roads. Given the higher land prices in city centres, UDCs continue to be located at increasing distances from final consumers, limiting the modal shift possibilities and exacerbating urban congestion. In this scenario, two-wheeler infrastructures, for bicycles and scooters, develop marginally to ensure ever shorter delivery times. Carriers tend to use smaller vehicles for final delivery to enable easier and faster travel, with LCVs and HGVs less than or equal to 19 tonnes GVWR. Moreover, cities are implementing parking space management and video surveillance systems to prevent the phenomenon of (illegal) double parking, which contributes to road congestion.

In scenario 2, the trading system and the urbanisation model encourage more flexible and fluid deliveries. Urban areas integrate freight transport and logistics activities into their strategies for travel and urban planning. Local authorities organise and link decentralised storage areas (reception points) with "downstream" multimodal logistics platforms, such as UDCs. Management of traffic, parking spaces and access to reception points may involve control centres associated with the UDCs. Local authorities develop the necessary support for actors in the sector and infrastructures adapted to their strategies, such as: cargo bike lanes, new parking spaces linked to decentralised storage areas, or land available for UCDs at the centre of consumer areas. While smaller towns also take into account the development of delivery to end customers. Authorities organising mobility implement centralised storage areas in municipalities, with secure access to carriers, businesses and households to promote massification of flows, optimisation of vehicle loading and to limit the least efficient options for last-mile delivery.

In addition, cities develop automatic video surveillance systems to facilitate the optimisation of parking spaces and, due to the transformation of time constraints, establish new rules to de-synchronise freight and passenger traffic (for example, the use of silent vehicles to develop night-time deliveries to decentralised and automated reception depots).

Logistics operations and service provision

Infrastructural choices can enable the deployment of competitive rail services, especially over long distances.

In scenario 1, the demand structure, the infrastructures investment strategies and the regulation of access conditions do not solve the main difficulties that limit rail competitiveness, unlike scenario 2 which achieves transformations in the speeds, costs and quality of rail services.

In scenario 2, the above mentioned transformations in investment in rail infrastructures or multimodal logistics platforms, in the improvement of the conditions of access and circulation on railways, and in the integration of negative road externalities, are all elements that create a favourable situation for the competitiveness and development of the rail sector. Rail services will be redeployed towards trains that are increasingly shared among several clients and batches, and the provision of intermodal transport will increase, due in part to the structuring of trade around interconnected multimodal platforms and improvement in the quality of train tracks, which increases commercial speeds. Intermodal rail-road transport services will quickly develop where time-price competitiveness is enabled, particularly for very long distance journeys, over 500 km at first, and then on inter-regional distances over 150 km. Digital innovation in connected objects will enable good traceability of batches throughout journeys, and will support all of the transformations described.

Proximity of trade and rail development can enable working condition improvements in the road sector.

In scenario 1, EU competition and the dependence on road freight makes it difficult to improve salaries and working hours. The harmonisation of European social legislation is therefore more likely to align with a system of low guarantees for these trades, to keep down the sector's wage costs, which is key to maintaining current supply chains. Conversely, scenario 2 reduces dependence on road transport for long distances by offering rail or river alternatives, it also strengthens local trade and maintains the central place of regional road transport. This scenario is more conducive to the general improvement in the sector's working conditions.

In scenario 2, wages, which have stagnated or even slightly decreased in recent years due to fierce intra-European competition, increase by around 20% over the period, making it possible to attract new employees to these trades. Working conditions are also improved, through systems for controlling the working hours of HGV and LCV drivers, French and other nationalities, to guarantee compliance with driving times, especially over long distances. As a consequence of these various changes which induce an increase in monetary costs, road transport loses market shares to the detriment of rail over long distances, which means that social support for the sector is therefore necessary to perpetuate this transition. However, the road transport markets remain key for regional transport and continue as an attractive sector that creates local jobs. These improvements lead to a slight increase in road transport prices over short distances.

Time constraints, infrastructural choices and digital innovations can improve loading rates.

In both scenarios, the development of digital innovations such as the physical internet or blockchains will enable exchanges of information between shippers and carriers, but also secure trading. This transformation requires consultation and specific support to enable transparency and the inclusion of all actors, while keeping some information confidential. A better sharing of information on the supply and demand of freight transport (also related to the emergence of new digital brokers and freight exchanges) will optimise vehicles loading rates (in tonnage and volumes) and reduce partly empty journeys and unoccupied volumes. These changes will be generally more significant for inter-regional long distance journeys. However, the relaxation of time constraints and the massification of flows made possible by scenario 2's multimodal investments provides greater improvement potential.

Mainstreaming of digital apps will improve vehicle fuel consumption.

Finally, in scenarios 1 and 2, by 2020 carriers will have mainstreamed the use of "routing" apps to optimise journeys in terms of time and energy consumption, while by 2025 they will have mainstreamed eco-driving protocols and solutions for the partial automation of certain functions, with driver training to monitor fuel consumption.

Vehicles for freight transport

Transformation of the energy system, as well as European and national regulations, promote energy efficiency and the emergence of low-carbon vehicles.

In both scenarios, the transport of goods by road, rail and river is totally carbon-free by 2050.

The latest European regulations for goods transport by road have placed constraints on the emission levels of new vehicles. From 2020, manufacturers will be required to reduce CO_2 emissions from new HGVs by an average of 15% by 2025 and 30% by 2030, compared to 2019 levels, or face a financial penalty for their emissions surplus. Moreover, they will have to reach a minimum sales of zero emissions and low emission HGVs of up to 2% of their annual sales in 2025. LCVs are also affected and manufacturers will be required to reduce average carbon dioxide emissions of new LCVs by 15% by 2025 and 30% by 2030, in this case in comparison to 2021 levels. Moving beyond 2030, both scenarios reinforce these vehicle emissions regulations, aiming for complete decarbonisation in 2050.

At the national level, both scenarios integrate the cost of global warming through the carbon component of the French domestic tax on energy products (*Taxe intérieure de consommation sur les produits énergétiques* - TICPE), which will increase from 30 to 300 euros per tonne of CO_2 in 2050; compensation mechanisms for disadvantaged populations and sectors will be implemented to facilitate the transition.

In scenario 2, the non-CO_2 component of TICPE is redefined to also integrate the social public health costs linked to the emission of local air pollutants and noise pollution. This represents an increase of around 20-25% in the non-CO_2 share by 2050 for internal combustion engines. To make these regulations relevant for the road transport sector, scenario 2 also assumes that the partial exemption for carriers of 30% of the TICPE will be halved by 2050. The proceeds from these taxes are used to cover the social and environmental costs of the various energy carriers and will also be used to finance the transition of the vehicle fleet, as well as the multimodal system.

Finally, for both scenarios, urban zones of more than 50,000 inhabitants in France play a leading role in initiating policies by organising, at their scale, the gradual phasing out of freight vehicles that emit air pollutants (for example, Grenoble has banned access to the city by diesel LCVs and HGVs from 2025). From the 2020-2030 period, they will develop "low emission zones" (LEZ) where deliveries will only be permitted using low and zero emission modes, such as: cargo bikes, on foot, or small electric vehicles. To achieve this, they set up a vehicle tax system based on engine age and vehicle size. Local authorities will thus be able to identify and support fleet transitions.

Energy efficiency gains on road vehicles help facilitate the electrification of road transport.

In both scenarios, innovations for road vehicles between 2010 and 2050 mainly focus on the improvement of engines, aerodynamics, tyres and regenerative braking systems, which can reduce the energy consumption of internal combustion engines by up to 40%, and up to 10% for electric vehicle engines. These efficiency improvements for electric engines are particularly important to improve battery size and to enable the electrification of road transport.

The nature of LCV journeys and the availability of technological solutions favour the penetration of low-emission vehicles.

In both scenarios, most LCVs for goods transport travel only short distances each day, typically less than 200 km. Given the current development of electric vehicles in the segment, the majority of LCVs could already be replaced by electric vehicles. In scenarios 1 and 2, battery electric vehicles (BEVs) reach up to 80-90% of the LCV stock by 2050.

Nature of transport demand and structure of regional or long-distance journeys have a strong impact on the need for autonomy and the technological choices of HGVs.

In both scenarios, rigid and articulated HGVs for regional transport travel daily distances of between 200 and 400 km. The first examples of rigid electric lorries, with GVWR from 16 to 26 tonnes, are starting to emerge with ranges from 200 to 300 km. Given current developments, from 2030 it will be possible to use, in economically competitive conditions, electric lorries with ranges of 300 to 500 km and batteries from 400 to 700 kWh.

However, HGVs for long distance transport can travel up to 800 km each day and, taking into account the significant uncertainties linked to the development of fuel supply infrastructures, the prices of fuels and tractor units, different engines may exist for these long-distance travellers: hybrid electric engines with biodiesel or hydrogen, or conventional engines fuelled by liquid or gaseous agro-fuels.

Given the significant demand for long-distance transport in scenario 1, the need for long range lorries is more important, and they therefore represent a greater proportion of the stock. Conversely, in scenario 2, the proximity of commercial activities makes it possible to have a greater penetration of electric HGVs.

Decarbonisation objectives for rail freight transport favour the development of regulations for infrastructure management towards an increased use of electric and dual-mode locomotives.

Both scenarios anticipate an end to emissions from rail freight transport by 2050. To counter the development of diesel traction in recent years, even on electrified tracks, network managers will be able to implement incentivising tax systems, as well as a video surveillance at several points, to maximise the use of electric locomotives where possible and favour the transition of the fleet. Even though the main rail network in France today is electrified, there remain many secondary tracks that are not. Therefore, partial electrification solutions will be developed on the secondary network, where an increase in the use of electrical energy is possible. The need for rail electrification is greater in scenario 2 than in scenario 1, given the position of regional rail transport.

The majority of electric and hybrid biodiesel locomotives will develop in the circulating fleet due to complementary electrification solutions and management control regarding the use of electricity on electrified tracks. However, this transformation requires implementing a strategy to change the locomotive fleet and to do so at a pace capable of aligning the economic constraints of the actors and the environmental constraints of the national strategy. As locomotives have a long service life, the renewal of engine technologies represents a major challenge for owners. The planned renewal, along with accompanying incentive measures, will make it possible to increase the proportion of tonnes-kilometres transported by electric power to 85% in 2050 in scenario 1, and 95% in 2050 in scenario 2.

Decarbonisation targets for freight transport favour the transformation of barge fleets towards the use of low carbon fuels.

A specific plan will improve the energy efficiency of boat fleets by 30% for thermal engines and 15% for electric engines by 2050, and will thus encourage the switch from thermal to electric engines where possible. *It should be noted that this work did not include specific further study of issues associated to the decarbonisation of river transport.*

Production and distribution of low carbon fuels

Transformations in international trade and the agri-food system condition the potential use of liquid biofuels for freight transport.

In scenario 1, liquid biofuels dedicated solely to freight transport have the potential to reach up to 50 TWh. This is the result of a transformation in the agri-food system, producing biofuels in France and acquiring complementary international imports to meet domestic demand.

Scenario 2 limits the potential for liquid biofuels to French production, due to the integration of new sustainability criteria into international trade. This French production is mainly limited to existing production means: around 30 TWh from first generation techniques based on energy crops and around 5 TWh from more advanced second generation techniques. Indeed, from an agroecological perspective, the development of energy crops is not encouraged due to their harmful impact on the agricultural sector and land use. 80% of this combined potential of 35 TWh is dedicated to goods transport, leading to an available resource of 28 TWh (almost half that of scenario 1).

Transformation of the agri-food system and competition in the use of gas conditions the potential use of gaseous biofuels for freight transport.

The continuity of the agri-food system and the demand for long-distance road transport in scenario 1 encourage the significant development of gaseous biofuel production by methanisation, pyro-gasification and power-to-gas, which could reach 142 TWh of potential available energy by 2050. Conversely, the agroecological transformation in scenario 2 does not enable such large-scale intensification, and limits the development of dedicated energy crops, but allows intermediate crops. This agroecological system is still able to provide 83 TWh.

In both scenarios, industry has priority over transport and in scenario 1, power generation also has priority over transportation. Electrification levels in the industry sector differ between high electrification in scenario 1 with 78%, and 33% in scenario 2, which means in the latter case that the industry sector has a significant need for gaseous biofuels. This competition in the usage of gas, associated to the production constraints on agricultural systems, results in there being 60 TWh of gaseous biofuels available for freight transport in scenario 1, and only 4 TWh for scenario 2.

Competition for fuels can influence emissions from the electric mix.

In scenarios 1 and 2, 94% of the electricity mix in 2050 derives from renewable or nuclear energy, 5.5% from gaseous fuels and 0.5% from liquid fuels. In addition, the priorities for access to biofuels are different. Electricity production in scenario 1 is one of the priority access sectors, which makes a fossil fuel exit possible in this sector. In scenario 2, the volumes of gaseous biofuels are primarily oriented towards industry and the rest towards transport, which means the gaseous fuels used in thermal electric power stations remain fossil-based. There is a difference in the carbon content of electricity between both scenarios, with a figure of around 10 gCO_2/kWh in scenario 1 and around 20 gCO_2/kWh in scenario 2, including indirect emissions linked to fuel production.

Nature of the demand for road freight transport conditions the need for infrastructure for energy distribution.

In both scenarios, electric road vehicles for regional journeys will generally be able to charge in the evening, which would not therefore require too much investment in additional infrastructure. It is only electric vehicles with an insufficient range for their daily activities, or that make journeys without the possibility of night-time recharging, that will require the development of specific infrastructure to be distributed throughout the national territory.

Road vehicles in scenario 1 make more long distance journeys than in scenario 2. Consequently, the need for electric charging infrastructure will be different, and this scenario may favour the deployment of partial electrification solutions for certain routes around major cities or the busiest highways. In Scenario 2, long-distance road vehicles are more scarce and the electrification of road sections makes less sense. In this scenario, the logistics platforms that are distributed throughout the territory, will be able to offer fast charging points, especially during waiting times.

Dashboard
Transformation indicators up to 2050

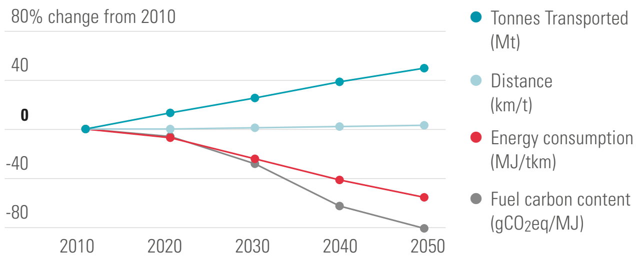
Quantitative summary of the two scenarios

Scenario 1 - Dashboard presentation
Scenario 2 - Dashboard presentation

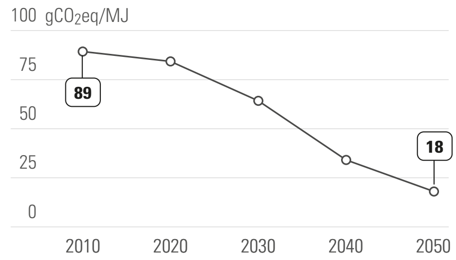
FRANCE - Scenario 1

A1. National energy consumption and related emissions (1)

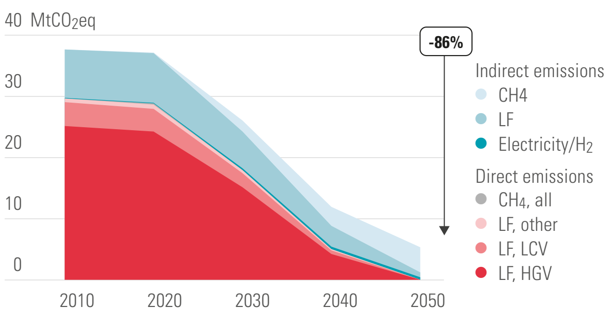
1.a Emission drivers



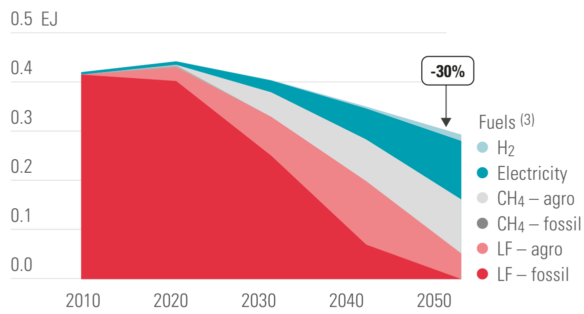
1.c Carbon content of energy



1.b GHG emissions



1.d Final energy consumption

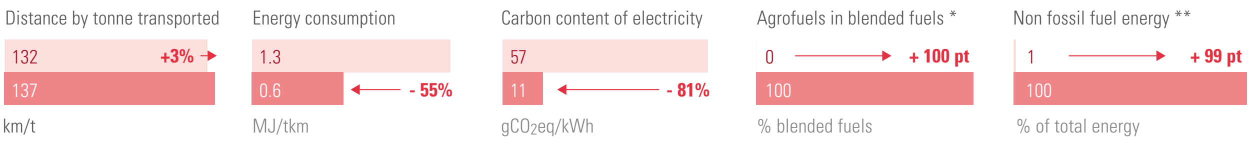


A2. The pillars of decarbonization

Pillar 1
Energy efficiency

Pillar 2
Decarbonization of electricity and fuels

Pillar 3
Shifting to low carbon fuels

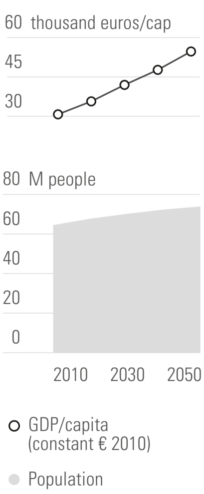


** Liquid fuels and CH_4 gas*

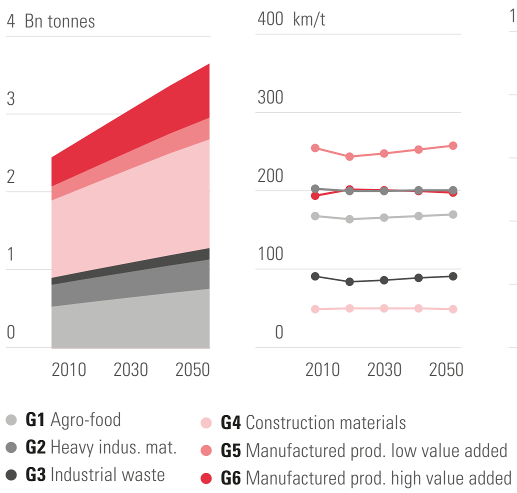
*** Integrating electricity, liquid and gaseous agrofuels, hydrogen*

A3. Goods and mobility (2)

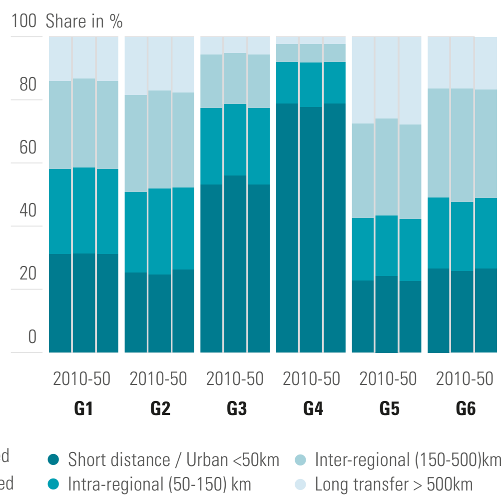
3.a Population and GDP



3.b Goods transported and distance by tonne



3.c Goods transported by distance class



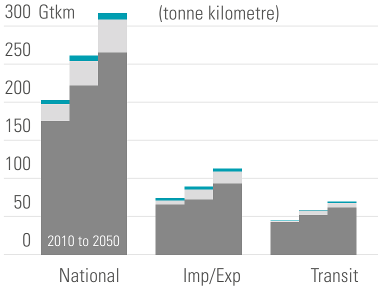
(1) Including direct emissions from fuel combustion and indirect emissions from fuel production (electricity, liquid and gaseous fuels) expressed in CO_2eq.

(2) Only domestic transport carried out by road, rail, river for import, export, transit and national transport.

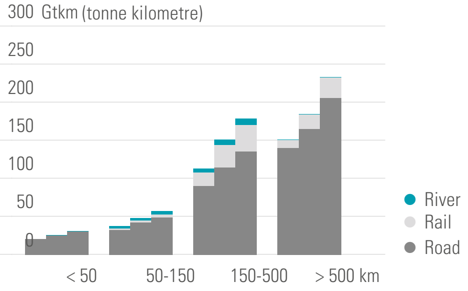
(3) H_2: hydrogen, CH_4: methane, main component of natural gas, LF: liquid fuel.

A4. Modal structure

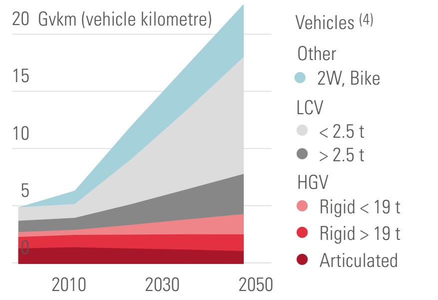
4.a Modal structure by type of transport



4.b Modal structure by distance class

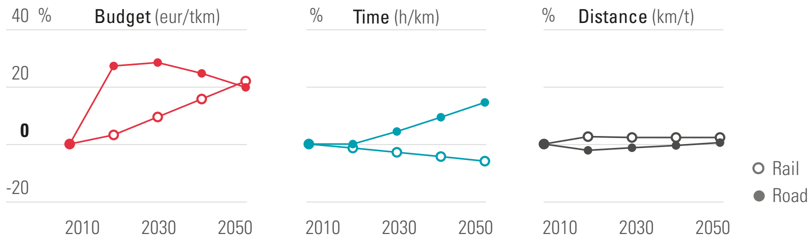


4.c Short distance and urban traffic

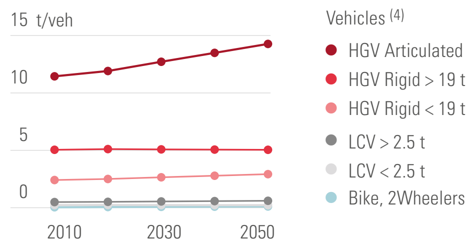


A5. Rail and road logistics indicators

5.a Indicators for rail – road comparison

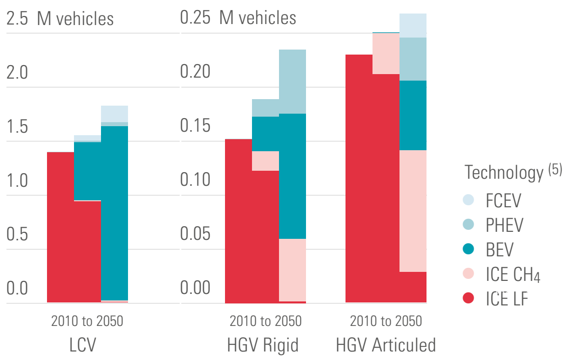


5.b Average load factor of vehicles

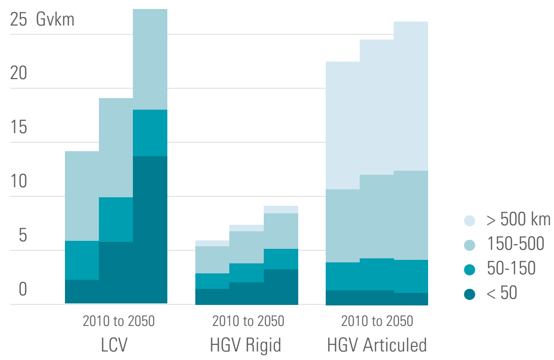


A6. Road freight transport

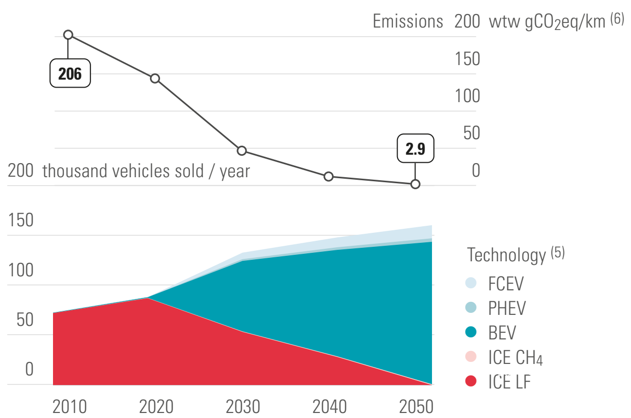
6.a Stock and technology mix



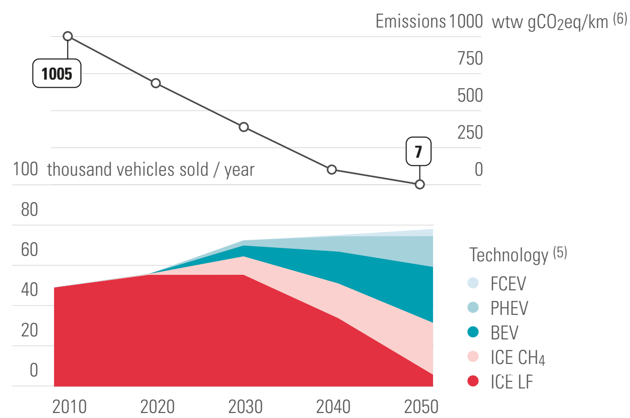
6.b Traffic share by distance class



6.c LCV sales and emissions



6.d HGV sales and emissions



(4) 2W: 2 wheelers, LCV: Light commercial vehicle, GVWR<2,5t and 2,5t<GVWR<3,5t, HGV: Heavy duty vehicle, Rigid GVWR<19t and >19t, Articulated: mainly 34-44t GVWR.

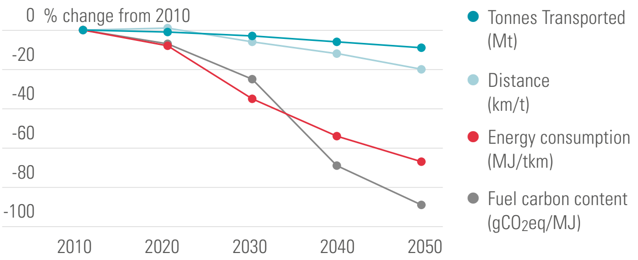
(5) FCEV: Fuel Cell Electric Vehicle, PHEV: Plug-in Hybrid Electric Vehicle, BEV: Battery Electric Vehicle, ICE CH_4: Internal Combustion Engines CH_4, ICE LF: Internal Combustion Engines Liquid Fuel.

(6) Emissions of average car sales is expressed in "well-to-wheel" gCO_2eq per vkm travelled which include emissions from fuel combustion and fuel production and distribution.

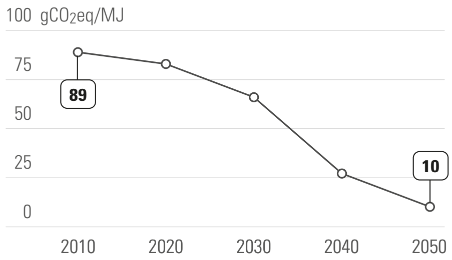
FRANCE - Scenario 2

A1. National energy consumption and related emissions (1)

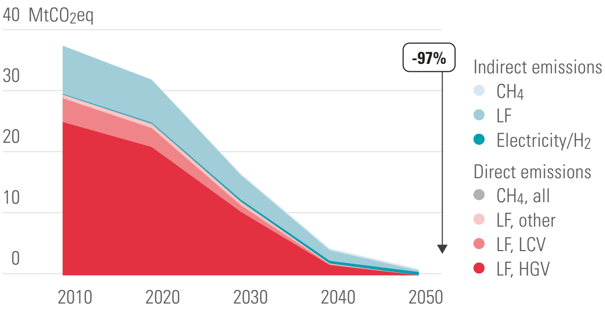
1.a Emission drivers



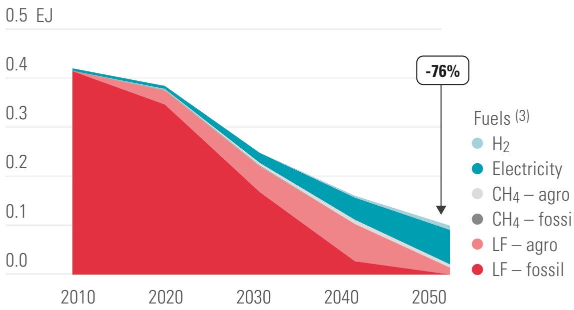
1.c Carbon content of energy



1.b GHG emissions

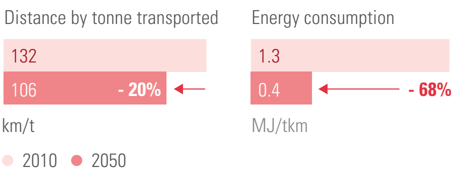


1.d Final energy consumption

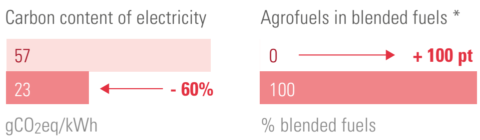


A2. The pillars of decarbonization

Pillar 1
Energy efficiency

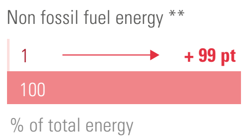


Pillar 2
Decarbonization of electricity and fuels



** Liquid fuels and CH_4 gas*

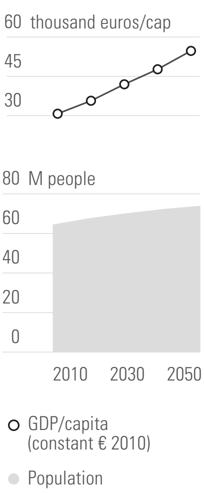
Pillar 3
Shifting to low carbon fuels



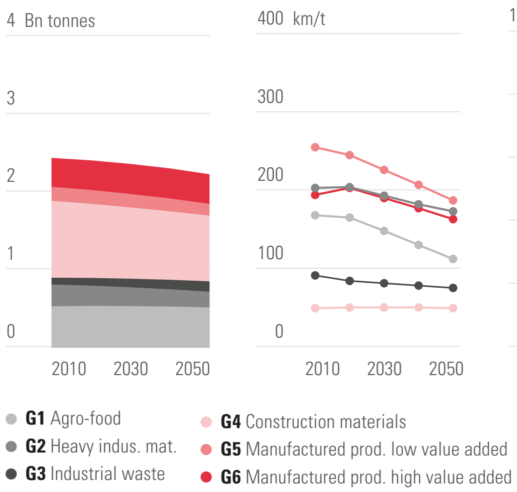
*** Integrating electricity, liquid and gaseous agrofuels, hydrogen*

A3. Goods and mobility (2)

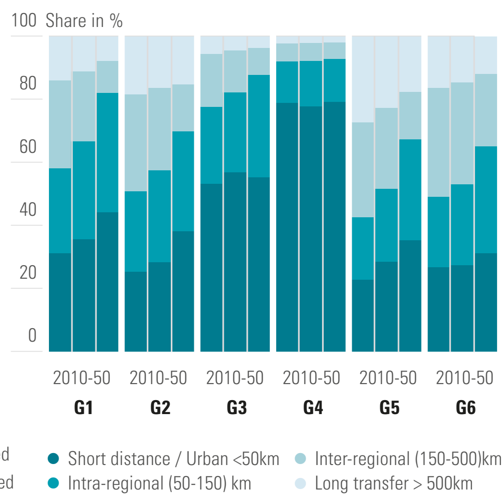
3.a Population and GDP



3.b Goods transported and distance by tonne



3.c Goods transported by distance class



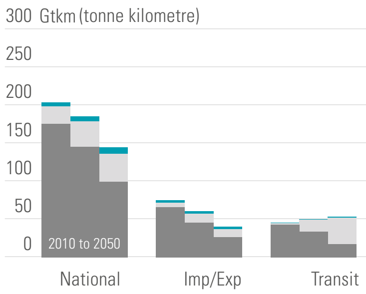
(1) Including direct emissions from fuel combustion and indirect emissions from fuel production (electricity, liquid and gaseous fuels) expressed in CO_2eq.

(2) Only domestic transport carried out by road, rail, river for import, export, transit and national transport.

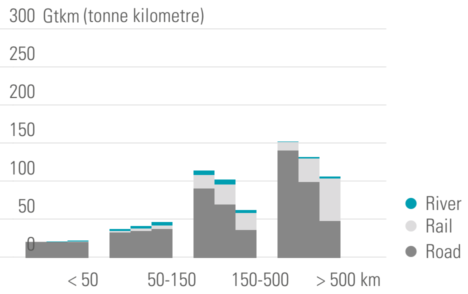
(3) H_2: hydrogen, CH_4: methane, main component of natural gas, LF: liquid fuel.

A4. Modal structure

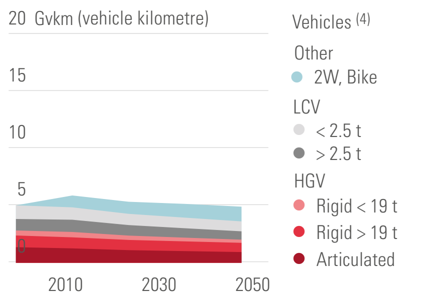
4.a Modal structure by type of transport



4.b Modal structure by distance class

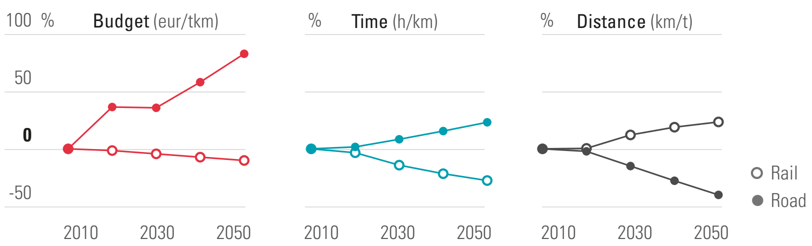


4.c Short distance and urban traffic

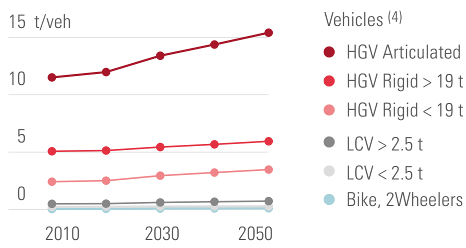


A5. Rail and road logistics indicators

5.a Indicators for rail – road comparison

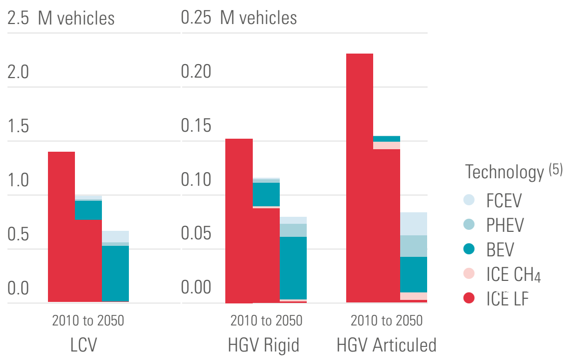


5.b Average load factor of vehicles

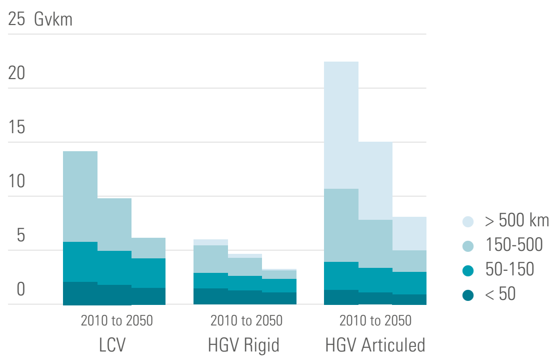


A6. Road freight transport

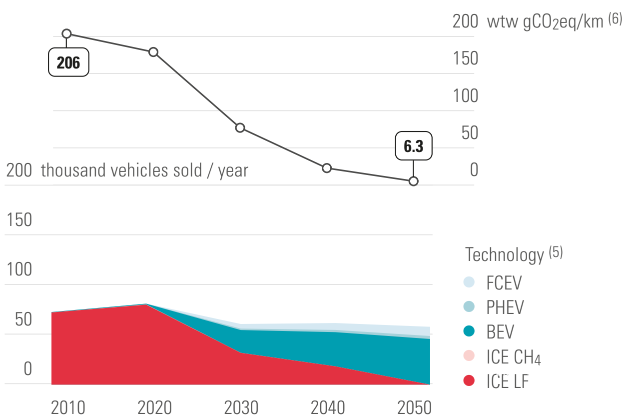
6.a Stock and technology mix



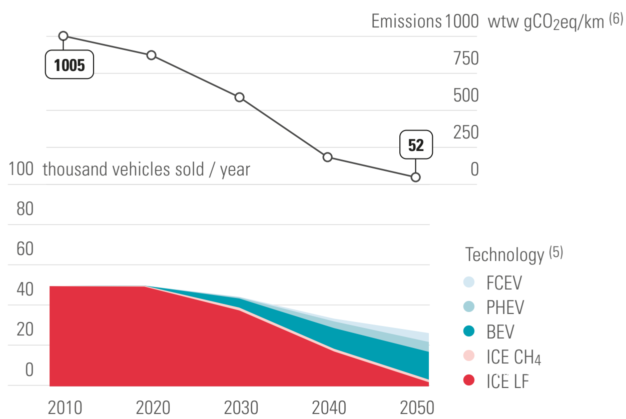
6.b Traffic share by distance class



6.c LCV sales and emissions



6.d HGV sales and emissions



(4) 2W: 2 wheelers, LCV: Light commercial vehicle, GVWR<2,5t and 2,5t<GVWR<3,5t, HGV: Heavy duty vehicle, Rigid GVWR<19t and >19t, Articulated: mainly 34-44t GVWR.

(5) FCEV: Fuel Cell Electric Vehicle, PHEV: Plug-in Hybrid Electric Vehicle, BEV: Battery Electric Vehicle, ICE CH_4: Internal Combustion Engines CH_4, ICE LF: Internal Combustion Engines Liquid Fuel.

(6) Emissions of average car sales is expressed in "well-to-wheel" gCO_2eq per vkm travelled which include emissions from fuel combustion and fuel production and distribution.

Scenario 1 - Dashboard presentation

Goods and mobility

Changes in tonnes of goods transported

Tonnes transported increased by around 50% over the period 2010 to 2050, from 2.4 billion to 3.7 billion tonnes transported per year in 2050 (despite a decrease during 2010 to 2015 following the 2008-2009 financial crisis). This increase is driven by all sectors, although with differences according to the type of goods.

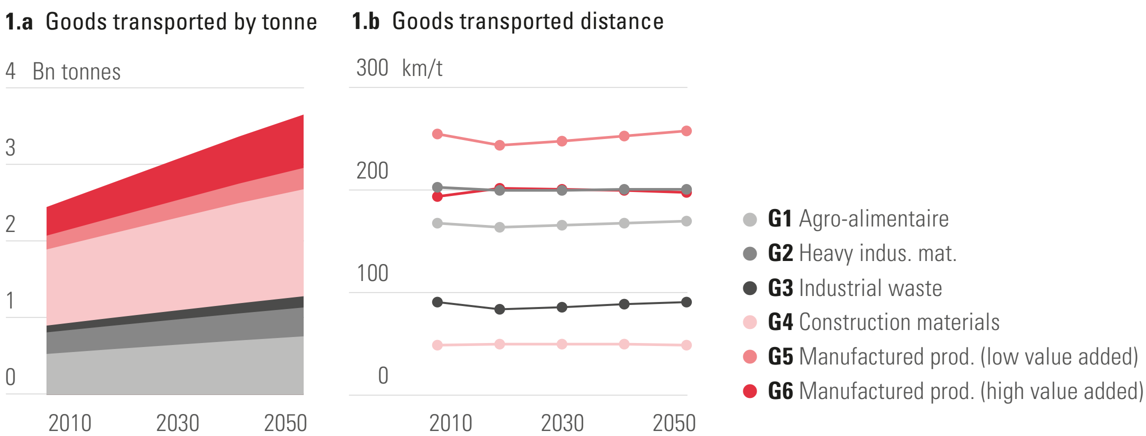
The continuity of the agri-food system, which requires increasing amounts of chemical inputs (NPK) and other crop protection products, and of consumption behaviours lead to an average increase in tonnes of agricultural and agri-food goods transported annually per inhabitant (G1) of 43% in 40 years. This increase is due to both an increase in consumption per person in 2050, and an increase in the consumption of animal products that are more intensive in terms of transport.

The transport sector for heavy and primary industrial materials (G2) is undergoing profound changes: coal and crude or refined petroleum, two materials transported in significant quantities in the sector, almost disappear (a small proportion of which is replaced by liquid and gaseous biofuels). In addition, chemical inputs (NPK) and other crop protection products that are necessary for the agri-food system are included in this category and continue to increase. The demand in terms of tonnes of G2 goods transported increases on average by 34% in 40 years, the slowest growth rate out of all goods categories. (**Figure 1**).

The construction materials sector (G4) does not undergo major transformations. The energy transition in the building sector provides better insulation for housing and therefore an increase in the materials used per constructed area. But, above all, the urbanisation model continues to extend the urban sprawl phenomenon which, together with changes in family structures, increases the number of tonnes transported on average. In total, the demand for transport in terms of tonnes of construction materials per household per year increases on average by 10% over the period, which represents an increase of 41% in 40 years.

Finally, the French economy increasingly specialises in high added value products (G6) and undergoes a very strong increase in the production and transport of these products in France. Moreover, French society

Figure 1. Transport demand per goods type, in billion tonnes transported



is still undergoing a period of high consumption of manufactured goods with low (G5) and high (G6) added value. These two phenomena lead to an 86% increase in the tonnes of G6 goods transported, the largest increase, and also to a significant increase of 55% of the tonnes of G5 goods transported.

Transformation of distances travelled

The average distances travelled of tonnage transported show only slight variations depending on the different types of goods, and the type of journey (national, imports, exports, transit) between 2010 and 2050. These distances have already increased considerably in recent decades and are now stabilising around current logistics chain lengths. Manufactured products with low added value (G5) are the products which travel the most kilometres on average, while building materials (G4) are those which rely most on local chains.

European social, fiscal and environmental harmonisation leads to a reduction in production cost differentials between European territories. However, competitiveness in the transport sector and the centrality of this link in economic exchanges, in the absence of alternatives, force actors in the sector to maintain low road transport costs. These changes in the cost structure are not, ultimately, sufficient to encourage the actors to reduce the distances travelled and therefore to change the organisation of their supply chains. The majority of goods (G1, G2, G5, G6) continue to be produced far from their places of consumption, the ranges of distances greater than 150 km and greater than 500 km are dominant. (**Figure 2**).

In total, the number of kilometres travelled by all tonnes of goods transported increased by 54% between 2010 and 2050 to reach the level of around 500 Gtkm in 2050. This is mainly due to a roughly 50% increase in tonnage transported and a slight increase in average distances travelled.

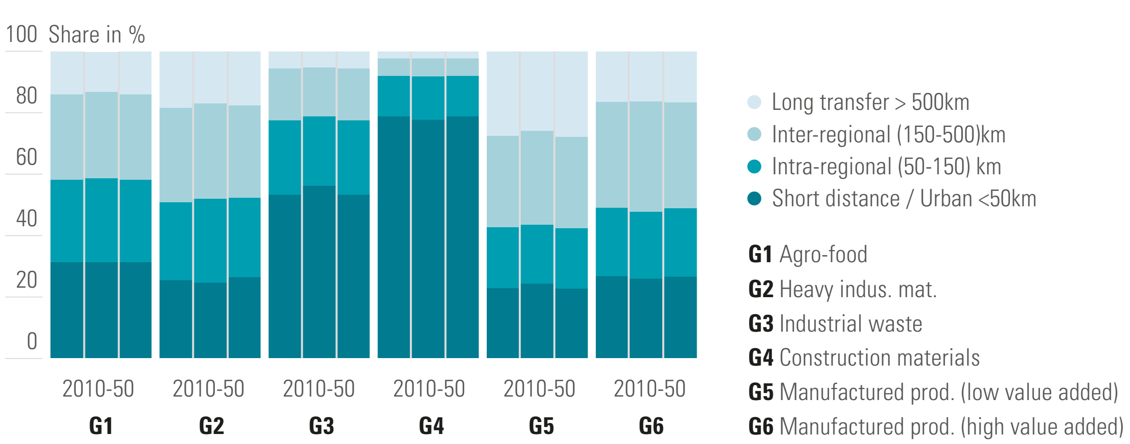
Modal structure of freight traffic

National and long distance transport (over 500 km) remain predominant. National transport, all distances combined, represents more than 60% of tkm in 2050, while transport for journeys greater than 500 km, including all types of transport, represents 47% of tkm in 2050.

Road transport remains the dominant mode, even if its modal share decreases slightly from 88 to 84% over the period 2010-2050. This is particularly noticeable over distances of less than 150 km and in particular for short-distance urban transport.

Rail freight transport develops mainly in connection with the development of large port infrastructure for heavy goods (G1, G2) and manufactured goods (G5, G6) and for ranges of distances mainly greater than 150 km. Rail traffic is ultimately more or less doubled and goes from 30 to 66 Gtkm over the period 2010 to 2050, both mechanically, as a result of the increase in freight traffic of all modes (+ 54%), but also due to an increase in its modal share, which represents between 9 and 14% of traffic in 2050, depending on the different transport types (national, import, export, transit).

Figure 2. Traffic by distance classes (domestic)



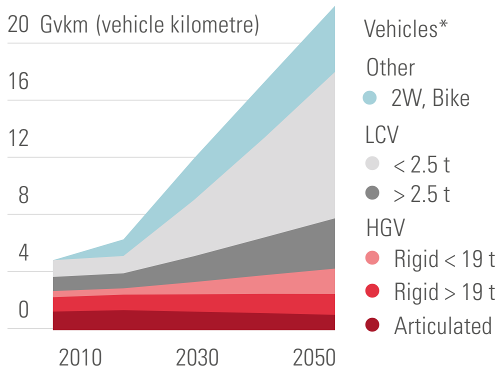
Finally, inland waterways across the territory remain a marginal mode and its modal distribution does not change significantly for the different types of transport and distance ranges. (**Figure 3**).

Urban logistics

The transport of goods for less than 50 km (mainly urban journeys) remains essentially road based, but the vehicles used in this segment are significantly transformed. Indeed, over the 2010-2050 period, small vehicle traffic increases while large articulated HGV traffic decreases. Among the smallest vehicles, the cargo bike and scooter traffic reaches approximately 4.6 Gvkm, while it was almost zero in 2010, LCV traffic increases five-fold and reaches around 13.7 Gvkm, and the traffic of rigid HGVs up to 19 tonnes GVWR nearly triples to reach around 1.8 Gvkm.

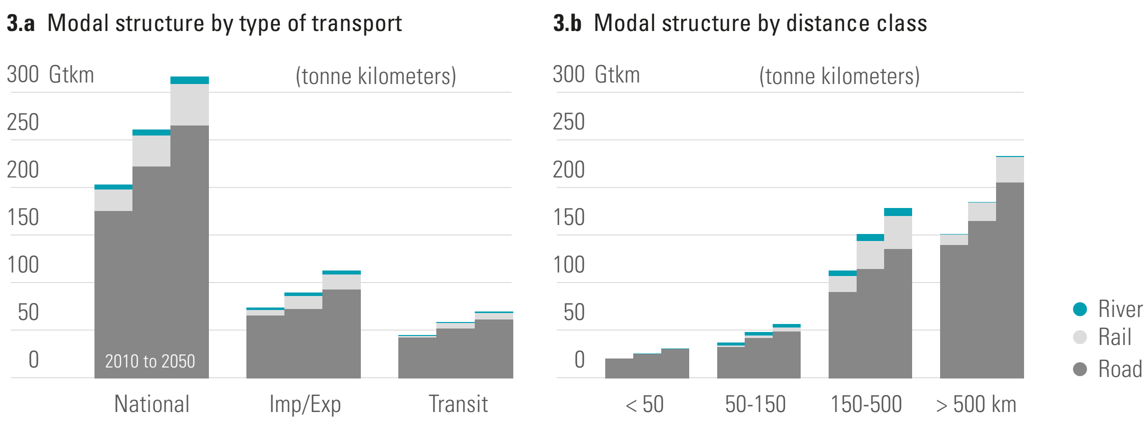
There is a particular surge in LCVs and two-wheeled vehicle traffic, going from 44% to 81% of traffic over this distance range over the period 2010-2050. These vehicles make a larger share of journeys, with a total of 11% tkm in 2050, as compared to less than 3% of tkm in 2010. This is due to the fact that these small vehicles are encouraged in urban areas, because they enable the continuation of fast goods delivery, despite congestion that does not reduce. On the other hand, they are used to move goods which are often light but that can be bulky, and their average loads in circulation remain lower than that of larger vehicles; structurally, the increase in tkm generates more vkm for these types of vehicles. (**Figure 4**).

Figure 4. Distribution of urban tonne kilometres (<50km) according to road vehicle type



* LCV >2.5 t PTAC (<3.5 t PTAC), HGV Rigid < 9.1 t CU (<19 t PTAC) HGV Articulated (mainly 34-44 t)

Figure 3. Modal structure by distances



Rail transport	2010 - Gtkm	2010 - % Gtkm all modes	2050 - Gtkm	2050 - % Gtkm all modes
National	23	11%	44	14%
Import/Export	6	8%	16	14%
Transit	2	4%	6	9%
Total Rail	31	9%	66	13%

Logistics indicators

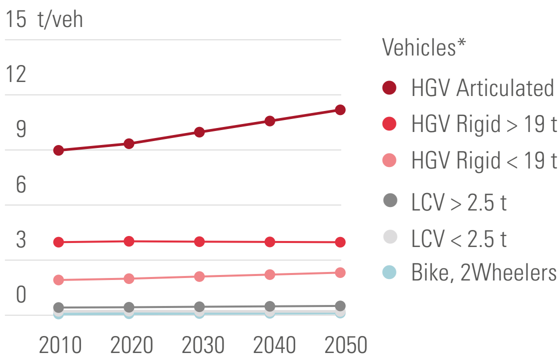
Over the 2010-2050 period, the technical and economic characteristics of the road and rail sectors remain unchanged and retain their current specificities, particularly in terms of slowness (h/km) or average distances. We note a slight decrease in slowness for rail, mainly due to improvement in traffic speeds related to investment in rail track repair, and a slight increase for road transport, mainly due to the decrease in traffic speeds related to congestion in urban or peri-urban areas (distances less than 150 km).
In addition, the average cost of road transport increases by around 20% by 2050 due to the transformation of the vehicle fleet and the increase in the use of smaller vehicles; this increase is limited by gains in terms of fuel consumption and the use of low-carbon fuels, mainly electricity. Rail, for its part, does not see any significant improvement, due to the lack of an economic model adapted to the changing freight transport demand, and its average transport cost increases by around 25% over the period 2010-2050. (**Figure 5**).

Filling rate and empty running

The average load factor (tkm/vkm) increases on average for the different vehicle types, except for HGVs greater than 19t GVWR and LCVs less than 2.5t GVWR. This is the result of structural transformations in the uses and distances travelled by the different vehicles, but also from the improvement in filling rates and a decrease in empty running.
Overall, the shorter the distances, the higher the filling rates and the greater the empty running for a range of vehicles. There is an improvement in filling rate for all types of road vehicles that is progressive according to journey distance, up to 25-30% over the period 2010-2050. During the same period, HGVs and LCVs experience a decrease in empty running rates ranging from 5 to 15% depending on the distances travelled. Only HGVs greater than 19t GVWR do not improve, since they are mainly used for the transport of construction materials and are already optimised. These improvements are mainly the result of advances made by logistics actors in sharing, managing and using transport flow data. (**Figure 6**).

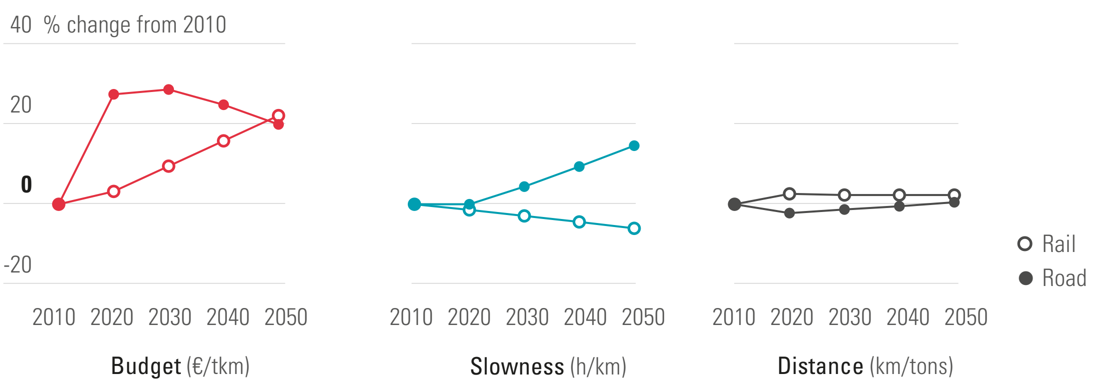
Figure 6. Change in tonnes transported by freight vehicles

(including empty running)



* *2W: 2 wheelers, LCV: Light commercial vehicle, PTAC<2,5t and 2,5t<PTAC<3,5t, HGV: Heavy duty vehicle, Rigid PTAC<19t et >19t, Articulated: mainly 34-44t PTAC.*

Figure 5. Indicators for rail and road logistics



Road freight transport

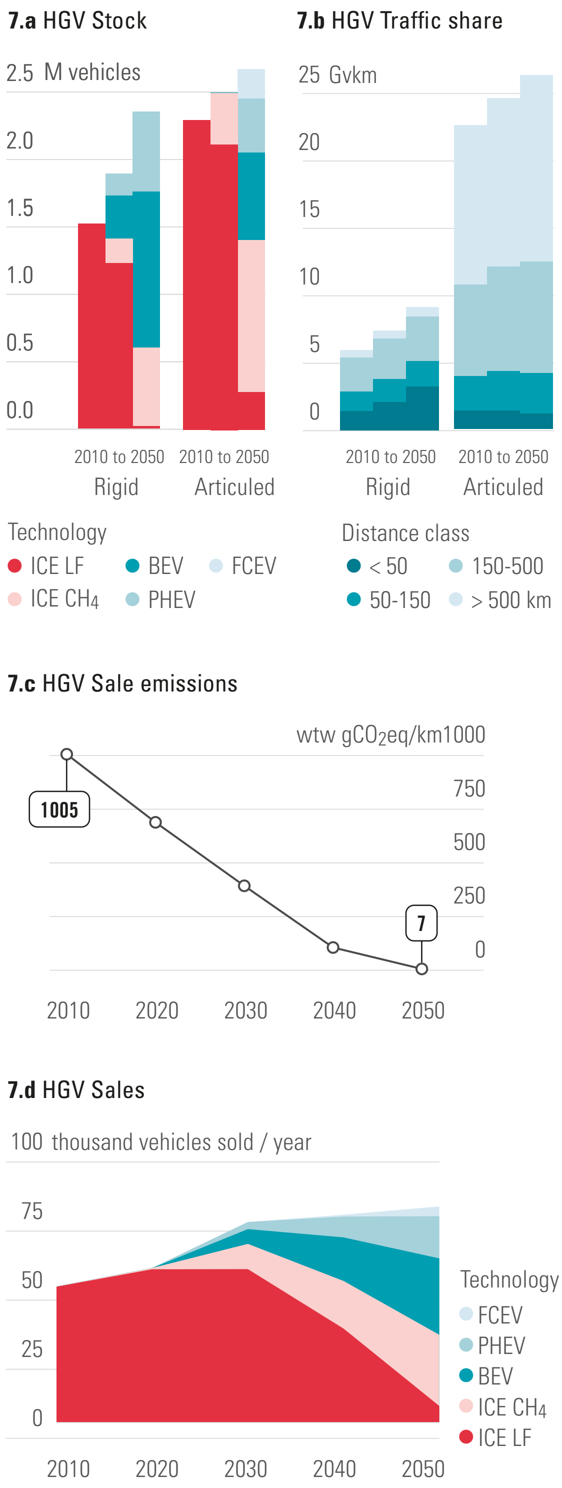
Use of HGVs and transformation of the stock

The structure of logistics chains and the place of road transport do not change fundamentally between 2010 and 2050. Only short-distance mainly urban journeys of less than 50 km require a transformation in the use of road vehicles with smaller and lighter vehicles, mainly due to time and traffic constraints as explained previously in point 2.2. The slight decrease in the circulation of articulated HGVs in urban traffic is barely noticeable given the significance of other distances. Conversely, the increase in the proportion of journeys of less than 50 km in the circulation of rigid HGVs (+10 percentage points) is clear.

In this scenario of growth in transport demand, rigid and articulated HGVs keep their average annual mileage of 30-50,000 km for rigid HGVs, and 100,000 km per year for articulated HGVs. Despite improvements in the average load, the stock of rigid HGVs increases by 54% (from 152,000 to 235,000 vehicles) and the stock of articulated HGVs increases by 17% (from 230,000 to 268,000 vehicles). This implies an increase in average annual sales of all HGVs, reaching a total of 78,000 HGVs per year.

In terms of engine choice for articulated HGVs, gas and liquid internal combustion engines in HGVs represent around 53% of the stock in 2050, with PHEV and FCEV HGVs at around 23%. This reflects the significance of articulated long-distance HGVs in this scenario and their need for ranges greater than 500 km. In addition, BEV HGVs strongly infiltrate the regional transport sector, representing a total of 24% of the stock in 2050. Regarding rigid HGVs, gas and liquid internal combustion engine HGVs only represent about 25% of the stock, reflecting the less significant need for long ranges. These HGVs also make up a greater share of transport for distances of less than 500 km, which enables BEV technologies to gain greater traction, to represent around 50% of the stock by 2050. These trends are reflected in terms of sales, with rising sales of ICE, PHEV/FCEV and BEV HGVs reaching 41%, 24%, 35% of sales, respectively, in 2050, leading to a drastic reduction in "well-to-wheel" (wtw) emissions from new vehicles, going from around 1,000 wtw gCO_2eq/km* in 2010 to less than 10 wtw gCO_2eq/km in 2050. (**Figure 7**).

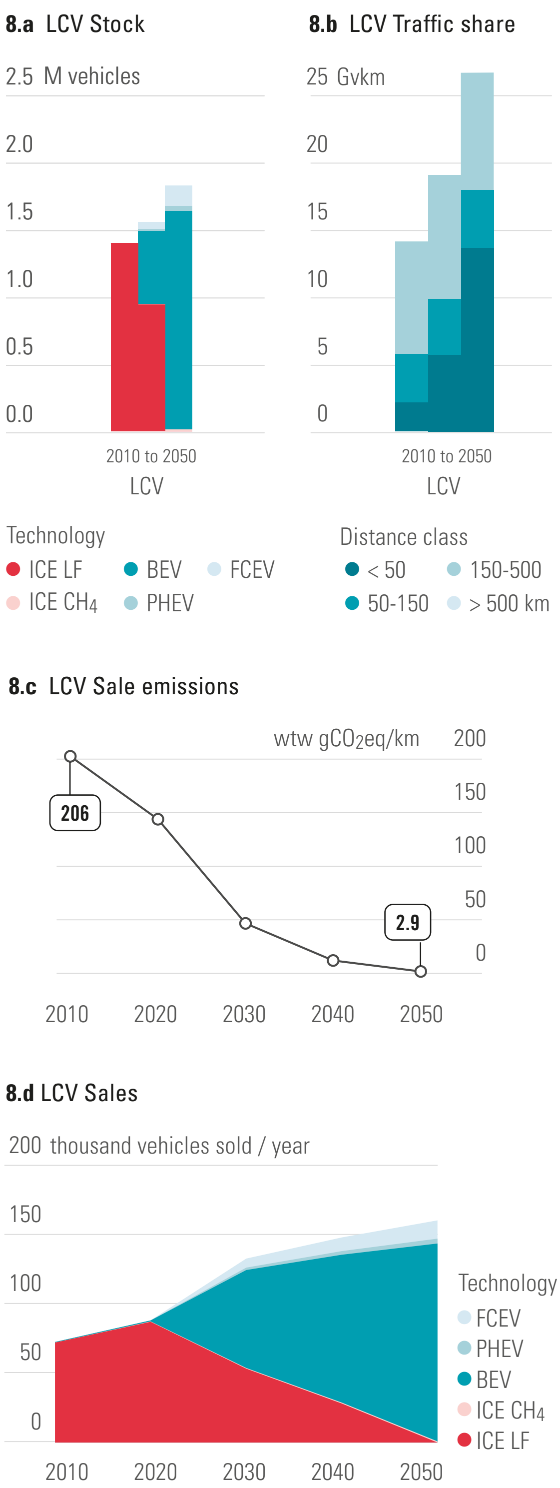
Figure 7. HGV : stock, sale, trafic and technologies



***Techonolgies**: ICE LF – Internal combustion engine for liquid fuel, ICE CH4 – Internal combustion engine for methane, BEV – Battery electric vehicle, PHEV – Plug in hybrid electric vehicle, FCEV – Fuel cell electric vehicle.*

***Emissions**: well-to-wheel (wtw) emissions includes "upstream" emissions related to the production and distribution of fuels and emissions "in the vehicles" related to the fuel combustion.*

Figure 8. LCV : stock, sale, trafic and technologies



__Techonolgies__: ICE LF – Internal combustion engine for liquid fuel, ICE CH4 – Internal combustion engine for methane, BEV – Battery electric vehicle, PHEV – Plug in hybrid electric vehicle, FCEV – Fuel cell electric vehicle.

__Emissions__: well-to-wheel (wtw) emissions includes "upstream" emissions related to the production and distribution of fuels and emissions "in the vehicles" related to the fuel combustion.

Use of LCVs and fleet transformation

LCVs become even more important for urban deliveries because they make more frequent deliveries with tighter deadlines and are easier to drive in increasingly congested urban traffic. The increase in the share of journeys of less than 50 km in LCV traffic (+35 pp) is very clear; this trend is all the more important since journeys of less than 50 km are generally marked by a low load factor for short distances.

Similarly, in this general growth scenario, to which is added a stronger growth of LCVs for last mile delivery, the annual mileage of LCVs increases from 6,000 km annually for small LCVs, and 14,000 km annually for large LCVs in 2010, to 15,000 km/year in 2050 for all; the LCV fleet increases by 30% and represents around 1.8 million vehicles. This implies a significant increase in annual sales which more than doubles to reach a figure of around 160,000 sales per year in 2050.

In terms of technological choices, BEVs strongly infiltrate this segment. Indeed, this technological solution is advantageous for journeys of less than 500 km and even more so for journeys of less than 150 km, which represent the bulk of distances travelled by these vehicles. For specific requirements for greater autonomy, FCEV or PHEV LCVs are also economically rational. From 2030, LCV BEV sales represent more than 50% of annual LCV sales and, by 2050, the average "well-to-wheel" (wtw) emissions from new LCVs will drop below the threshold of 10 wtw gCO_2eq/km. (**Figure 8**).

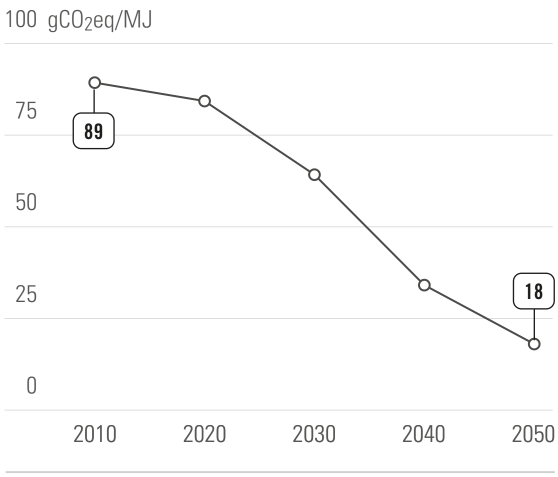
Energy consumption and emissions

The total energy consumption of the freight transport sector decreases by 30% over the period 2010-2050 to reach around 0.30 EJ, while at the same time, the demand for freight transport increases by about 50%. This significant decrease is due to gains on the unit energy consumption of vehicles, to logistic gains to improve loading and reduce empty running, but also to the use of electric motors that are more efficient in energy conversion than conventional combustion engines. Average consumption reaches 0.6 MJ/tkm in 2050, compared to 1.3 MJ/tkm in 2010. (**Figure 9**).

By 2050, all traction energy used is in the form of "decarbonised" carriers, that is to say low-carbon electricity (11 gCO_2/kWh in 2050), liquid and gaseous biofuels and hydrogen produced by electrolysis. The most important energy carriers are gaseous biofuels, which account for 37% of the energy consumed. Total direct emissions from the freight transport sector are zero, but indirect emissions from the sector represent around 5 $MtCO_2eq$/year in 2050. These residual emissions are solely indirect emissions related to the production of the various fuels, and mainly to the production of gaseous biofuels.

Thus, including direct and indirect emissions from energy production, which in reality depend on emissions from electricity production and the production of biofuels, the average carbon content of the energy used decreases by 80%, from 89 gCO_2/MJ in 2010 to 18 gCO_2/MJ in 2050. (**Figure 10**).

Figure 10. Carbon intensity



Conclusion

The decarbonisation of scenario 1 during the period 2010-2050 is mainly based on energy pillars related to the improvement of energy consumption (-30%) and the exclusive use of decarbonised energy sources, despite an increased demand for freight transport (**Figure 11**):

- number of tonnes transported (Mt): +49%
- average distances travelled (km/t): +3%
- energy consumption per unit of tkm (MJ/tkm): -55%
- carbon emissions from fuels used (gCO_2/MJ) : -80%

However, this decarbonisation scenario is not without consequences for a set of other aspects (see **Table 2**).

Figure 9. CO_2 emissions per road vehicle, according to fuel, and energy consumption according to energy source

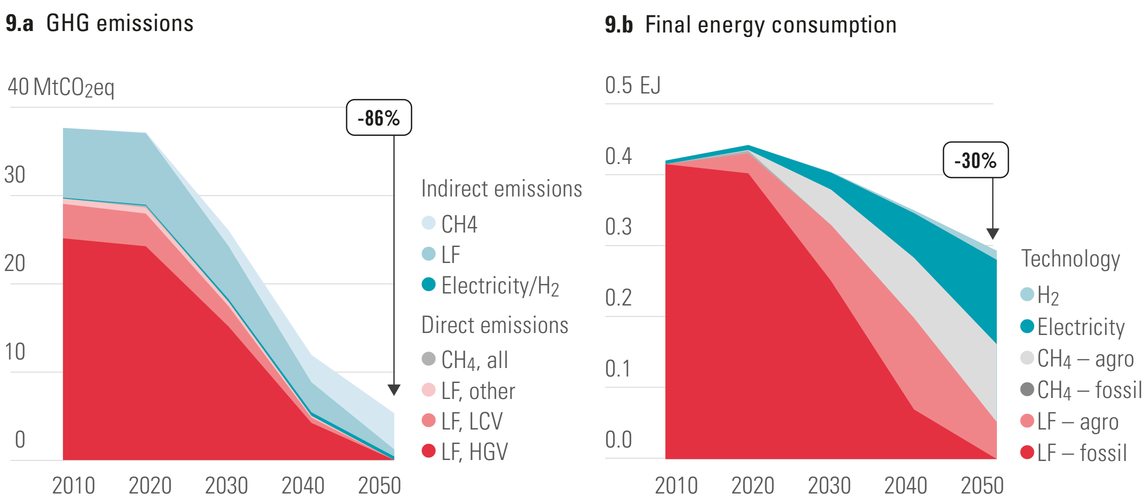


Figure 11. Emission drivers

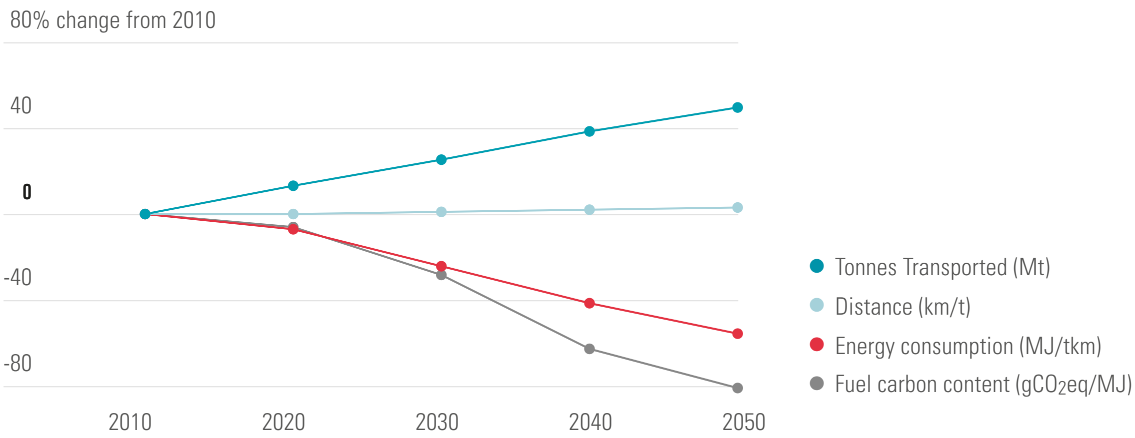


Table 2. Other aspects

	Change compared to 2010
Accidentology	Similar
Road wear	Higher due to more traffic
Congestion	Higher, particularly in towns
Noise pollution	Lower, but still an issue with the use of ICE vehicles
Local pollution and health	Slight decrease in emissions coming from combustion (fossil and biofuel ICE, electric hybrids), but increased traffic, ambiguous effect on emissions from other sources (braking, tyres, dust recircula-tion, etc.)
HGV battery resources	Large EV stock: around 65,000 articulated HGVs, 116,000 rigid HGVs and 1,623,000 LCVs. (Excluding PHEV and FCEV)
Infrastructure material resources	Mainly road development and low investment in rail infrastructure
Land use competition	Significant demand for biofuels, intensification of production in France and competition for land use, recourse to imports.
Working conditions in the sector	Identical without improvement

Scenario 2 – Dashboard presentation

Goods and mobility

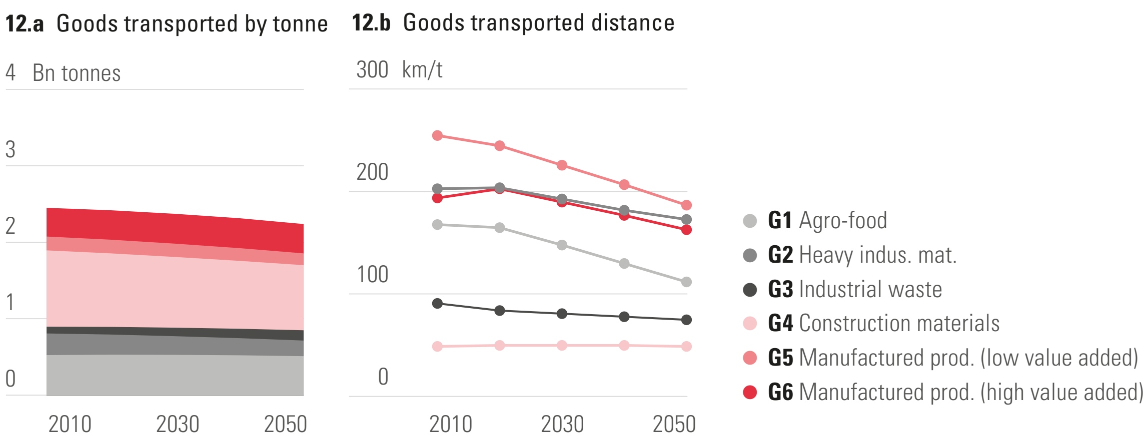
Changes in tonnes of transported goods

Loaded tonnes decreases by 9% between 2010 and 2050, from 2.5 to 2.2 billion tonnes transported annually. All types of goods are affected by this decrease. The only exception are recycling products and waste (G3). They will on the contrary increase due to the better recycling and recovery of other goods. (**Figure 12**). Agri-food product (G1) transportation is impacted by the establishment of agroecological agriculture. It, indeed reduces the tonnes transported by 15% per capita annually over 40 years, while ensuring good food quality.
Due to the transition of the agricultural and energy sectors, fossil primary industrial goods (G2) - such as coal, crude or refined oil, plastics, chemical inputs for intensive agriculture (NPK) and other crop protection products - will strongly reduce, or even disappear. . These transformations result in a 30% decrease (in tonnes transported) of G2 goods within 40 years.
The demand for the transport of construction materials (G4) follows the increase in households. But the use of new materials, the densification of secondary cities, as well as the optimisation of the use of materials for housing enable a 33% reduction in the number of tonnes of G4 goods transported annually per household, from 34 to 23 tonnes transported in 2050.
The transport of manufactured goods with low (G5) and high (G6) added value is strongly impacted by the development of the circular economy, which combines eco-designing, repairing, recycling and goods-sharing. This enables a 33% and a 20% decrease, in the amount of tonnes per household of low and high added value goods that are transported annually. However, this will not enable an absolute reduction in the number of tonnes transported by 2050 for goods with high added value.

Transformation of distances travelled

Average distances travelled by one tonne of cargo will on average decrease by 20% between 2010 and 2050. These variations depend on the type of goods and the type of travel. For all goods, the tonnes transported over very long distances (over 500 km) and inter-regional distances (between 150 and 500 km) decrease in favour of tonnes transported over intra-regional (between 50 and 150 km) and local (below 50 km) distances.

Figure 12. Demande de transport par marchandise et distance de transport



European social, fiscal and environmental harmonisation leads to a reduction in the gap of production cost between European territories. Simultaneously, the integration of negative road externalities in a distance-based toll, the improvement of lorry drivers' working conditions and technological and infrastructural investments lead to an increase in the average cost of transportation. These changes in cost structure modify the behaviour of goods producers, who thus favour locating production activities as close as possible to consumption centres. Moreover, the reduction in just-in-time deliveries, sustained by a demand for local products, contributes to both the development of these regional ecosystems and the shortening of logistic chains. (**Figure 13**).

Some other elements can also explain this transformation of distances. Agroecology and short channels popularise the consumer-producer relationship and enable a more regionalised production. By diminishing the use of liquid fuels, the energy transition reduces the long travels, related to their transport. A low carbon industry results in a lower carbon metal production. The producers are organising recycling systems at their own level and encourage the development of reuse systems related to their activities. Due to the weight of materials that need to be moved, the building material economy is already a local one; this distribution will not change and this economy will find new growth sources with local eco-materials. Eventually the repair economy generates shorter distance flows and allows new craftsmen to emerge. A part of long distance travel is reduced, for instance that which was related to the transport of new products.

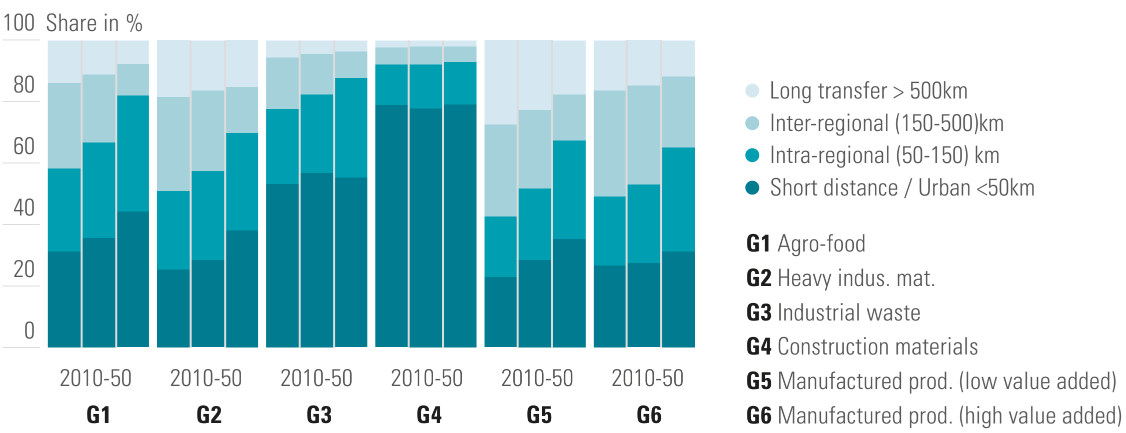
As a whole, the decrease in tonnes transported and in average unit distances, as mentioned above, leads between 2010 and 2050 to a 27% reduction in the volume of all transported goods; thus reaching 238 Gtkm.

Modal structure of freight traffic

National transport maintains a predominant position, representing more than 60% of tkm in 2050. Tonne-kilometres for journeys greater than 150 km and 500 km are still the major contributors but decrease between 2010 and 2050.

The rank of the different modes of goods transport is transformed particularly for long distance journeys. For journeys over 500 km, the majority of which are international, the share of rail reaches 52% of Gtkm and, compared to 2010, traffic increases four-fold. For inter-regional journeys between 150 and 500 km, the proportion of rail reaches 35% of Gtkm and traffic increases by 27% in absolute terms compared to 2010. For intra-regional (between 50 and 150 km) and local (< 50 km) journeys, the proportion of rail is 9% and 2%, respectively. Given the meshing of the road network and the characteristics of road transport vehicles, road transport is generally much better adapted to short-distance transport and remains an essential link for the first and last miles. Road transport will remain predominant over these distances.

Figure 13. Marchandises transportées par classes de distance



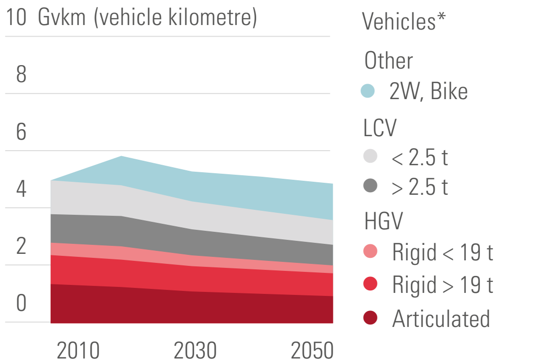
For all distance ranges combined, rail transport increases its level of national transport from 23 to 36 Gtkm in 2050, representing a 25% modal share . It increases slightly its import and export international transport, from 6 to 10 Gtkm in 2050. It increases considerably in terms of transit: from 2 to 36 Gtkm in 2050. In total, all distance ranges combined and all transport types combined, the proportion of rail in domestic goods transport increases from 9% in 2010 to 34% in 2050. (**Figure 14**).

These transformations are due to changes in the demand for goods transport, as described above. They are due to logistic and infrastructure investments that are made in order to develop efficient multimodality at the national level with a system of "interconnected hubs". They are also due to changes in the transport speed of each mode, changes in modal costs, as well as changes in consumption and delivery behaviours. We note that these evolutions enable both the transformation of rail services, making them more competitive (speed, costs, availability), but also the transformation of some characteristics of the demand (reduction of just-in-time delivery, re-massification of flows) and of road transport (speeds, costs), enabling the creation of a rail model for long distances.

Urban logistics

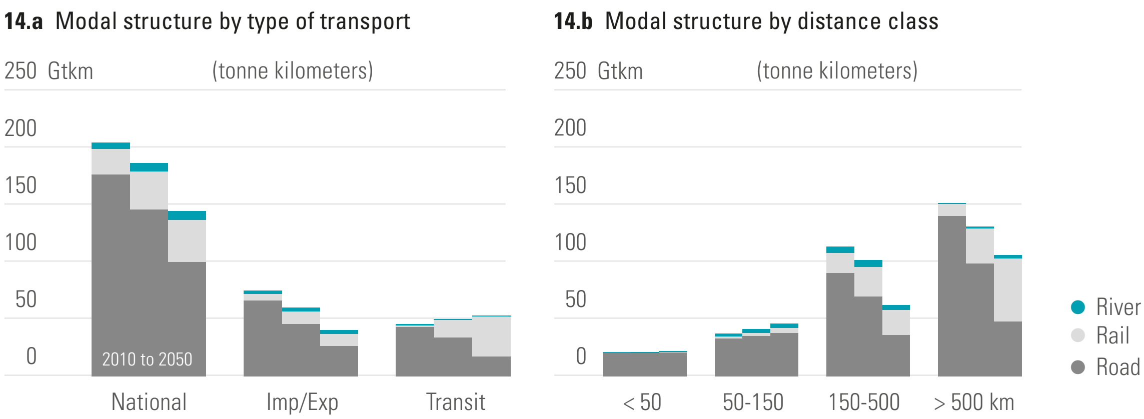
More than 90% of short distances (<50 km) and most urban goods transport is done by road in 2050. On this segment, the volume of transport, in tkm, remains around 22 Gtkm and the importance of different vehicles in carrying out this transport is unchanged between 2010 and 2050. Traffic decreases slightly over the period 2010-2050 due to the improvement of the average load factor for all vehicles. (**Figure 15**).

Figure 15. Distribution of urban tonne kilometres according to road vehicle type



* *LCV >2.5 t PTAC (<3.5 t PTAC), HGV Rigid < 9.1 t CU (<19 t PTAC) HGV Articulated (mainly 34-44 t)*

Figure 14. Modal structure by distances



Rail transport	2010 - Gtkm	2010 - % Gtkm all modes	2050 - Gtkm	2050 - % Gtkm all modes
National	23	11%	36	25%
Import/Export	6	8%	10	26%
Transit	2	4%	35	66%
Total Rail	31	9%	81	34%

These transformations are mainly due to the reforms undertaken by major agglomerations to better manage urban freight and the associated pollution. The transformation of the organisation of "upstream" logistics requires fine-tuning up to the edges of large cities with "downstream" platforms, urban distribution centres (UDCs) and decentralised reception points within cities, to restructure, enlarge flows, de-synchronise and allow the use of alternative and low carbon modes. These transformations towards more efficiency enable the continued use of HGVs while avoiding an increase in congestion.

Logistics indicators

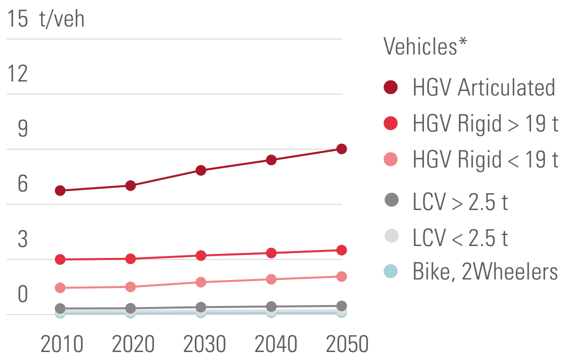
Over the 2010-2050 period, in the road sector, the average distance travelled will be halved, the average cost (eur/tkm) will be nearly tripled and slowness (h/km) will increase by 23%. At the same time, in the rail sector, the average distance travelled per tonne transported remains stable, the average cost (eur/tkm) is reduced by 10% and the slowness (h/km) is reduced by 28%.
Changes in the cost of road are mainly due to the integration of social and environmental costs into a toll, as well as the improvement of the sector's pay conditions. Changes in delivery time are mainly due to the restructuring of flows and the reduction in road transport speeds, particularly over long distances. For rail, cost and time improvements are mainly due to a structural effect related to the increase in the importance of rail over long distances, but also to transformations of rail and multimodal infrastructure, and improvements in rail logistics supply which reduces costs, traffic speeds and offloading. (**Figure 16**).

Filling rate and empty running

Over the 2010-2050 period, road vehicles increase their filling rate per vehicle up to 60% and decrease their empty running up to 50% . This depends both on the vehicles and journey distances. (**Figure 17**).
These improvements in average load factor are made possible by the organisation of the transport system into hubs, which allow the massification of flows, and by several other elements acting both on filling rate and empty returns: time management, better collaboration between actors, average increase in the cost of road, additional incentive for filling, etc.

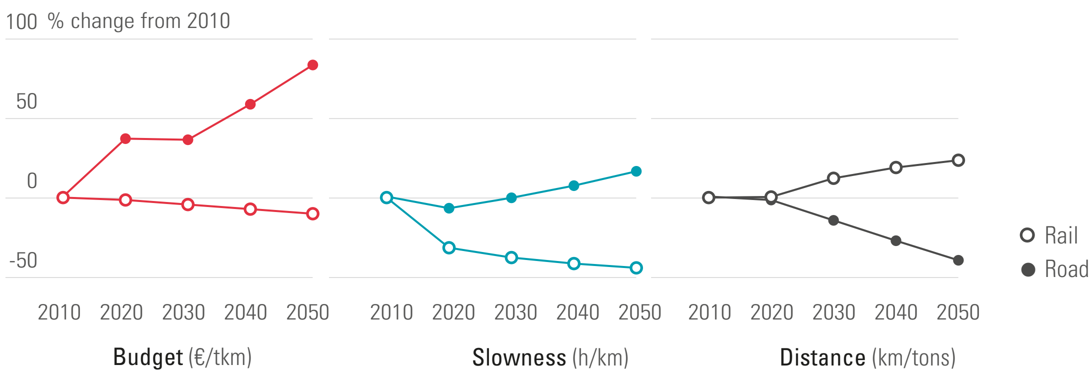
Figure 17. Change in tonnes transported by freight vehicles

(including empty running)



* *2W: 2 wheelers, LCV: Light commercial vehicle, PTAC<2,5t and 2,5t<PTAC<3,5t, HGV: Heavy duty vehicle, Rigid PTAC<19t et >19t, Articulated: mainly 34-44t PTAC.*

Figure 16. Indicators for rail and road logistics



Road freight transport

Use of HGVs and transformation of the stock

The role of road transport and HGVs changes entirely in this scenario. Road transport remains dominant for regional and local transport but givespart of its long distance and inter-regional journeys to rail transport. Moreover, due to the overall reduction in freight transport and the improvement in the average load factor of vehicles, vehicle kilometres decrease structurally and therefore, for the same mileage, the vehicle fleet also decreases.

HGVs cover approximately 72% fewer kilometres over long distances (>150 km) and only 29% of HGV kilometres are still carried out for very long distances greater than 500 km. The vast majority of the remaining HGVs are focused on regional and inter-regional transport, with daily distances rarely exceeding 400 km. In particular, articulated HGVs, become less significant for very long distance transport, and carry out twice as many kilometres for regional journeys (<150 km) than before, which represents approximately 37% of HGV kilometres in 2050.

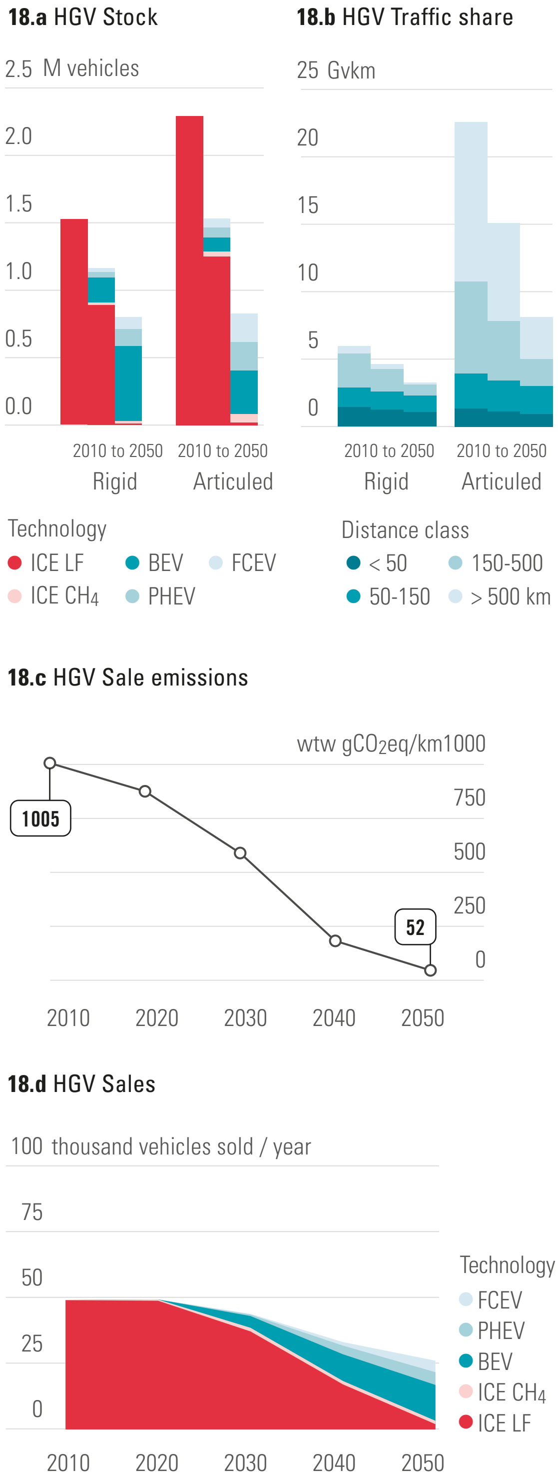
The total number of HGVs used falls by more than half between 2010 and 2050, reaching a fleet level of 163,000 units, with a halving of annual sales by 2050. The total stock of articulated HGVs in particular decreases by 64%.

The regionalisation of trade, the integration of environmental externalities of ICE engines and technical progress on batteries makes possible the increased electrification of rigid and articulated HGVs, with BEV HGVs representing around 56% of the fleet in 2050 for shorter journeys (inter-regional). Some HGVs will be able to reach ranges of between 300 to 500 km with on-board batteries ranging from 400 to 700 kWh. By 2050, other HGV technologies in the fleet will include around 37% of PHEV or FCEV HGVs, and only 6% and 2% respectively are gas or liquid powered. (**Figure 18**).

Use of LCVs and stock transformation

LCV traffic decreases sharply, particularly over inter-regional distances (150-500 km), being redirected towards intra-regional journeys (<150 km). In total, the decrease in road traffic leads to a halving

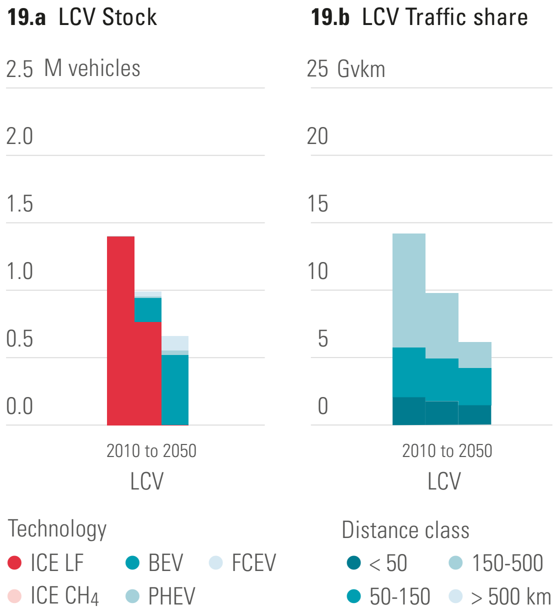
Figure 18. HGV : stock, sale, trafic and technologies

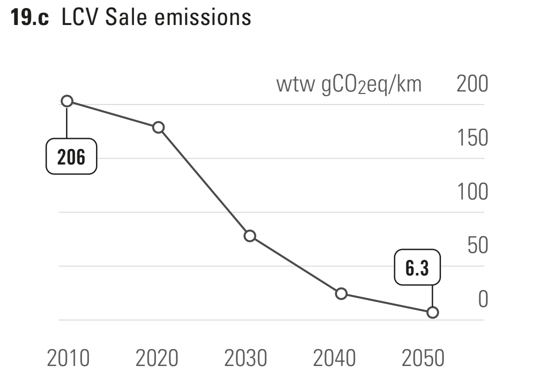


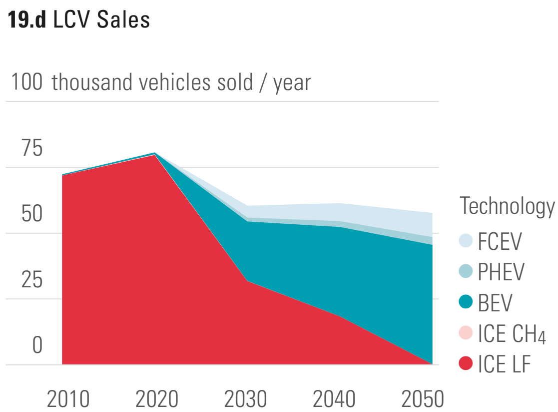
***Techonolgies**: ICE LF – Internal combustion engine for liquid fuel, ICE CH4 – Internal combustion engine for methane, BEV – Battery electric vehicle, PHEV – Plug in hybrid electric vehicle, FCEV – Fuel cell electric vehicle.*

***Emissions**: well-to-wheel (wtw) emissions includes "upstream" emissions related to the production and distribution of fuels and emissions "in the vehicles" related to the fuel combustion.*

Figure 19. VUL : stock, sale, trafic and technologies







***Techonolgies**: ICE LF – Internal combustion engine for liquid fuel, ICE CH4 – Internal combustion engine for methane, BEV – Battery electric vehicle, PHEV – Plug in hybrid electric vehicle, FCEV – Fuel cell electric vehicle.*

***Emissions**: well-to-wheel (wtw) emissions includes "upstream" emissions related to the production and distribution of fuels and emissions "in the vehicles" related to the fuel combustion.*

of the stock of LCVs, reaching around 660,000 vehicles in 2050.

The LCV fleet can be electrified to a large extent without risk because the refocusing of these vehicles towards intra-regional distances reduces the need for range. BEV LCVs represent around 79% of the fleet in 2050, and PHEV and FCEV LCVs make up the rest of the fleet in 2050. Liquid-fuelled internal combustion engines make up only a tiny fraction. Total LCV sales decrease over the 2010-2050 period, but there is a boom in sales of electric LCVs.

All these transformations are due to a general shortening of the logistics chains, to changes in the role of the road in the new multimodal system, as well as improvements in the filling rates and empty running of vehicles. But, they are also due to new regulations in major cities that encourage the use of less polluting vehicles. (**Figure 19**).

Energy consumption and emissions

Energy consumption in the goods transport sector undergoes a four-fold decrease during the period 2010-2050 and reaches 0.10 EJ in 2050. Fossil fuels disappear entirely, and electricity becomes the main energy carrier in the sector, representing around 70% of final consumption. These energy gains are due to a volume effect related to the reduction in freight transport demand, but also due to an increased share of rail transport, described above. They are also due to other transformations like the logistic improvements, the electrification of road transport and the unit consumption gains of vehicles. Average consumption reaches 0.4 MJ/tkm in 2050 compared to 1.3 MJ/tkm in 2010. (**Figure 22**).

Total direct emissions from the freight transport sector are zero in 2050, and indirect emissions from the sector represent less than 1 $MtCO_2eq$/year in 2050. These remaining emissions are solely indirect emissions related to the production of various fuels, mainly electricity production.

Thus, by including direct and indirect emissions from energy production, which in reality depend on emissions from electricity production and biofuel production, the average carbon content of the energy used in 2050 is around 10 gCO_2/MJ. (**Figure 21**).

Conclusion

The decarbonisation of scenario 2 over the period 2010-2050 is based on a distribution of efforts between the different pillars of decarbonization (**Figure 22**):

- number of tonnes transported (Mt): -9%
- average distances travelled (km/t): -20%
- energy consumption per unit of tkm (MJ/tkm): -67%
- carbon emissions from fuels used (gCO_2/MJ): -89%

However, this decarbonisation scenario is not without consequences for other aspects (see **Table 4**).

Figure 21. Carbon intensity

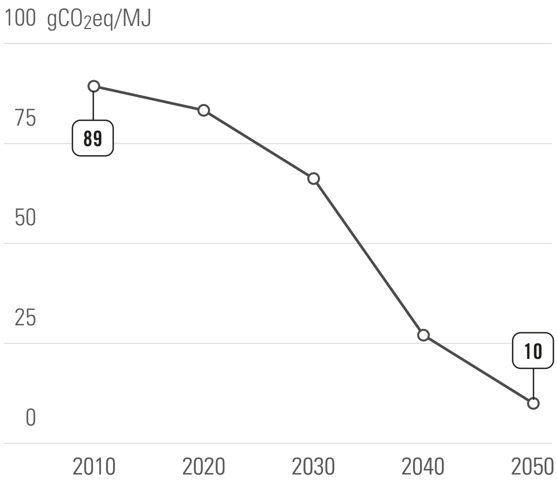
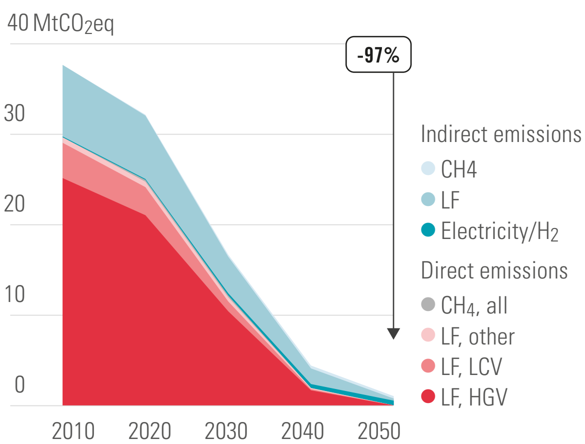


Figure 20. CO_2 emissions per road vehicle, according to fuel, and energy consumption according to energy source

9.a GHG emissions



9.b Final energy consumption

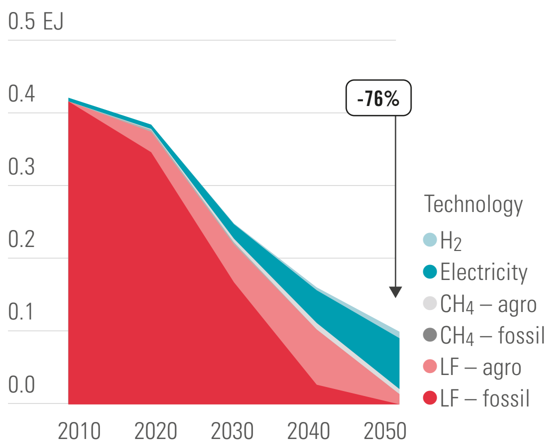


Figure 22. Emission drivers

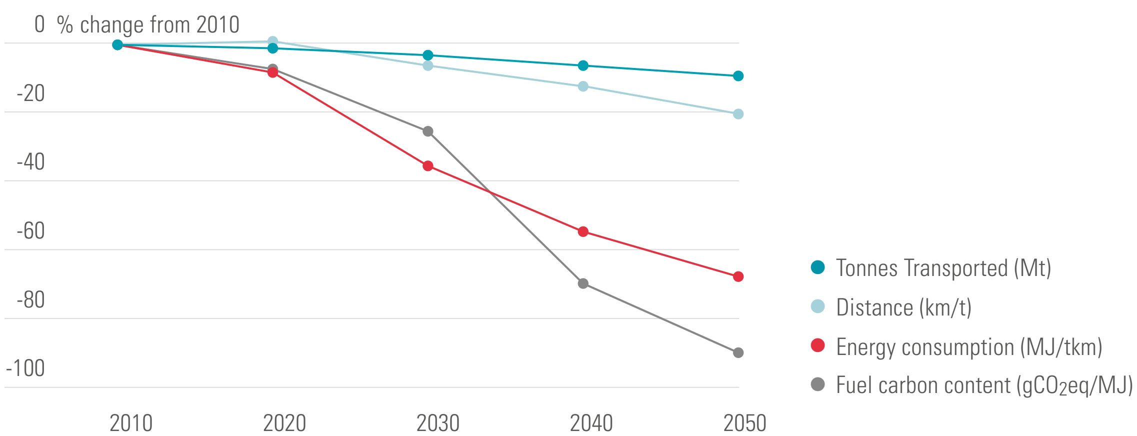


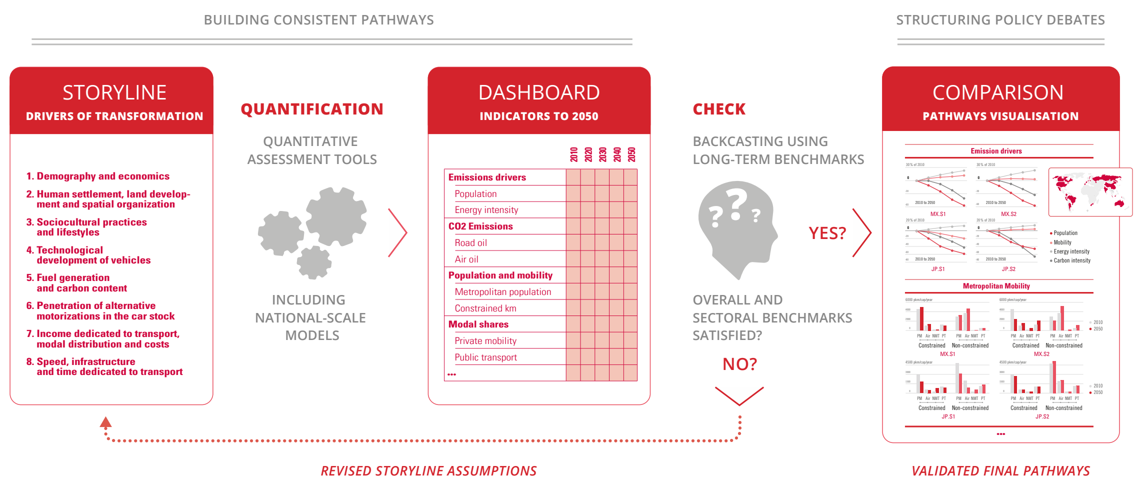
Table 4. Other aspects

Other aspects	Change compared to 2010
Accidentology	Reduced due to distance-based toll, reduced traffic, reduced speed
Road wear	Reduced due to reduced traffic
Congestion	Reduced due to reduced traffic and distance-based toll
Noise pollution	Less significant on road but increasing on rail
Local pollution and health	Reduced due to the decline in internal combustion engines and the strong infiltration of electric vehicles, due to the overall reduction of traffic
HGV battery resources	BEV stock: around 33,000 articulated HGVs, 58,000 rigid HGVs and 520,000 LCVs. (Excluding PHEV and FCEV vehicles)
Infrastructure materials resources	Significant resources for the development of rail infrastructure and logistics platforms
Land use competition	Demand for biofuels is low and compatible with agroecology in France, no recourse to im-ports
Road sector working conditions	Improvements in salaries and working hours

Annexes

Annex 1 – Method

Figure 23. Method



The DDP approach proposes to combine qualitative and quantitative approaches for the purposes of an iterative and "backcasting" foresight study with an exploratory 2050 time horizon. Above all, this approach is a tool designed for experts in the sector to build long-term deep decarbonisation trajectories to 2050 that are consistent with the Paris agreement and capable of informing the short-term decisions of the various sectoral actors. This approach also aims to structure national dialogues around the comparison of long-term trajectories.

It consists of five main steps: "*Storyline*", "*Quantification*", "*Dashboard*", "*Check*" and "*Comparison*", as illustrated in the figure below.

***Storyline* - the story of the transformations:**
- Description of a coherent narrative describing the transformations of the various drivers of the sector
- Speaks to all actors in society (politicians, citizens, businesses…) and clearly describes the transformations

Quantification
- Detailed, flexible and open quantitative description
- Capable of integrating different quantitative tools (models, international references, expert opinions), adapting to the needs of the story and the representation of the Dashboard indicators

***Dashboard* – useful indicators for public debate:**
- Brief quantitative description gathering all indicators useful for the public debate
- Able to describe and verify a number of key parameters

***Check* – Consistency tests and iterative loop**
- Analysis of the consistency of quantified indicators with key national goals, analysis of the coherence of the narrative with indicators and iteration

***Comparaison* – Graphic visualisation of trajectories**
- Graphical presentation of the dashboard indicators to facilitate dialogue and exchange

Many methods enable the representation of the transformations described in the narrative as a set of quantified indicators. In this work, we used different quantification approaches, aiming to take all influencing factors into account. Existing scientific knowledge based on literatures like elasticities between variables, constraints of physical resources and interactions with other sectors: agricultural, industry, energy have been used. Other scientific knowledge based on existing literature benchmarks and expert judgements have also been used to estimate some values. Different economic tools such as the analysis of the total cost of ownership, the analysis of negative externalities, and changes in the average cost of transport have also been applied, etc.

For more information about the approach:

- A pathway design framework for national low greenhouse gas emission development strategies, Nature Climate Change, 2019, Waisman et al.
- How to structure the public debate on the low-carbon future of passenger transport?, Issue Brief N13, 2018, Briand et al.
- A policy-relevant pathway design framework for sectoral deep decarbonisation: the case of passenger transportation, (yet to be published), Lefevre et al.
- Website: ddpinitiative.org

Annex 2 – Data segmentation

A. Goods categories

Source data are in general categorised according to "*Standard goods classification for transport statistics (NST)*", which divides into 20 categories.[2]

Given that this exercise already comprises a complex set of relationships between different elements, for the purposes of simplification, six "supra-categories" were created. The categorisation choices were made with the intention of creating coherent groups according to the production sectors and the characteristics of goods. The following six categories capture most of the major trends from different key economic sectors: the agri-food sector (G1), the construction sector (G4) and the industrial sectors (G2 - raw or intermediate materials, G3 - waste, G5 and G6 - products). (See **Table 5**).

Groups 5 and 6 bring together a very diverse range of goods. Group 5 assembles a set of products with fairly low added value: textiles, wood and paper industries, cars and other transport vehicles, furniture, etc. Group 6 brings together a set of complex products: equipment/machines with high AV, mail/parcel, other goods and grouped goods. The majority of the tonnes transported in this group are grouped goods and products of an unknown nature which have been put in this category by default.

B. Transport typology

The demand for freight transport is segmented according to four types of transport: national, imports, exports and transit. These types of transport make it possible to characterise very different dynamics. Na-

Table 5. NST Categories

"Supra-categories" - DDP Freight	NST Categories	Label – DDP Fret
1	1 and 4	Agri-food products
2	2, 7, 8, 10	Heavy industrial products (energy, chemicals, plastic, metals)
3	14	Wastes
4	3 and 9	Construction materials
5	5, 6, 12, 13, 16	Low added-value manufactured products
6	11, 15, 17, 18, 19, 20	High added-value manufactured products

2 A full description of NST 2007 is available at: https://ec.europa.eu/eurostat/statistics-explained/index.php/Glossary:Standard_goods_classification_for_transport_statistics_(NST)

tional transport represents entirely domestic flows, while imports, exports and transit represent international flows. The distances, costs, times, modes can be very different, according to the journey types. Consequently, it is useful to analyse them separately.

National: national transport represents any transport that occurs between loading and unloading points within France, regardless of the vehicle's flag.

Imports: import transport represents any transport that takes place between a foreign loading point and an unloading point in France, regardless of the vehicle's flag.

Exports: export transport represents any transport that takes place between a loading point in France and a foreign unloading point, regardless of the vehicle's flag.

Transit: transit transport represents any transport which takes place between a foreign loading point and a different foreign unloading point, which crosses part of the French territory en route, regardless of the vehicle's flag.

Note: For international transport (imports, exports and transit) only the kilometres travelled on French national territory are included in the accounting of the transport demand of French goods. This is known as the demand for "domestic" transport.

Note: "Transport" is defined as transport between loading and unloading points. If a commodity is first transported from its production site to a storage depot, where another lorry then transports it to its consumption point, this counts as two different transports.

Example: A heavy goods vehicle crosses the border into France and arrives at a logistics centre situated 5 kilometres from the German border. Its goods are unloaded and then reloaded onto a train that travels to Paris. The HGV transport is counted as an "import", with only 5 kilometres travelled. The rail transport is counted as "national".

C. Distance ranges

Freight transport demand has been divided into four distance ranges: less than 50 km, between 50 and 100 km, between 150 and 500 km, more than 500 km. These distance ranges were chosen to represent the spatial organisation of the transport demand and to be able to consider different logistic realities on the load factor.

Local and urban freight (less than 50 km): This distance range corresponds to short distance travel, more often in urban areas.

Intra-regional freight (50-150 km): This distance range corresponds to journeys with an average distance at the regional level (for example Nantes-Angers or Lyon-Grenoble).

Near inter-regional freight (150-500 km): This distance range corresponds to distances that can be inter-regional, depending on the size of the region, but also greater than the size of a region (for example Lille-Paris or Le Mans-Paris) and characterises inter-regional travel.

Long distance inter-regional freight (more than 500 km): This distance range corresponds to long national distances (for example Quimper-Paris or Bordeaux-Paris).

D. Road vehicles

Road freight vehicles have been divided into five vehicle types: two types of light commercial vehicles (LCVs) and three types of heavy goods vehicles (HGVs) based on their total permissible laden weight (GVWR).

LCV < 2.5t GVWR: Light commercial vehicles weighing up to 2.5 tonnes and carrying payloads of up to approximately 0.75 tonnes.

LCV > 2.5t GVWR: Light commercial vehicles weighing between 2.5t and 3.5t and transporting payloads of up to 1.2 tonnes.

HGV <= 19t GVWR : Rigid heavy goods vehicles weighing a maximum of 19t and transporting payloads of up to 9t.

HGV > 19t GVWR: Rigid heavy goods vehicles weighing between 21t to 26t and upwards, and transporting payloads of over 9 tonnes.

Articulated HGV: Articulated heavy goods vehicles weighing between 34t and 44t and transporting payloads of up to a maximum of 25t for the largest vehicles.

GVWR definition: the maximum authorised weight for a road vehicle. It includes the weight of the unladen vehicle, the maximum cargo (payload), as well as the maximum weight of the driver and passengers.

E. Simplified representation of key data (2010 to 2050)

Description of demand

Quantity (Mt)
Distance (km/t)
Distances travelled (tkm)

Detail according to:
- Category of goods
- Distance range
- Modes

Focus on road freight transport

Tonnes transported by different veh. (tkm)
Laden weight transported (t/vehicle)
Empty running proportion (% vkm)
Vehicle traffic (vkm)
HGV and LCV stock and sales (veh)

Details according to:
- Tkm per Type X, distance range, 5 vehicle types
- Transported weights/empty running/traffic per vehicle types and distance range
- Stock/sales of 5 engine types

Motor fuel used

For national road freight (% vkm)
Details according to 5 vehicle types, 4 distance ranges, and 4 fuel types

For other modes (% tkm)
Details according to 4 fuel types:
- liquid fuels
- CH_4-based gaseous fuels
- electric fuels
- H_2-based gaseous fuels

Energy consumption of vehicles used

For domestic road transport (MJ/vkm)
Details according to 5 vehicle types and 3 engine types

For other modes (MJ/tkm)
Details according to 3 engine types:
- Internal combustion engine
- 100% electric engine
- Electric engine with heat pump

Calculation of energy consumption (TJ)
Details according to 4 fuel types and different modes

Production methods for 4 fuel types

For electricity (% consumption)
Details according to electricity mix as a function of 5 production methods

For other liquid and gaseous fuels (TJ)
Details according to the production of alternative decarbonised fuels:
liquids, gaseous CH4, gaseous H2 from electrolysis (TJ)
and the proportion of biofuels in the different fuel types (% TJ)

Carbon content of production method for 4 fuel types

For electricity (gCO_2/kWh)
Details according to the carbon intensity of 5 production methods

For other liquid and gaseous fuels (gCO_2/MJ)
Details according to carbon intensity of production methods: 3 conventional and 3 decarbonised alternatives

Calculation of emissions ($MtCO_2$)
Detail according to 4 fuel types and different modes

F. Main data sources

Road:
- "Road freight transport" database, French and European, for 2010 and 2015, published in 2011 and 2016
- "Light commercial vehicle survey 2011" database, published in 2012
- Transport accounts in 2010 and 2015, SDES, published in 2011 and 2016

Rail:
- Transport accounts in 2010 and 2015, SDES, published in 2011 and 2016
- Evolution of land freight over a 10-year period, CGEDD, published in July 2010

Rivers:
- "VNF river transport" database, French and European, for 2010 and 2015, published in 2011 and 2016
- Transport accounts for 2010 and 2015, SDES, published in 2011 and 2016.

We are very grateful to members of the Data and Statistical Studies Service (SDES) who allowed us to access certain databases.

Annex 3 – Scope of emissions

This work focused solely on an analysis of territorial and terrestrial emission sources (road, rail, river), i.e. emissions from any vehicle travelling on the national territory. This includes vehicles registered in France and abroad, as well as the distances travelled on the territory for import, export and transit transport.

Emission data for foreign LCVs are not available and it is difficult to estimate the actual freight transport that these vehicles have accounted for to date.

Emissions from French overseas departments, regions communities (DROM-COM) are included in the scope of Kyoto, but are not included in our accounting. The specific nature of goods transport in the DROM-COM must be subject to its own analysis. In 2015, heavy goods vehicles (including buses and coaches) in these regions emitted less than 1 $MtCO_2eq$, compared to more than 20 $MtCO_2eq$ in mainland France.

Domestic emissions from aviation are not taken into account in this work, because the available data does not provide a sufficient level of confidence regarding the types of goods transported, or the way in which they are transported (specific freight vehicles or combined passenger/freight vehicle). In total, domestic air freight on routes within mainland France represented around 0.07 Mt transported in 2016. Domestic maritime emissions are also not taken into account in this work, because they have only recently been standardised, and maritime transport between mainland French ports is not significant. The transport of goods between French ports represented only around 20 Mt transported in 2017. Domestic emissions from air and maritime transport must be analysed by integrating the connections between French mainland regions and the DROM-COM.

The International Research Center on Environment and Development (Cired) was founded in 1973 by Professor Ignacy Sachs and is today a joint venture between the French National Centre for Scientific Research (CNRS) and four other institutions (ENPC, EHESS, AgroParisTech and Cirad). Research programmes focus on the relationship between the environment, natural resources and development, with particular emphasis on three key areas: energy, urban infrastructure, and agriculture and forestry. These areas require a constant dialogue between the social sciences, natural sciences and engineering expertise. To do this, the research team is multidisciplinary and relies on researchers from varied intellectual backgrounds. Finally, Cired strives to preserve strong links between modelling, which is considered as a tool to integrate knowledge from many disciplines, and the economic analysis of public policy instruments in various institutional contexts and deliberative processes.

www.centre-cired.fr

EDF R&D is the research and development unit of Electricité de France. This unit comprises nearly 2,000 people dedicated to research programmes concerning each link of the energy chain: uses, transport, distribution, and generation. Thus, EDF R&D has endeavoured to better understand the behaviour of end customers, and has developed models based on a bottom-up methodology, which encompasses the technological, economic, societal and political aspects of energy demand to inform the long-term decarbonisation of the energy system. Understanding mobility practices, analysing the technological roadmap for batteries and smart charging issues in the context of smart cities is a particularly important area of study at EDF R&D.

www.edf.fr

The Institute for Sustainable Development and International Relations (IDDRI) is an independent, not-for-profit policy research institute based in Paris. Its objective is to identify the conditions and propose tools to put sustainable development at the heart of international relations and public and private policies. IDDRI is also a multi-stakeholder dialogue platform and supports stakeholders in global governance debates on the major issues of common interest, such as actions to mitigate climate change, protect biodiversity, strengthen food security, and to manage urbanisation. The institute also participates in work to build development trajectories that are compatible with national priorities and the sustainable development goals.

www.iddri.org

The University was born out of the merger of Université Paris-Est Marne-la-Vallée and IFSTTAR, the Institute for European Research on Cities and Regions, Transport and Civil Engineering. It includes a school of architecture, EAV&T, and three engineering schools, EIVP, ENSG Géomatique and ESIEE Paris. By creating for the first time in France a three-way partnership between a university, research organisations and schools of architecture and engineering , it will have the specific purpose of fostering national and international partnerships to meet the major societal challenges generated by the profound changes in urban areas, which are already home to 55% of mankind.

www.univ-gustave-eiffel.fr

www.ifsttar.fr