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How to explain the past trends in transport CO_2 emissions in France?

A decomposition analysis for the 1960-2017 period

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Abstract

This paper analyses the drivers of French transport CO_2 emissions over the period 1960-2017. This period has experienced a large growth in transport CO_2 emissions from 33 to 126 $MtCO_2$, after a peak at 136 $MtCO_2$ in the early 2000s. A decomposition analysis is used to evaluate the relative contribution of five key drivers of passenger and freight transports emissions: transport demand, modal shift, vehicle load factor, energy efficiency and carbon intensity of the energy. It highlights the strong relation between CO_2 emissions and transport demand, while the four other factors have mainly compensated: modal shift towards road transport and the decrease of the car load factor have participated in the increase of CO_2 emissions, whereas the increasing load factor of road freight transport, energy efficiency and the slight carbon intensity improvement have balanced these negative effects. The impact of public policies on emissions appears to be limited for now.

Keywords: Transport, CO_2 emissions, Drivers, Past evolution, France, Transport demand

Résumé

Le papier analyse les facteurs ayant influencé les émissions de CO_2 des transports sur la période 1960-2017. La période a connu une forte hausse des émissions de CO_2 des transports de 33 à 126 $MtCO_2$ en 2017, après un pic à 136 $MtCO_2$ au début des années 2000. Une décomposition des émissions est utilisée pour évaluer la contribution relative de cinq facteurs pour les transports de passagers et de marchandises : la demande de transport, le report modal, le taux de remplissage, l'efficacité énergétique des véhicules et l'intensité carbone de l'énergie. Elle met en évidence la forte relation entre les émissions de CO_2 et la demande de transport, alors que les quatre autres facteurs se sont compensés : le report modal vers les transports routiers et la baisse du taux de remplissage des voitures ont participé à la hausse des émissions de CO_2, tandis que la hausse du taux de remplissage des camions, l'efficacité énergétique et la légère amélioration de l'intensité carbone ont compensé ces effets négatifs. L'impact des politiques publiques sur les émissions apparaît limité pour le moment.

Mots clés : Transport, émissions de CO_2, facteurs, évolution passée, France, demande

Executive Summary

The climate ambition of France is to reach carbon neutrality by 2050. In order to decrease the CO_2 emissions of the transport sector by 2050, the French strategy for clean mobility development is based on a set of measures decomposed in five key drivers of transport CO_2 emissions: transport demand, modal shift, vehicle load factor, energy efficiency and carbon intensity of the energy. This paper aims to better understand the past trends of these drivers and their relative contribution to the evolution of transport CO_2 emissions from 1960 to 2017.

The five factors are then used in a decomposition analysis in the same form as the Kaya identity, applying the log-mean divisia index (LMDI). The decomposition is conducted separately for passenger and freight transports, considering five passenger modes (individual road transport, collective road transport, rail, domestic aviation and active modes) and four freight transport modes (trucks and LCVs for road transport, rail, and navigation). Data on transport demand, traffic, energy consumption and CO_2 emissions has been collected for each of these modes from 1960 to 2017. Most of the statistics come from French public institutes.

The past trend shows a growth in transport CO_2 emissions from 33 to 126 $MtCO_2$ between 1960 and 2017, after a peak at 136 $MtCO_2$ in the early 2000s and a slight increase since 2014. Emissions from passenger transport represent around 70% of this total during the period. The decompositions show that this trend is mainly explained by the evolution of transport demand, both for passenger and freight transports, while the other four factors have mainly compensated each other. Indeed, CO_2 emissions have been multiplied by 4.2 and 3.3 for passenger and freight transports respectively, while their transport demands have been multiplied by 4.7 and 3.4, pointing out only a slight decoupling for passengers emissions. Modal shift towards road transport have also participated to the increase of CO_2 emissions especially for freight transport, but with a lower contribution than the transport demand. The load factor has decreased for passenger cars (thus participating in the CO_2 emissions growth), but it has increased for road freight (more tons are transported by vehicle) and almost all the other transport modes. Finally, energy efficiency has participated regularly in the emission reduction, whereas the impact of the carbon intensity of the energy was also positive but quite marginal on the global period.

The analysis of each factor shows a low impact of transportation, energy and climate policies on transport CO_2 emissions until now, despite some measurable positive impacts as the contribution of modal shift for passengers since the late 90s, and some policies favoring the truck load factor and energy efficiency. However, most of the increase in transport emissions has been driven by the increased access to rapid and flexible transport modes (especially cars and trucks) at a lower cost. The emission cap since the beginning of the 2000s appears to be mainly due to economic evolutions (fuel prices, GDP) and some saturation effects on the motorization rate and travel speeds, rather than the effects of proactive policies. The low contribution of the carbon intensity of the energy for now also contrasts with the national strategy by 2050 that relies highly on the decarbonization of the energy mix to achieve the emission reduction target. On the contrary, transport demand, which has been the main explaining factor in the past and will certainly remain as crucial in the near future, seems to be absent from the political debate and lacks of ambitious measures to address transport CO_2 emissions.

Keywords: Transport, CO_2 emissions, Drivers, Past evolution, France, Transport demand

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1. Introduction

In 2015 the French government promulgated a law for the energy transition for green growth. The **national low-carbon strategy** then fixed the allocation of carbon budgets for the different sectors for 2050 as well as the short- and medium-term periods of 2015-2018, 2019-2023 and 2024-2028. The transport sector had to reduce its emissions by at least 70% by 2050, and by 29% for the third budget period 2024-2028, compared to 2013 (MEDDE, 2015; MEEM, 2016).

The first data indicates that the transport carbon budget for 2015-2018 has been missed. The low-carbon strategy is currently in a revision process for the next periods in order to be consistent with the recent evolutions. It also needs to take into account the increasing long-term ambition towards carbon neutrality in 2050, implying a full decarbonization of the transport sector, except some remaining fossil fuels for aviation (MTES, 2019a).

In order to reach the objectives set for the transport sector, the 2016 strategy for the development of clean mobility introduced new measures on five drivers of transport CO_2 emissions: transport demand, modal shift, load factor of the vehicles, energy efficiency and the carbon intensity of the energy (MEEM, 2016).

This paper provides the **analysis of the impacts of these five factors** over the period 1960-2017, both for passenger and freight transport CO_2 emissions. It aims to better identify the needs to continue, accelerate or even reverse the past and current trends of the drivers influencing CO_2 emissions.

Decomposition methods allow conducting this kind of analysis and have been increasingly used in the recent years especially for the transport sector. An analysis of 39 transport index decomposition analyses (IDA) is proposed, of which 34 studies from the academic literature. The authors, perimeter and main driving factors identified within the papers are presented in Table 1. The **analysis of the literature** shows that GDP is often identified as the factor of demand and as a major driver of emissions, always contributing to the increase of CO_2 emissions for the studies considering it. Modal shift also appears generally as increasing emissions, due to the growing share of road transport on the considered periods. The vehicles load factor is rarely used within the decomposition analysis, without any clear trend among studies about its impact on emissions. Energy efficiency (or energy intensity) groups sometimes different drivers that are considered in this study, sometimes corresponding directly to energy consumption per unit of GDP or per unit of transport demand. It often appears in the studies as the most important factor that allowed limiting CO_2 emissions historically. Carbon intensity of the energy and fuel switch also contributed to CO_2 emission decrease according to some studies, but generally in a smaller extend.

Among these studies, there are **two decomposition analyses of the CO_2 emissions for the transport sector in France**. The first one, an analysis from the ministry in 2015, applied a similar decomposition only for road transport (i.e. without modal shift, and mixing passenger and freight transports) for the period 1960-2013, with a few comments on the effects of the considered drivers (MEDDE, 2015). Secondly, a recent analysis conducted two decomposition analyses both for passenger and freight transports for the period 1990-2017: the first ones considers only road transport, with the load factor but without the modal shift effect; the second one considers the equation for the whole passenger or freight transport, taking into account modal shift but not the load factor (CGDD 2019a).

Considering that these analysis didn’t fully exploit the possibilities from this decomposition, **this paper adds some key elements**: the period considered extends from 1960 to 2017, the longest period among the identified existing literature, which allows taking into account longer trends and to better identify the reasons for the recent cap in CO_2 emissions; the analysis integrates the LCVs (light commercial vehicles) into passenger and freight transports; active modes are taken into account, and the impact of international aviation is evaluated in a separate decomposition; it details the drivers for five passenger and four freight transport modes; it explores the recent impact of public policies to reduce transport emissions, it suggests the most important drivers for the next few years and then the chance to meet the carbon budgets targets.

After this introduction, the **paper is organized as follow**: section 2 introduces the methodology of the decomposition and the data used; section 3 presents the past global trends in transport CO_2 emissions; section 4 gives some details about the five studied drivers of emissions; section 5 discusses the results and addresses their policy implications.

2. Methodology and data

2.1. A decomposition analysis with 5 factors related to transport

A decomposition analysis based on an **expanded Kaya identity** is used to evaluate the relative weight of different multiplicative factors influencing transport CO_2 emissions. The Kaya identity was proposed in 1990 at an IPCC workshop, and aims at decomposing the evolution of energy-related CO_2 emissions into 4 contributing factors: population growth, GDP per capita, the energy intensity of GDP, and carbon intensity of GDP (Kaya, 1990):

$$CO_2 = Pop.\frac{GDP}{Pop}.\frac{E}{GDP}.\frac{CO_2}{E} \qquad [1]$$

where Pop represents the population; GDP is the growth domestic product; E is the energy consumption; and CO_2 relates to the CO_2 emissions.

This kind of decomposition has been increasingly used in the past years, especially to study the driving factors of energy consumptions and CO_2 emissions for different sectors. It also benefitted from extensions in order to take into account some structural changes, for instance incorporating different industrial sectors or various transport modes in the equation.

The **decomposition analyses applied to transport** generally considers around five factors, ranging from three to nine drivers (Table 1). A common view of possible policies to reduce transport emissions is based on the drivers Avoid – Shift – Improve, considering the factors of transport demand, modal shift and the environmental performance of transport. But some papers develop a more detailed analysis, by decomposing the factors driving transport demand (with population, GDP and transportation intensity relative to GDP) or the environmental performance of transport (energy efficiency, carbon intensity, fuel shift among others).

The decomposition used for this analysis considers **five factors** of transport CO_2 emissions, which are the five drivers of the French national strategy for clean mobility development (MEEM 2016): transport demand (TD), modal shift (MS), vehicle load factors (LF), vehicle energy efficiency (EE), and the carbon intensity of energy (CI). The global equation is a sum of this decomposition for each of the considered modes i:

$$\boldsymbol{CO_{2,Transport} = \sum_i D.\frac{D_i}{D}.\frac{C_i}{D_i}.\frac{E_i}{C_i}.\frac{CO_{2,i}}{E_i}} \qquad [2]$$

where D is the total transport demand (in pass.km for passengers or t.km for freight) and D_i the demand for each mode; C_i the traffic of the mode i; E_i and $CO_{2,i}$ represent the energy consumption and the CO_2 emission of the transport mode.

This decomposition is applied both to **passengers and freight transport**. The analysis must be carried out separately due to the different units of transport demand (pass.km and t.km).

Table 1: Literature on the main driving factors of transport CO_2 emissions through decomposition analysis

En: Energy use; CO_2: CO_2 emissions; P: population; GDP: gross domestic product; TI: transport intensity; VO: vehicle ownership; TD: transport demand; MS: modal shift; LF: load factor; EI: energy intensity; CI: carbon intensity; FS: fuel shift.

En and CO_2 are the dependent variables; in red when increased on the studied period; black no clear trend; green decreased. Factors in red when participated to the increase of energy use and CO_2 emissions; black no clear trend; green to the decrease; bold when the study identified a major impact of this factor. ≈: not taken into account directly in the decomposition but studied in the paper.

Papers	Study area	Sector	Period	En.	CO_2	Factors	P	GDP	TI	VO	TD	MS	LF	EI	CI	FS	Other factors / notes*
Schipper et al, 1992	8 OECD countries	Passenger	1970-1987	X		3					X	X	≈	X			
Scholl et al, 1996	9 OECD countries	Passenger	1973-1992	X	X	4					X	X		X	X		
Schipper et al, 1997	10 industrialized countries	Freight	1973-1992	X	X	4					X	X		X	X		
Lakshmanan and Han, 1997	USA	Passenger	1970-1991	X	X	5	X				X	X		X			Interaction term
		Freight		X	X	5		X	X			X		X			Interaction term
Greening et al, 1999	10 OECD countries	Freight	1970-1993		(X)	4					≈	X		X	X	X	Decomposition of the aggregate CI
Mazzarino, 2000	Italy	Transport	1980-1995		X	6	X	X	X			X		X		X	
Greening, 2004	10 OECD countries	Passenger	1970-1993		(X)							X	≈	X	X	X	Decomposition of the aggregate CI
Kwon, 2005	Great Britain	Passenger cars	1970-2000		X	3	X			≈	X	≈	≈	≈	X	≈	*Various decompo. analysis
Steenhof et al, 2006	Canada	Freight	1990-2003		X	4					X	X		X	X		
Kamakaté and Schipper, 2009	5 OECD countries	Freight	1973-2005	X	X	3-5		X				X	≈	X	X		
Papagiannaki and Diakoulaki, 2009	Greece, Denmark	Passenger cars	1990-2005		X	6	X			X				X		X	Distance per car, engine capacity
Timilsina and Shrestha, 2009	20 Latin Am. and Carribean countries	Transport	1980-2005		X	5		X				X		X	X	X	
Timilsina and Shrestha, 2009	12 Asian countries	Transport	1980-2005		X	6	X	X				X		X	X	X	
EEA, 2011	EU	Freight	1990-2008		X	5					X	X		X	X	X	
Kumbaroğlu, 2011	Turkey	Economy, of which transport	1990-2007		X	4		X				X		X	X		
Mendiluce and Schipper, 2011	Spain	Passenger	1990-2008		X	4					X	X		X	X		
		Freight			X	4					X	X		X	X		
Schipper et al, 2011	US	Passenger	1960-2008		X	5					X	X		X	X	X	
		Freight			X	5					X	X		X	X	X	
Wang et al, 2011	China	Transport	1985-2009		X	6	X	X	X			X			X	X	
Zhang et al, 2011	China	Transport	1980-2006	X		4					X	X		X			Passenger–freight share effect
Andreoni and Galmarini, 2012	Europe	Water and aviation	2001-2008		X	4		X						X	X		Structural changes
Eom et al, 2012	11 IEA countries	Freight	1990-2007		X	5		X	X			X	≈	X		X	
Wang et al, 2012	China	Road freight	1995-2006		X	9		X					X	X	X		Factors related to freight enterprises and industrialization
Li et al, 2013	China	Road freight	1985-2007		X	9		X	X					X	X		
Guo et al, 2014	China, regional and provincial levels	Transport	2005-2012		X	4	X	X						X		X	
Lin and Xie, 2014	China	Transport	1980-2010		X	4		X						X	X		Urbanization rate
Sobrino and Monzon, 2014	Spain	Road transport	1990-2010		X	7		X		X				X	X		Job, workers income and road use intensities
MEDDE, 2015	France	Road transport	1960-2013		X	5	X				X			X	X	X	
M'raihi et al, 2015	Tunisia	Freight	1990-2006		X	5		X	X			X		X	X		
Fan and Lei, 2016	Beijing	Transport	1995-2012		X	6	X	X	X					X		X	Output value per unit traffic turnover
Gupta and Singh, 2016	India	Road passenger	1971-2011		X	5	X	X			X			X	X		
Kharbach and Chfadi, 2017	Morocco	Road transport	2000-2011		X	4	X			X				X	X		
Luo et al, 2017	Shanghai and Tokyo	Urban transport	1965-2005		X	4	X			≈	X	X	≈	≈	X		*Various decompo. analysis
IEA, 2018 (CO2)	US, EU, China, India	Transport	2000-2016		X	4	X	X						X	X		
IEA, 2018 (EE)	World	Passenger	2000-2017	X		5					X	X	X	X			Vehicle type
		Freight		X		4					X	X		X			Vehicle type
Wang et al, 2018	China	Passenger	1990-2015		X	5	X	X	X			X			X		
		Freight			X	5	X	X	X			X			X		
CGDD, 2019	France	Passenger	1990-2017	X	X	6	X				X	X	X	X	X		
		Freight		X	X	5					X	X	X	X	X		
Guo and Meng, 2019	China, Beijing-Tianjin-Hebei region	Transport	1995-2016		X	7		X			X			X	X	X	Freight turnover of unit ind. output, industrialization
Li et al, 2019	China, 341 cities	Transport	2005-2015		X	4	X	X				X					TCEs per GDP
Solaymani, 2019	7 top carbon emitters	Transport	2000-2015		X	6		X				X		X	X	X	Electricity structure

2.2. The log-mean divisia index (LMDI) to decompose emissions

Based on the above decomposition, we use the **log-mean divisia index** to evaluate the relative contribution of the different drivers. This decomposition index is found by Ang (2004) as the most relevant for emission decomposition analysis, as it has solid theoretical foundation as the factor- and time-reversal tests, it gives perfect decomposition, and is easy to use and interpret. This method has been increasingly used within the energy and emissions IDA in the recent years (Xu and Ang, 2013).

With the **additive form** of the LMDI, the objective is to decompose the variation of CO_2 emissions between two years, into different additive contributions of the factors considered:

$$\Delta \boldsymbol{CO_2} = \boldsymbol{CO_2^T} - \boldsymbol{CO_2^0} = \Delta CO_{2,TD} + \Delta CO_{2,MS} + \Delta CO_{2,LF} + \Delta CO_{2,EE} + \Delta CO_{2,CI} \qquad [3]$$

The LMDI methodology consists in calculating a **weighted sum of logarithmic growth rates**. For example, the formula to calculate the contribution of energy efficiency to the evolution of emissions between 2010 and 2015 is:

$$\Delta CO_{2,EE} = \sum_i L(CO_{2,i}^{2015}; CO_{2,i}^{2010}).\, ln\left(\frac{EE_i^{2015}}{EE_i^{2010}}\right) \qquad [4]$$

where $L(a,b) = \frac{a-b}{\ln a - \ln b}$ is the logarithmic mean of a and b. For instance, in order to calculate the weight of the mode i among the total, the following calculation is applied:

$$L(CO_{2,i}^{2015}; CO_{2,i}^{2010}) = \frac{CO_{2,i}^{2015} - CO_{2,i}^{2010}}{ln(CO_{2,i}^{2015}) - ln(CO_{2,i}^{2010})}$$

The **multiplicative form** of the decomposition, which is mainly used in this study, considers relative changes compared to a base year, the general decomposition used and the formula for energy efficiency give:

$$\boldsymbol{D_{tot}} = \frac{\boldsymbol{co_2^T}}{\boldsymbol{co_2^0}} = D_{Pop}.\, D_{Act}.\, D_{RM}.\, D_{TR}.\, D_{EE}.\, D_{IC} \qquad [5]$$

$$D_{EE} = exp\left(\sum_i \frac{L(CO_{2,i}^{2015}; CO_{2,i}^{2010})}{L(CO_2^{2015}; CO_2^{2010})}.\, ln\left(\frac{EE_i^{2015}}{EE_i^{2010}}\right)\right) \qquad [6]$$

2.3. Perimeter, data collection and sources

The perimeter of the study considers both **passenger and freight transport** from 1960 to 2017 in France. The main graphs consider only **domestic** transport, so emissions from international maritime and air transport are excluded (except an analysis with international air transport included, graph available in Annex 7.2.).

It is considered here that all air traffic is due to passenger transport, which is especially dominant for domestic air transport. On the contrary, all waterway and maritime transport (with origin and destination in France) are considered for freight transport.

The reported greenhouse gas emissions are only for **direct CO_2 emissions** (scope 1 or tank to wheel emissions). It implies that emissions from the fuel production, refining and transport are not included, neither the emissions related the biofuel combustion or to the electricity generation. This last choice is due to the statistics methodology, and doesn't change a lot the results, due to the low share of electricity in transport energy consumption (2%, mainly for rail and urban transport; CGDD, 2018), and the low carbon content of French electricity (considered at 48 gCO_2/kWh, compared to 490 gCO_2/kWh for the world average in 2016; MTES 2018; IEA 2018a).

The **sources of statistics** are compiled in the Table 1. As some data was not directly available, especially before 1990, and some other is subject to changes in methodology, an important work has been conducted to compile data from different sources, to correct them and estimate properly the lacking data.

Despite this important data collection work, some data used within the decomposition is subject to **imprecisions**, especially for the oldest period (for example for actives modes, motorized two-wheeled vehicles, the car load factor or the impact of LCVs). It is then important for the interpretation to focus on medium- and long-term trends and not on very short term evolutions, which can reflect statistics uncertainties. This explains why the results of the decomposition in its additive form are presented with a five-year time interval. Knowing the data precision in the calculation of the time series and the different data sources to calculate some ratios (for example the different data sources for pass.km and veh.km in cars, implying a possible problem of matching to calculate the car occupancy ratio) it has been very carefully evaluated: if some data would need some corrections or further data search; that none of these imprecisions could change significantly the final results and trends exposed in this report; that all the global conclusions drawn from this work don't depend on the data accuracy and are robust trends of the past evolution of transports in France and its CO_2 emissions.

An important hypothesis is related to the incorporation of **light commercial vehicles** (LCV) in the equations, as their use is balanced between passenger and freight transport. An estimation based on the inquiries of CGDD 2012 and CGDD 2014 led to a share of around 60% of veh.km used for passenger transport (as commuting, shopping, leisure, travel, etc.) and 40% serving to transport goods (as freight transport, transport of materials, waste, deliveries, etc.) which are added to the heavy duty vehicles (HDVs) within the road freight transport category. This proportion is supposed to be constant across time.

Table 1: Set of data needed and sources of the collected data to apply the decomposition

		Transport demand	Traffic	Energy	CO_2 emissions
Units		pass.km or t.km	veh.km	tep	tCO_2
Passengers	Individual road transport	CGDD, OECD	CITEPA, CGDD	CITEPA	CITEPA
	Buses	CGDD	CITEPA	CITEPA	CITEPA
	Rail transport	CGDD, SNCF	CGDD, SNCF, OMNIL	CITEPA, SNCF, ADEME	CITEPA, CGDD
	Air transport	CGDD, DGAC	DGAC	CITEPA	CITEPA
	Active modes	Estimation from Papon, 2012		ε	ε
Freight	Road freight transport	CGDD, CITEPA	CITEPA	CITEPA	CITEPA
	Rail	CGDD, SNCF	CGDD	CITEPA, SNCF	CITEPA, CGDD
	Waterway and maritime	CGDD	Estim. from CGDD	CITEPA	CITEPA
LCV	LCV	CGDD	CITEPA, CGDD	CITEPA	CITEPA

CGDD: General commission for sustainable development (organism of the ministry); CITEPA: Inter-professional technical center of atmospheric pollution study; ADEME: Agency for the environment and energy control; DGAC: Civil aviation general direction (organism of the ministry); SNCF: National railway company; OMNIL: Mobility observatory in Île-de-France.

3. Analysis of the past global trends and periods

3.1. The global period 1960-2017

From 1960 to 2017, CO_2 emissions have been **multiplied by 4.2 for passenger** (from 22.1 to 91.6 $MtCO_2$) and by **3.3 for freight transports** (from 10.6 to 34.5 $MtCO_2$; Figure 1).

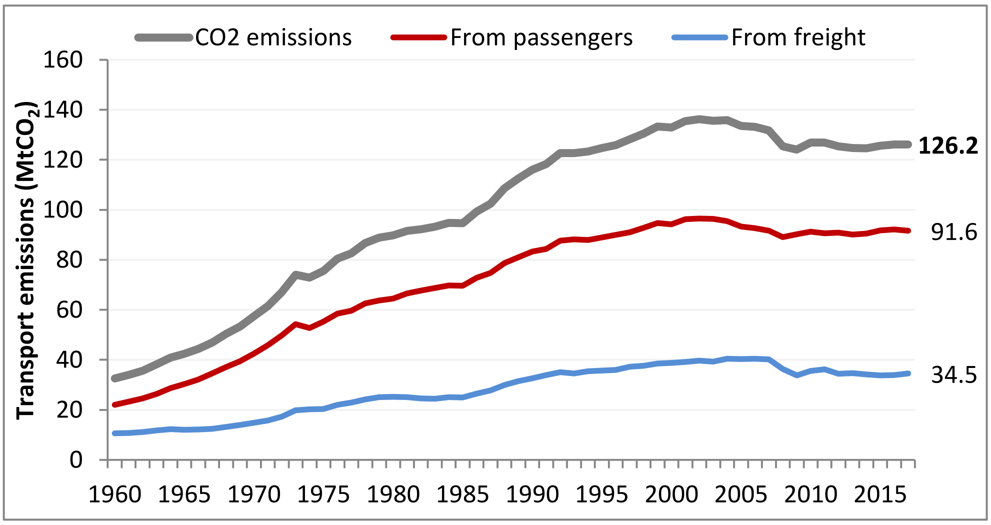

Figure 1: Transport CO_2 emissions for passengers and freight between 1960 and 2017

These emissions followed very closely the evolution of the **transport demand** (expressed in passagers.km and tonnes.km), which have been multiplied by 4.7 for passengers and 3.4 for freight (see Figure 2 and Figure 3 below for the multiplicative form, and Figure 13 and Figure 14 in appendix for the additive form).

The **other factors** then have mainly compensated on the global period: for passengers, the decrease in the occupancy rate of cars and modal shift towards road transport have played an important role in the increase of emissions, whereas energy efficiency have regularly participated in a reduction of the emissions; for freight transport, modal shift from rail to road has contributed the most towards an increase of CO_2 emissions, compensated mainly by the load factor, and partly by vehicle energy efficiency and the carbon intensity of the energy.

It is interesting to note that these global results are very similar to the decomposition for transport energy consumptions at the global level for the period 2000-2017 (IEA 2018b).
The **impacts of oil shocks** (1973 and 1979) and of the **economic crisis** (which followed a slower increase but regular increase in oil prices) appear as quite low and short-lived for passengers, and more important for freight transport. This impact manifested by a slower freight transport demand for a few years in the early 1980s and after the 2007-2008 crisis.

3.2. The inflexion of transport emissions in the early 2000s

Both for passenger and freight transports, the curve passed by a maximum a few years ago, in the early 2000s for passengers and just before the 2008 economic crisis for freight transport.

For **passengers**, this inflexion is partly due to the stabilization of total transport demand during the 2000s, while the other factors reduced the CO_2 emissions per km, mostly thanks to energy efficiency, but also by a small but positive contribution of modal shift with the deployment of public transportation, and by the deployment of biofuels.

For **freight** transport, the impact of the economic crisis appears clearly as the main driver of this inflexion in CO_2 emissions, as both curves appear very close since 2007. At the same time, the modal shares have remained approximately constant except a low increase in LCVs, while biofuels developed slightly.

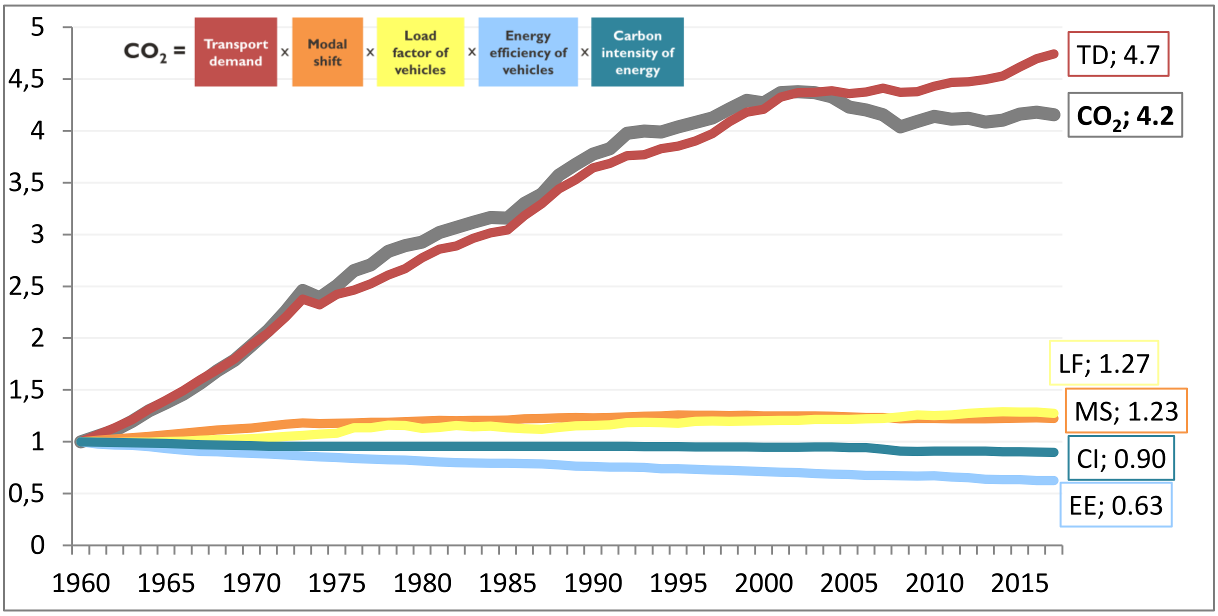

Figure 2: The multiplicative decomposition of passenger transport CO_2 emissions in France

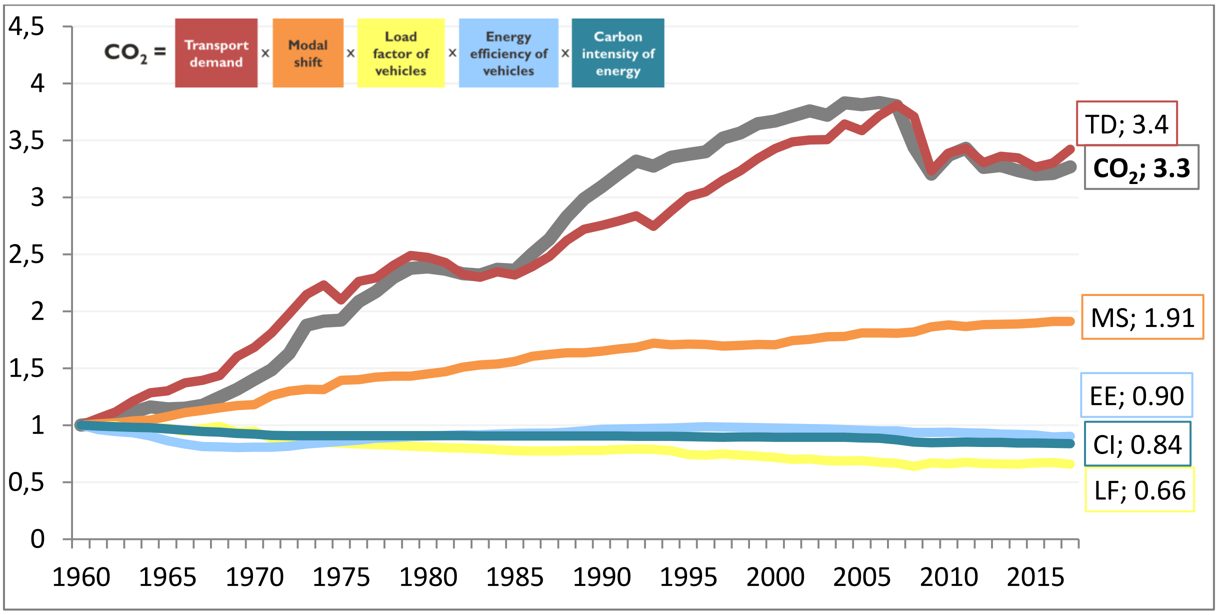

Figure 3: The multiplicative decomposition of freight transport CO_2 emissions in France

3.3. The slight increase of transport emissions since 2014

Although the interpretation of short-term variations is difficult due to statistical uncertainties, it is interesting to look at the **recent slight increase** of the total CO_2 emissions since 2014, which has been differentiated between passengers and freight.

The decomposition indicates that this growth seems to be driven by the increasing transport **demand**, as suggested for the recent years by the similar analysis from CGDD (2019a). It is not surprising due to the short-term adjustments of this factor, the observation of the importance of this driver, and due to the lower oil price since mid-2014 which has decreased the marginal cost of transport both for passengers and for freight operators.

4. Analysis for each factor influencing emissions

4.1. Transport demand

As highlighted by the previous graphs, transport demand has been the **most important factor** driving CO_2 emissions. This is right both for the global trend 1960-2017 and for short-term adjustments where CO_2 emissions and transport demand follow the same trends (Figure 5). The figure also shows that there is a downward trend for demand (-0.12%/year for passenger and -0.11%/year for freight) and also for CO_2 emissions. If this trend would continue, transport demand could decrease in the next years in average. We also see that the variations around the trend are stronger for freight demand, as indicated by the lower R² for freight for the trend line (0.20 instead of 0.55 for passengers). The explanation is that the reaction to GPD (gross domestic product) growth is more important for freight transport.

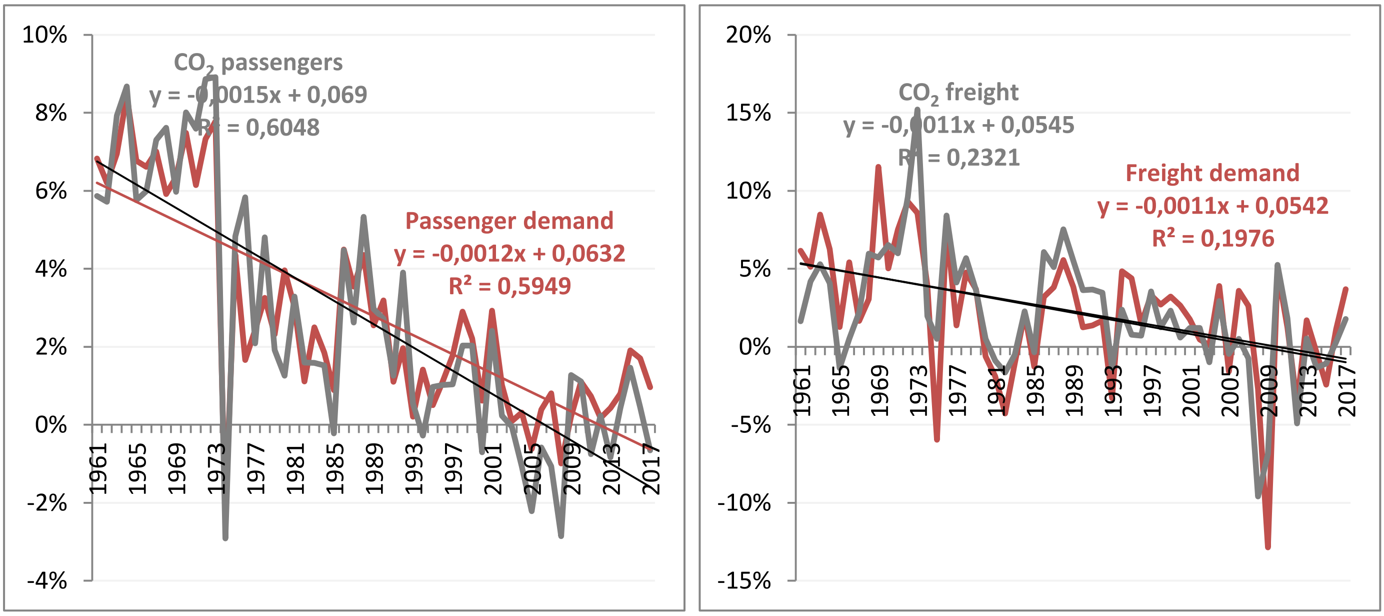

Figure 5: Evolution of transport demand and CO_2 emissions for passenger (on the left) and for freight transport (on the right)

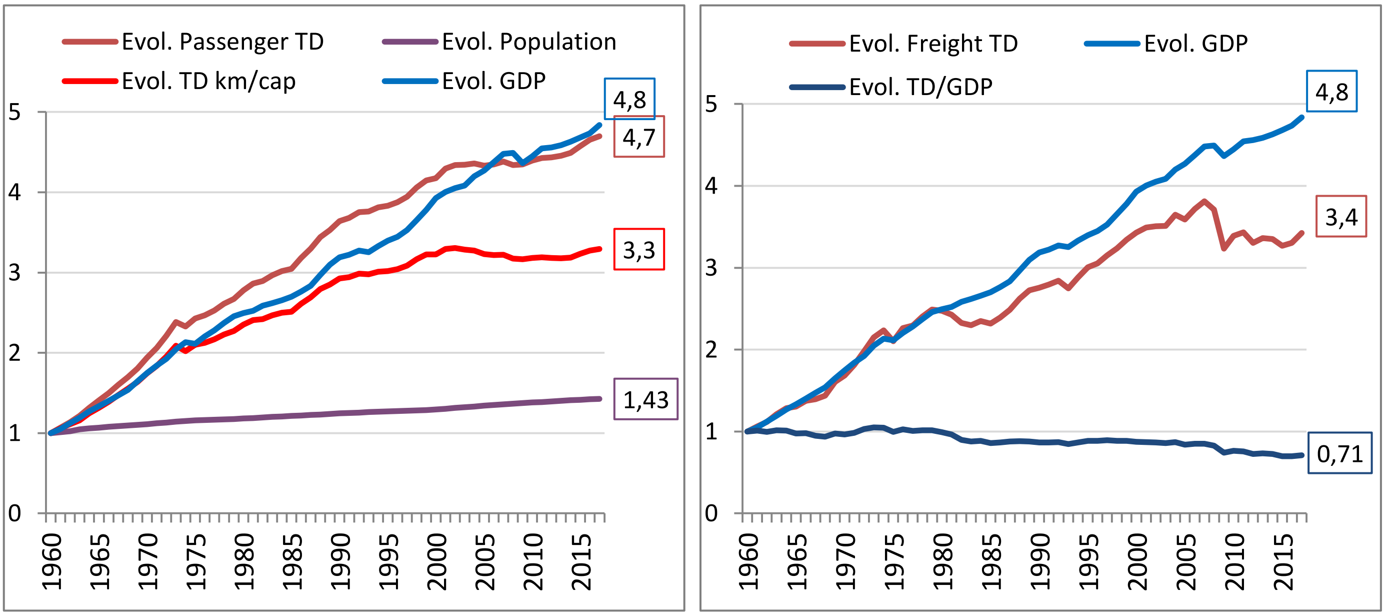

Figure 4: The evolution of transport demand for passengers (in pass.km, on the left) and for freight transport (in t.km, on the right)

Indeed, **GDP** is known as a key driver of the evolution of transport demand, both for freight and passengers (Schafer and Victor, 2000), and it is verified for France. On the global period, real GDP has been multiplied by 4.8, slightly above the growth of passenger demand (4.7) and above the growth of freight (3.4; see Figure 4). The decorrelation between GDP and freight growth resulted from a lower demand following the oil shock of 1979 and the 2007-2008 economic crisis, then confirming the stronger reaction to economic conditions for freight than for passengers.

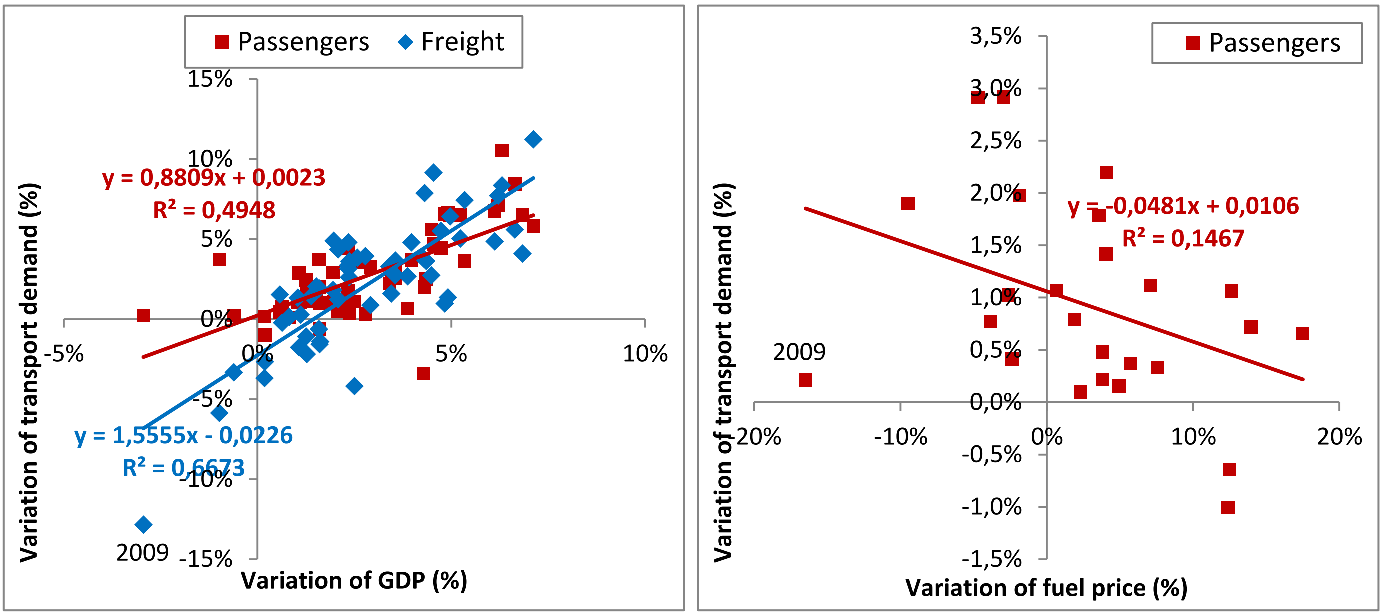

Figure 6: Evolution of transport demand compared to the evolution of GDP (on the left, for passengers and freight 1960-2015) and fuel prices (on the right, for passengers 1990-2015). Data CGDD.

Another driver for passenger demand is **population**, which has grown by 43% (from 45 to 65 million people) between 1960 and 2017, and represents the main driver of passenger transport demand since 2000. But the growth of individual demand has been much more important, as it has been multiplied by 3.3 on the same period. Most of this growth is due to the easier access to individual car mobility, which has multiplied by 5.5 and explains 86% of this growth.

In addition to GDP, another important economic driver for passenger transport demand is oil and **fuel prices**. The collected data indicates that the higher is the rise in fuel prices, the lower will be the transport demand evolution (Figure 6 for passengers; this relation is not observed for freight transport). The relation is more evident only considering the pass.km in car (we obtain a $R^2 = 0,42$, and even 0,55 without the point 2009 which corresponds to a kind of oil counter-shock), due to the combined effect of modal shift towards rail transport, that is observed by a positive correlation between the rail traffic and oil prices. The oil price increase at the beginning of the years 2000s is certainly one of the reasons for the decorrelation between GDP and transport demand.

Furthermore, **other parameters** can explain this peak demand or at least this peak car, a phenomenon that occurred in many OECD countries (Goodwin, 2013), and for which the transitory or permanent aspect is still under discussion. It could also imply some demographic, social, attitudinal or cultural changes, or the effect of transport policies. There is also a hypothesis of **saturation** of car demand in terms of motorization rate which capped some years ago. This concept of saturation could also be applied in the context of quite constant transport time budget for local trips (known as the law of Zahavi, 1973). If technical progress, access to rapid infrastructures and rapid transport modes allowed to accelerate the **mean transport speeds** and then permitted longer distances with a constant time budget, it is probable that the mean transport speeds also capped these last years. The last French inquiries to know this kind of data are however too distant (1994 and 2008) to verify this hypothesis.

4.2. Modal shift

Historically, modal shift has mainly operated adversely for the reduction of energy consumption in transport (coefficients of 1.24 and 1.91 for the global period), especially with the deployment of road transport both for passenger and freight transports (Figure 7).

For **passenger transportation**, individual road transport has risen from 63% to 80% (in pass.km) between 1960 and the first oil shock in 1973, at the expense of rail transport and active modes, which represented around 16% each in 1960. Since 1973, the modal shares are quite constant, between 79 and 83% for individual road transport (cars, motorized two-wheelers and 60% of LCVs), between 7.5 and 11% for rail with a low point in 1995 (year of a SNCF strike, and after some years of traffic reduction since 1989), and around 5-6% for buses. The rising share of rail transport since 1995 explains the inversion in the impact of modal shift on emissions, which is slightly positive since then. The estimation about active modes shows that its modal share was still important in 1960, even in terms of total kilometers travelled. This mileage has halved on the global period, essentially due to the decrease of walking (which still represents two thirds of the active modes in 2017), in a context of a strong increase of transport demand, explaining the fall of the modal share from 16% to 1.6%. Finally, domestic aviation alone (grouping metropolitan and overseas) represents a quite low share of air transport with 2.9% of the total pass.km. But the traffic would be multiplied by 6 by integrating international traffic, then bringing the modal share of aviation to 15.5%. The total CO_2 emissions, transport demand and impact of modal shift on emissions would be higher when taking this international traffic into account (see Appendix 7.2.).

For **freight transport**, the period has been marked by the strong increase of the share of road freight transport, gaining 50% of modal shares essentially to the detriment of rail freight that decreased from 56% to around 10% since 2005; finally, the modal share for navigation fell from 10% in 1960 to around 2-3% since the end of the 90s.

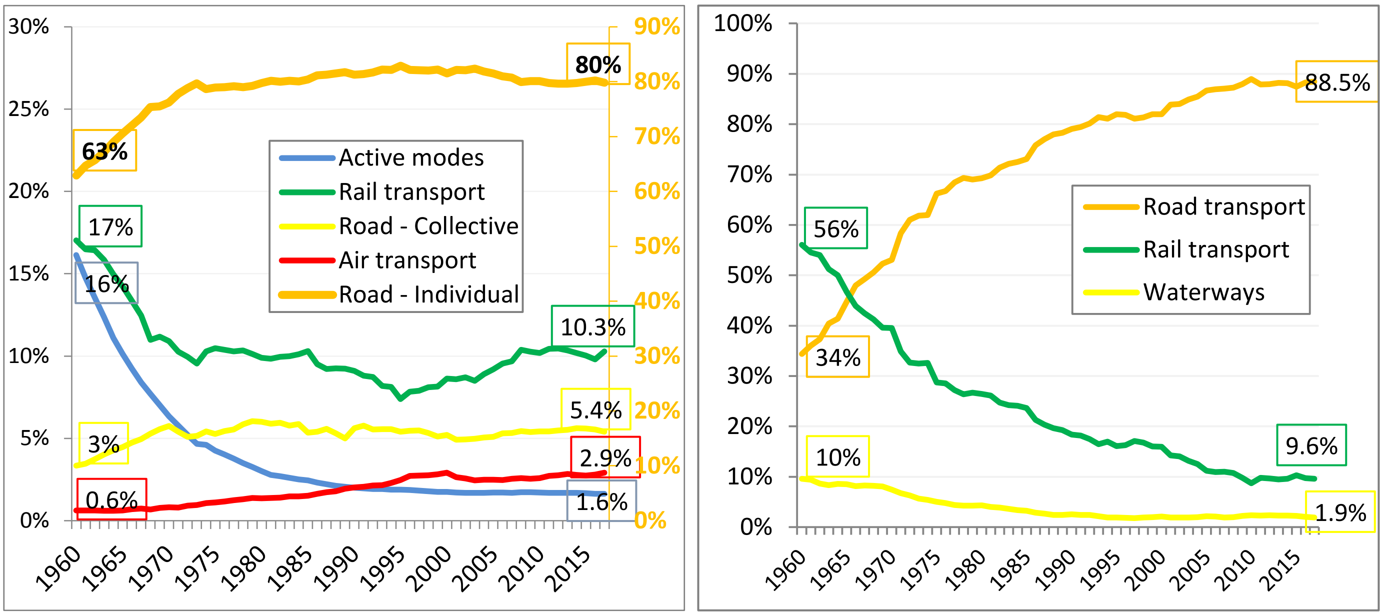

Figure 7: Modal shares of the different transport modes for passengers (on the left, in pass.km; right axis for individual road transport) and freight transport (on the right, in t.km) from 1960 to 2017

4.3. Load factor of vehicles

The collected data shows an **increase in the size of the vehicles** on the period for all transport modes, in terms of carrying capacity, mean load factor or weight: for freight transport, the mean carrying capacity of a wagon increased from 24 to 49 tons between 1960 and 2003, whereas the mean load factor of a freight train passed from around 300 to 500 t/train between 1960 and 2017; the carrying capacity of the domestic navigation vessels has increased from less than 400 tons in the 1960s to more than 1000 t/vessel today; for the container maritime transport, the average capacity has been multiplied by four since 1980; the size of the trucks has risen too, and the compilation of statistics suggests an increase of the mean load factor from 5.6 to 9.7 for the trucks with an authorized load weight exceeding 3.5 tons; for passengers, the weight of the average new car sold in France has risen from 778 kg in 1960 to 1262 kg in 2017; the trend is less clear for road public transport, as the number of places per bus has risen, but the load factor depends on the use, with the mean occupancy rate being lower for urban than for long-distance trips; the number of passengers for rail transport (urban and long-distance combined) has risen from 160 to 233 passengers per train; different statistics indicate an important increase of the size of the planes, as the number of passengers per movement which has increased from 42 to 107 between 1970 and 2015, for national plus international traffic combined (compilation mainly from CGDD 2018; L'Argus 2019 for cars; ITF 2015 for maritime container; World Bank 2019 for air transport).

As a result, the increase in the size of the transport modes vehicles has been the main driver for the **rising load factor of the vehicles**, which shows an important impact on freight transport emissions (-34%; see Figure 3). But there is an important **exception** to this global trend: indeed, although the weight of the cars has risen (mainly for security reasons, new equipment and comfort), the vehicle occupancy of cars has regularly decreased in the past decades, from around 2.3 people in 1960 to an average of 1.58 persons per car in 2017 (CGDD 2016; OECD 2019; see Figure 8). This decrease is partly explained by the easier and cheaper access to individual car mobility and in particular the increase in the (multi-)motorization rates from 30% to 84% between 1960 to 2017 (and from around 2% to 36% for multi-motorization), and to some societal changes as the reduction of the average number of people per household from approximately 3.1 in 1960 to 2.2 today (CGDD 2016; URF 2018; Insee, 2017, 2019).

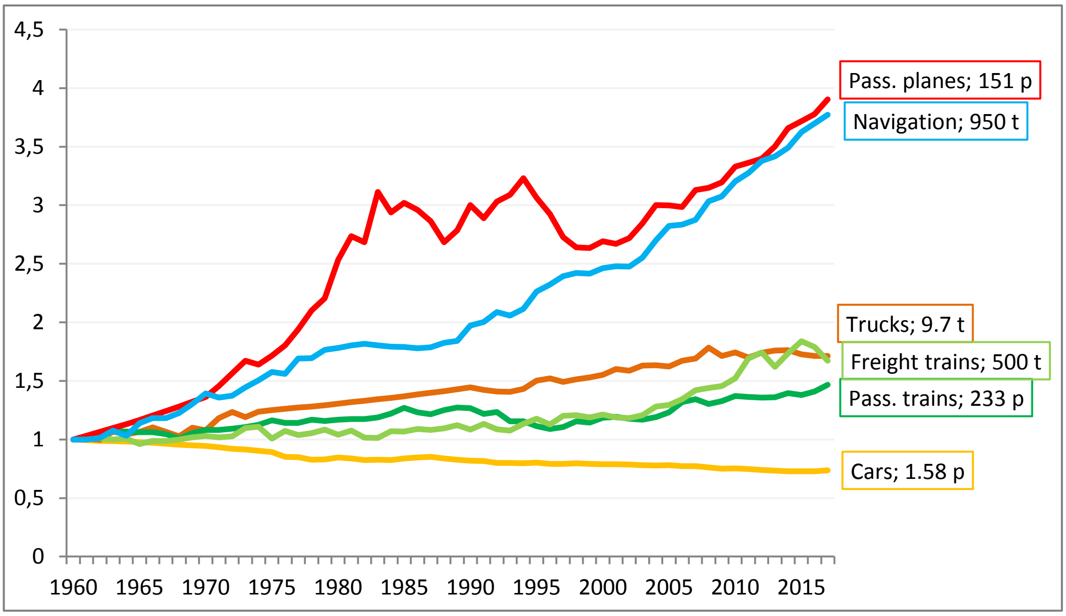

Figure 8: Evolution of the load factor of different transport modes from 1960 to 2017 (Evolution relative to 1960; value in 2017 on the right; p=passengers, t=tons)

Combining the effects of modal shift and the evolution of load factors, the criteria of **passengers and tons per vehicle for the whole transport modes**, shows a **decreasing trend** both for passenger and freight transports. For passenger, the mean load factor of motorized modes has decreased from 2.9 to 2 passengers per vehicle, reflecting the growth of individual transport modes. For freight, the mean load factor has passed from 9.7 to 4.6 tons per vehicle, due to modal shift towards road transport and the increase of LCVs, not compensating the important increase in the load factor of HDVs.

4.4. Energy efficiency

Energy efficiency has appeared as the **most important factor able to decrease the transport CO_2 emissions** in the past, from an order of magnitude of -37% for passenger transport and -10% for freight transport. The evolution for some transport modes is given in Figure 9.

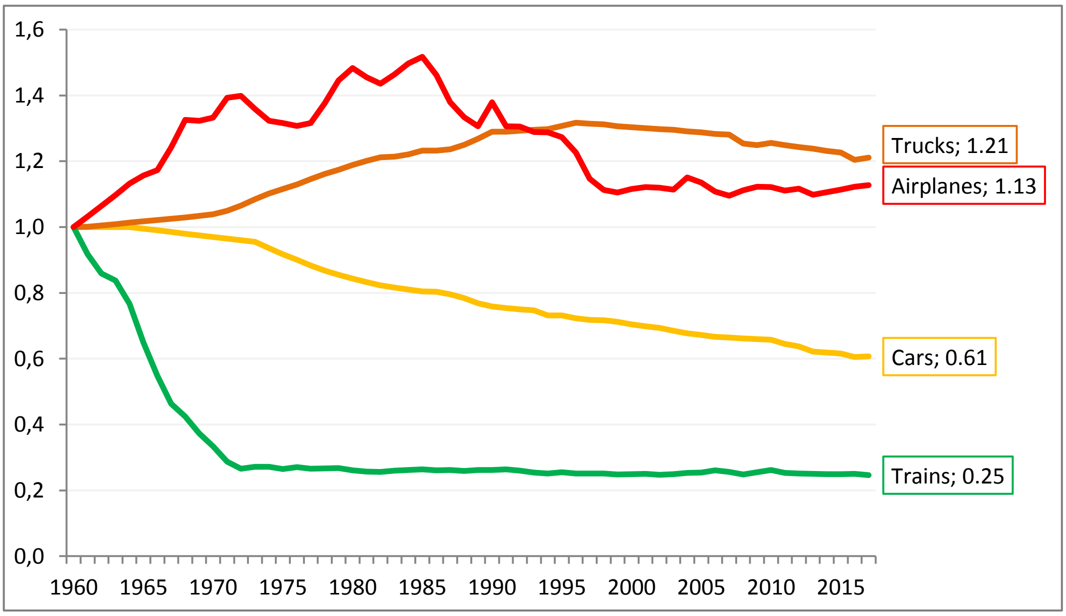

Figure 9 : Evolution of the energy efficiency (per veh.km) of different transport modes from 1960 (base 1) to 2017

But it is important to note that the energy efficiency (EE) factor has an important **interaction with the load factor** (LF). Indeed, in the context of an increasing size of the vehicles and their load factor, the energy consumption per vehicle.km (as it is measured in the decomposition) can't decrease as much as if the vehicle mass was constant. This explains why the energy efficiency of trucks has been getting worse from 1960 until the middle of the 90s.

The **energy efficiency measured per pass.km or t.km** could better represent the overall gains, especially when the load factor increased a lot (as for trucks, planes or vessels). Thus, the energy consumption per t.km progressed by -31% for trucks on the 1960-2017 period, instead of a +21% measured by veh.km. On the contrary, for passenger cars, despite the efficiency gains of -39% per veh.km, this has been partly compensated by the decreasing occupancy rate, and the consumption per pass.km in 2017 is only 14% below its 1960 level. The overall energy efficiency gains per pass.km or t.km are also: -38% for navigation; -73% for airplanes; -83% and -86% for passenger and freight trains; finally, there are some doubts about the data precision, but the data available seems to indicate that the energy consumptions for 2-wheelers and collective road transports are higher today than in 1960 (Figure 10).

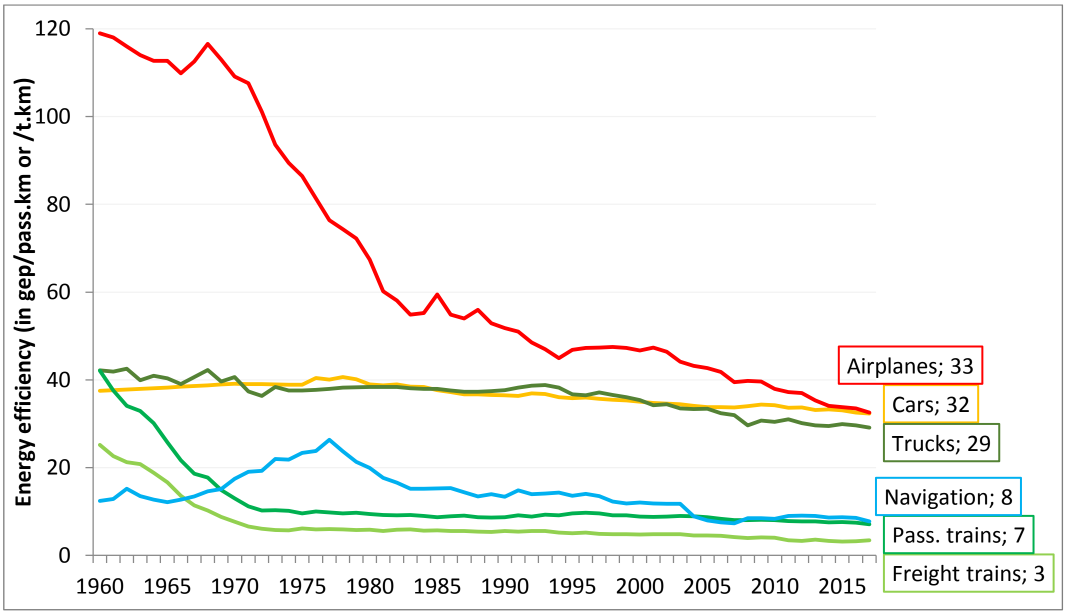

Figure 10 : Evolution of the energy consumption (per pass.km and t.km) of different transport modes from 1960 to 2017

Among all the transport modes, the most remarkable improvement in EE on the period concerns the **rail transport** between 1960 and the early 70s, at a time when the steam locomotives (most of them powered by coal, some of them by oil fuel), which represented 39% of the vehicles in 1960, rapidly disappeared from the traction vehicles. The steam engines were very inefficient in terms of energy use, the coal steam engines being around 4 times less efficient than diesel engines and 20 times less efficient than electric engines, the two kinds of vehicles that replaced the steam locomotives (CGDD 2019b, file 1975_1).

Aviation has also experienced important improvements on the global period, especially by improving the size and number of seats per airplane, while limiting the corresponding energy consumptions increases thanks to energy efficiency improvements. However, passenger aviation is still the most energy intense mode with consumptions per pass.km similar to cars.

The past energy efficiency gains have been achievable thanks to technical progress, in particular due to better engines efficiency. It is likely that these progresses will reach their limits as the easy improvement potentials are progressively used. It highlights the need for new policies in order to catch further potentials of energy efficiency improvements.

4.5. Carbon intensity of the energy

The fuel mix and the carbon intensity of the energy (measured in tCO_2/tep) has been the **less impacting factor** of the decomposition analysis, with limited improvements for the majority of transport modes (Figure 11). However, two important facts can be cited, although their impact on the overall transport CO_2 emissions is quite low.

Firstly, the energy mix of **rail transports** has greatly evolved, firstly moving from coal (until 1973) to diesel and electricity, and then progressively from diesel to electricity, the proportion of rail tracks km electrified expanding from 18% in 1960 to 57% in 2017. The energy consumption of the national operator SNCF turned from 65% coal, 22% fuel-oil, 5% diesel and 8% electricity in 1960, to 19% of diesel and 81% of electricity in 2017 (CGDD, 2019b).

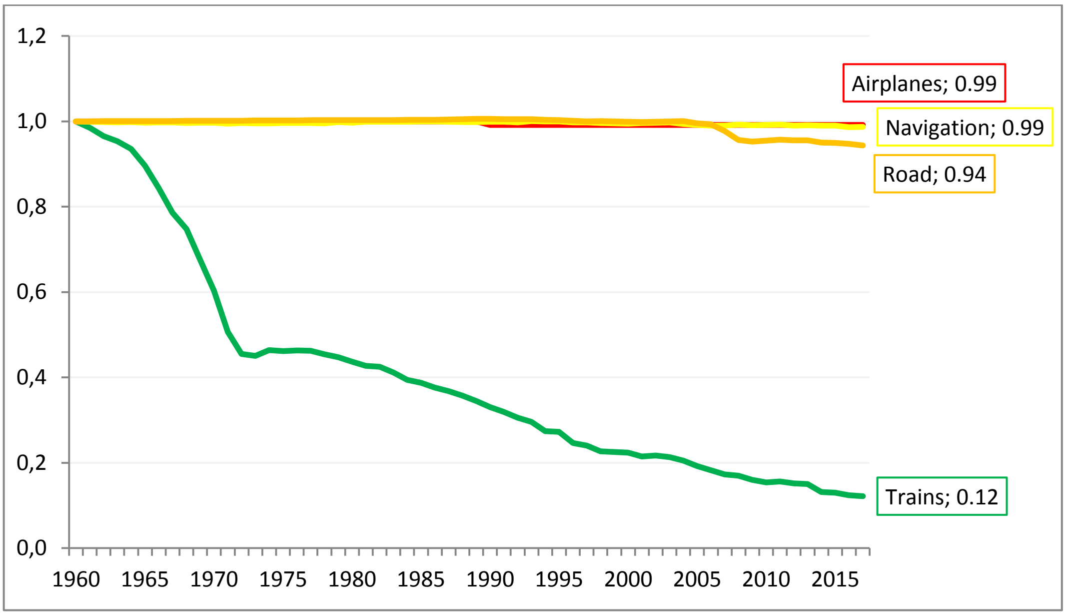

Figure 11: Evolution of the carbon intensity of the energy for different transport modes from 1960 (base 1) to 2017

Secondly, **biofuels** developed around 2007-2008, now representing around 7% of liquid fuels for road transport. Only considering the direct emissions of road transport, the additive decomposition highlights a decrease of around 7.4 Mt of CO_2 emissions due to biofuels. But taking into account the emissions linked to their production and the related possible land use changes (LUC) is important to figure out what has been the actual impact of biofuels deployment. An estimation of the mean carbon impact of biofuels used in France in 2017 has then been conducted and is summarized in Figure 12: the percentages indicate the importance of each biofuel, by converting the volumes consumed (from MTES 2019b) into energy consumptions (conversion factors from EU 2018), and it shows a net domination of rapeseed biofuels (51% of biofuel energy in France), followed by palm oil (used for biodiesel and bioethanol, 23% of biofuel energy at all), and various plants representing around 5% of biofuel energy (wheat, maize and sugar beet for bioethanol; soy, waste cooking oil and sunflower for biodiesel oils); the carbon impact of production, which combines cultivation, processing, transport and distribution of biofuels, is indicated in blue (EU 2018); finally, the most controversial aspect among studies is related to direct and indirect land use changes (LUC) of biofuel cultivation, so different estimations from the literature are taken into account to show the diversity of the results obtained, and are added to the production impact (see green bars). Bioethanol shows better results than biodiesel, and the global results for biofuels used in 2017 are as follows: with the median values taken from the existing literature review on LUC impact conducted by De Cara et al in 2012, the emissions of biofuels appear 1% higher than for oil fuels; this value is close from the estimation of -3% using the values from the study commissioned in 2011 to IFPRI by the European Commission (Laborde, 2011); the highest value is obtained by using the values from the quite controversial re-actualization by ECOFYS in 2015, for which the analysis would conclude that biofuels have a greater impact of +53% compared to oil fuels; finally, an estimation of -23% of carbon impact is obtained with the generally lower values of CARB (2019), where the LUC impact is considered zero for wheat, sugar beet and sunflower (12% altogether) due to lack of data.

While there are a lot of uncertainties and controversies on these LUC estimations, this analysis shows that it seems very likely that the deployment of biofuels in France has not allowed any significant emissions reduction.

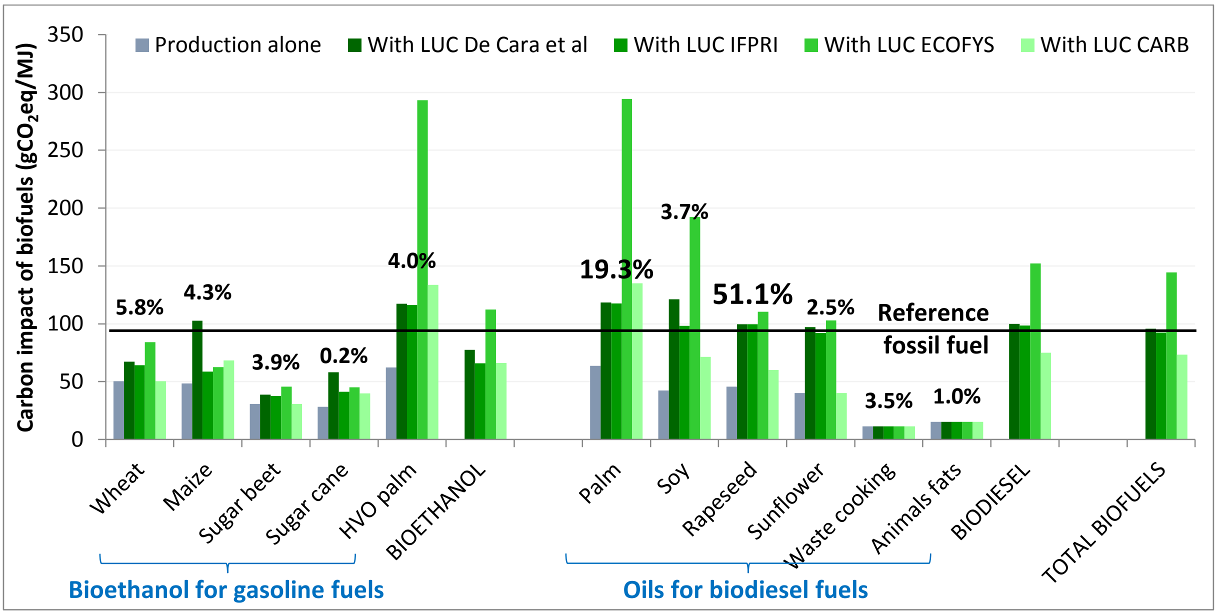

Figure 12: Shares and carbon impacts (production and land use change - LUC) of the biofuels used in France in 2017 (total of 140 PJ or 3.35 Mtep; 99.3% shown on the graph)

5. Discussion and conclusions

5.1. Interactions and tradeoffs between factors

The direct interaction between the load and energy efficiency factors has already been mentioned. However, more indirect interactions also exist.

For **energy efficiency** as for the improvements in the **load factor** of the vehicles, although the direct effects sometimes led to important reductions in CO_2 emissions, the savings in energy costs have certainly participated in the possibility to transport more for an equivalent cost, and not only to maintain the same transport demand at a lower cost. The indirect effect of energy efficiency gains on transport demand, known as the rebound effect, has been particularly observed for personal car transport, either due to a lower oil price (as mentioned above) or a fewer energy consumption. This kind of indirect effect has also probably played a role for the freight transport and the higher load factor for trucks that fosters demand and modal shift from rail or waterway transports.

It implies that the **impact of the measures** needs to take into account these indirect effects in order to assess the global impact of their implementation. Furthermore, the measures favoring simultaneously different drivers or with positive feedbacks have to be encouraged: this is for example the case of territory planning and activities location implemented towards the reduction of distances and densification around intermodal poles, which then facilitate modal shift towards public transit and active modes (walking, cycling, etc.).

On the contrary, the main **past political measures** to reduce transport emissions have been driven by the increase of the public transport supply (both for long-distance rail and urban public transit), incentives for engine efficiency through the bonus-malus implementation for new cars, and the increase of the HDVs (heavy-duty vehicles) load factor. By reducing the transport cost, these measures have potentially led to an increase in transport demand, then reducing the CO_2 emission gains initially expected. This first element questions more globally the relevance and the impact of the political transport, energy and climate policies on the evolution of transport CO_2 emissions.

5.2. A weak influence of climate policies until now

The decomposition has shown that the main contributing factor to the evolution of transport emissions has been the **transport demand**. Its evolution has been mainly driven by factors exogenous to the transport sector, as GDP and oil prices. These economic evolutions have been the main driver of the peak in transport CO_2 at the beginning of the 21st century, together with the saturation of the motorization rate for passengers and a possible saturation effect on transport speeds and then the time spent in transport. Therefore, this favorable evolution for transport emissions has not been influenced by the public policies, which have failed in limiting urban sprawl and the corresponding increasing distances. Policies on this crucial emissions driver are still lacking and absent from the political agenda on mobility, as in the recent discussions about the mobility orientation law (LOM in French). On the contrary, the increase of transport demand is generally seen as positive, even if it comes with higher externalities, increasing monetary costs and sometimes higher time spent in transport.

As for transport demand, the contribution of **modal shift** to the evolution of CO_2 emissions was negative during the end of the 20th century, before a positive contribution for passengers since 1995. Here we can at least partly attribute the more positive role of modal shares to the public policies favoring public policies. However, the effect of modal shift has been quite low: the additive decomposition (see Figure 13) shows that the positive contribution of modal shift since 1995 is around 2.6 $MtCO_2$ for passenger transport (approximately 2% of current transport emissions). In the meantime, the modal share of non-road freight modes has failed during the period and is now roughly constant around 12% since 2005, far from the target of the 2009 environment Grenelle that aimed to increase the modal share of non-road and non-air freight transport from 14% to 25% by 2022 (Legifrance, Article 11).

Regarding the **load factor** of the vehicles, it has decreased for cars, due at least to the structural effects of the growth of the (multi-)motorization rate and the decrease of the number of people per household, two elements that have not been influenced by the public policies for the transportation sector. The recent deployment of carpooling for long-distance trips and the political will to support this practice has not showed a significant impact neither on the mean occupancy rates of cars, nor on transport CO_2 emissions due to the rebound effects on transport demand and modal shift (several public estimates, of which ADEME, 2015). On the contrary, the increasing load factor for heavy-duty vehicles is partly due to public policies that progressively permitted heavier trucks on the roads. However, this evolution is also due to economic incentives for freight operators to optimize the vehicle load, justifying that these progress have been quite regular during the period (**Figure 8**), without any visible recent acceleration; finally, it is possible that the corresponding savings have encouraged a higher demand and modal shift from non-road transport modes.

For **energy efficiency**, we have seen that this factor has regularly contributed to the decrease of energy consumption and associated emissions, and the efficiency gains have partly permitted to drive longer distances. The main public policy encouraging more efficient vehicles on the period is the instauration of a bonus-malus tax system for car sales in 2008, based on their CO_2 emissions per kilometer. The data from the ICCT shows that the annual gain for new cars was -1.8 gCO_2/km between 2001 and 2007 for NEDC measurements, and improved to -3.8 g between 2007 and 2017. Unfortunately, more than half of these gains since 2007 are artificial, due to the increasing gap between laboratory and on-road emissions on this period (ICCT 2018a, 2018b). The system is now showing some limits, as the emissions for new cars have risen in France in 2017 and 2018, because of the increasing share of SUVs (sport utility vehicles) and the decrease of diesel cars compared to gasoline ones.

Finally, the **carbon intensity** of the energy improved slightly in the recent years due to biofuels, but the analysis of their production and land use change impacts showed that their impact on emissions is somewhat similar to oil fuels.

5.3. Conclusions and policy implications for the carbon budgets

The decomposition analysis considered five key drivers of CO_2 emissions both for passenger and freight transports, from 1960 to 2017.

Among these drivers, **transport demand** appears as the dominant driver of the emissions, both for short-term and long-term evolutions. It has followed quite closely the evolution of GDP growth in the past decades, despite a recent slight decorrelation for passenger transport and two periods of relative decorrelation following the 1979 oil shock and the 2007-2008 crisis for freight demand, also illustrating the importance of oil price volatility on transport demand. This past correlation between CO_2 emissions and transport demand is projected to continue for the next years, as it is still projected to react quickly to the short-term adjustments of GDP growth and to the high price volatility of oil. The most promising policies to moderate this demand are related to: territory planning, in order to better connect it with transport policies, to avoid urban sprawl and to favor densification, especially around railway stations; fiscal incentives on energy (as the end of exoneration of fuel taxes on road freight, aviation and maritime transports), transport infrastructures and housing; by limiting transport speeds.

Apart from the transport demand factor, the other ones have globally compensated on the global period 1960-2017. They also participated more weakly to the evolution of CO_2 emissions and are subject to slower evolutions.

For **modal shares**, almost all transport modes have increased their traffic since 2014 but the modal shares have not changed significantly. The evolution of oil prices in the near future could be determinant for short-term incentives for low-carbon modes.

The **load factor** of vehicles is relatively constant for cars for a few years, and carpooling should develop primarily in low density areas (then limiting modal shift and induced demand, which have been observed to be large for the deployment of long-distance carpooling) in order to result in a significant CO_2 impact. The question of the development of LCVs for short-distance deliveries is critical for the load factor of road freight transport.

For **energy efficiency**, the technical gains on engines are reaching their limit, with an increase of the emissions of new cars in 2017 and 2018. It thus highlights the need for new policy instruments to encourage lighter and more fuel-efficient vehicles, or to reduce speed limits and power.

Finally the **decarbonization** by the electric vehicles seems to be the most promising energy vector for the next few years for cars, but its deployment is still too low to allow significant CO_2 emissions reductions. Even achieving the government objective to 2022 (i.e. to multiply by 5 the sales) would only represent an increase of the electric vehicles share from 0.4 to 1.4% of the total car fleet. This decarbonization of the fleet and the energy mix risks to be even slower for freight transport, as electric vehicles are less relevant than for cars, and the deployment of natural gas vehicles and biogas is still low.

This shows that the **carbon budgets targets** in order to be in line with the long-term objective of carbon neutrality are very challenging, they will highly depend on the evolution of the economic context, and definitely need more ambitious measures and incentives to be reached.

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7. Appendix

7.1. The additive decompositions of transport CO_2 emissions

The grey curves for Figure 13 and Figure 14 represent the **passenger and freight transport CO_2 emissions** from 1960 to 2015, with a 5-years interval in order to only catch the structural changes and not the very short adjustments complicating the interpretation. The passenger emissions evolution from 1960 to 1965 (8.1 $MtCO_2$) is represented by a point on the blue curve. The relative contribution of the 5 key factors explaining this difference is shown by the bars, some factors contributing to the increase of CO_2 emissions (as the load factor for passengers) and some others to its decrease (as energy efficiency for passengers).

These graphs are another way to present the results of the same decomposition as for the Figure 2 and Figure 3.

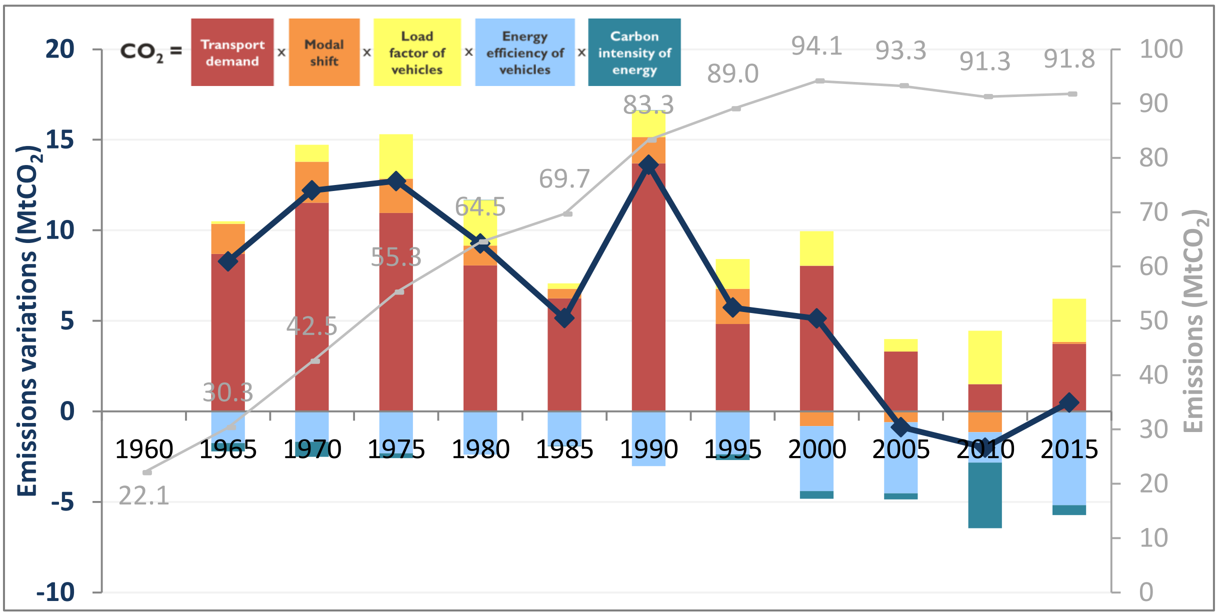

Figure 13: The additive decomposition of passenger transport CO_2 emissions between 1960 and 2015

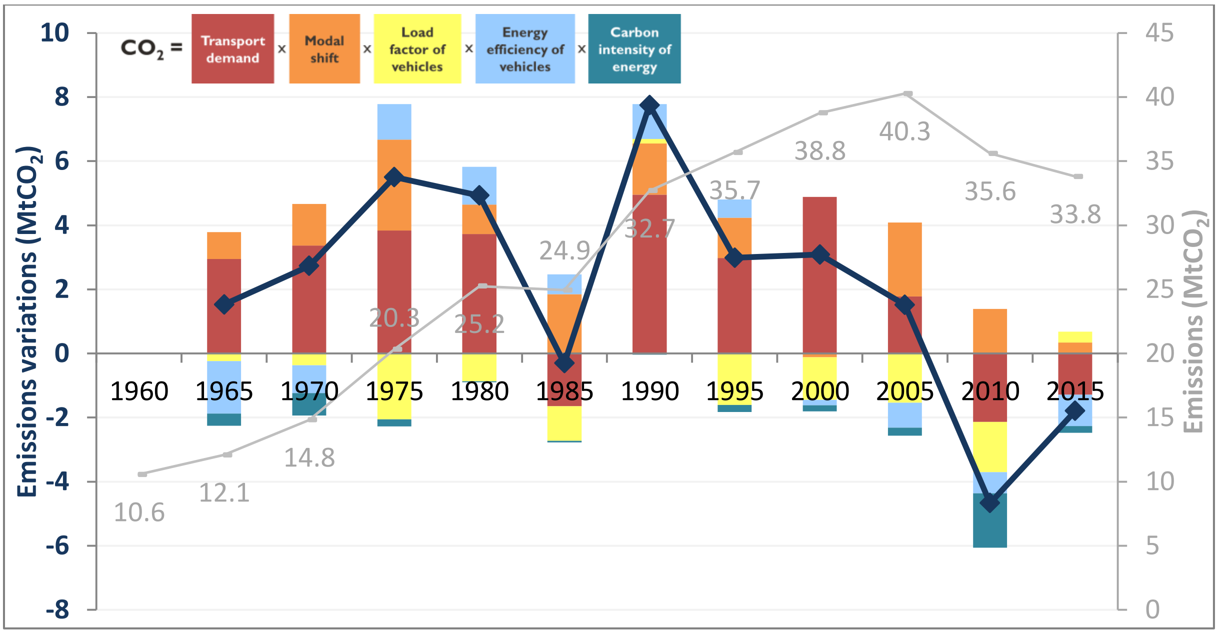

Figure 14: The additive decomposition of freight transport CO_2 emissions between 1960 and 2015

7.2. The multiplicative decomposition with international air transport

When **considering international air transport**, the increase of transport emissions and demand appears higher than when only domestic transport is included. It passes from 4.2 to 4.7 for CO_2 emissions, and from 4.7 to 5.3 for transport demand. Moreover, the contribution of modal shift on CO_2 increase here appears as more important than the load factor.

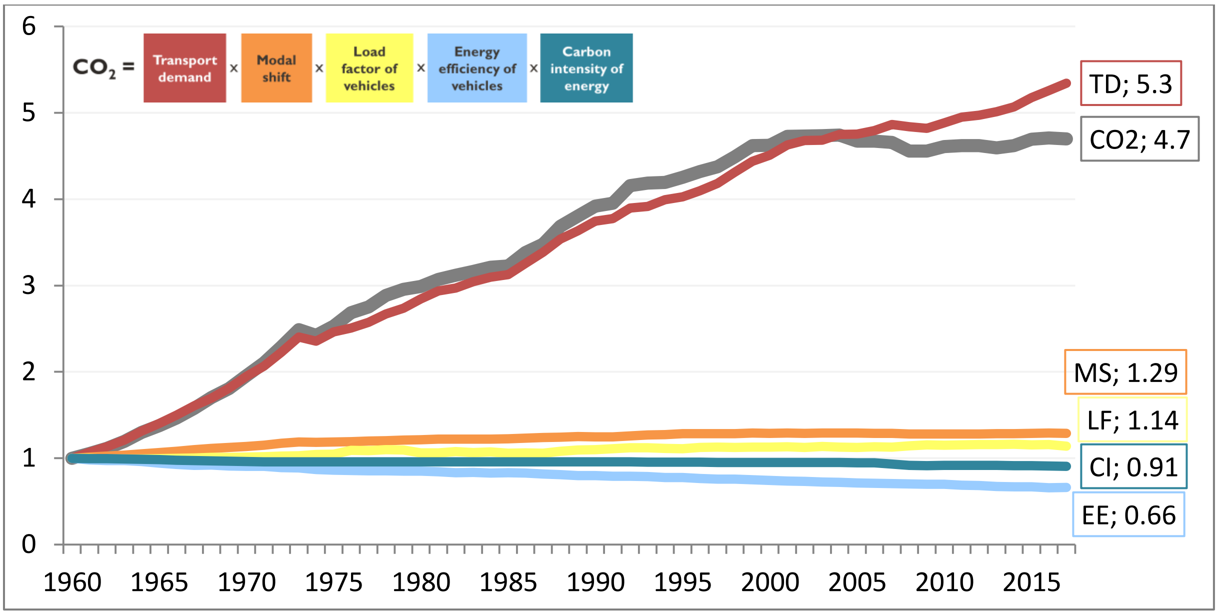

Figure 15: The multiplicative decomposition of passenger transport CO_2 emissions between 1960 and 2017, including international air transport