Assessing the impact of telework enhancing policies for reducing car emissions: Exploring calculation methods for data-missing urban areas

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Assessing the impact of telework enhancing policies for reducing car emissions: exploring calculation methods for data-missing urban areas

Example of a medium-sized European city (Besançon, France)

1. ABSTRACT

Teleworking has been identified as a potential key lever for reducing air pollution. Yet, evaluating the atmospheric outcomes of teleworking enhancing policies remains difficult, especially when official databases on telework, household equipment and car emissions are incomplete or non existent. Here we propose several techniques to efficiently assess the impact of an increase in teleworking rates, and to explore the resulting bias, in a typical medium-sized European metropolitan area where few data are available: Besançon, France. Population and cartographical data are introduced in an individual-based daily mobility simulation model. We then calculate the resulting emissions for twenty atmospheric pollutants, using three different methodologies that aim to compensate, with different precision levels, for the lack of accurate information regarding vehicle fleets. Our results confirms the efficiency of telework for reducing emissions, with an average reduction of -0.42% in emission for an increase of 1% in teleworking rate. The precision level of data used strongly impacts the estimated quantity of air pollutant emissions (up to a factor ten). Failing to correctly account for inequalities in teleworking rate and vehicle equipment between socio-occupational categories introduces strong biases in the results, which may degrade the correct evaluation of environmental benefits of teleworking enhancing planning policies.

Keywords: teleworking; daily mobility; greenhouse gases; air pollution; planning policies

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2. INTRODUCTION

Metropolitan areas have become the focal point for human activities and are expected to host more than 80% of the population in developed country by 2025 (UN, 2008a) (UN, 2008b). They are also the sources of various pollutants that impact both health and the environment (WHO, 2003) (WHO Europe, 2005) (WHO, 2013) (WHO, 2014). The conjunction of high levels of environmental contamination with high population densities results in important health risks that have become a major social concern worldwide (European Commission, 2013) (UN, 2015). In Europe, metropolitan areas ranging from 100 000 to 500 000 inhabitants host the largest part of the population (44%) (Giffinger et al., 2007). Thus, these "medium-sized cities" are key entities for the development of environmental, social and health policies.

Daily commuting using private motorized vehicles is a major contributor to both environmental pollution and greenhouse gas (GHG) emissions (US Congress (106th), 2000) (EEA, 2012) (CITEPA, 2013). Over the past three decades, telework, tele-commuting, and home-based working have regularly been identified as potential key levers with which to reduce road traffic and the resulting air pollution (Hamer et al., 1991) (Pendyala et al., 1991) (Balepur et al., 1998) (US DT, 1999) (WWF, 2009) (Fuhr and Pociask, 2011) (Aguilera et al., 2016) (Bigazzi and Rouleau, 2017) (Cerqueira et al., 2020), but they proved far less successful than expected due to several, extensively documented, technical and social obstacles (Bailey and Kurland, 2002) (Mokhtarian, 2002) (Salomon and Mokhtarian, 2008) (Martin and MacDonnell, 2012) (Hynes, 2014) (Giovanis, 2018) (Ravalet and Rérat, 2019) (Bojovic et al., 2020). Telework consists in using information and communication technologies (ICT) for nomadic work outside of the office (Nilles, 1998). Tele-commuting consists in allowing employees to work part-time from home (Leonhard, 1995). Home-based working concerns those workers who work full-time at home. In the rest of the paper, these three concepts are grouped under the general term "teleworking". Recently, there has been a revival of interest in teleworking among both policy makers and scholars as concerns about global warming have grown, ICT has become widespread in contemporary society, and their use has even increased with the current COVID-19 pandemic (Hynes, 2014) (Rau and Hynes, 2014) (SNBC, 2015) (Aguilera et al., 2016) (O'Brien and Aliabadi, 2020) (Hook et al., 2020). However, literature indicates a need for complementary studies that i) assess telework efficiency as a tool for reducing air pollution in the current context (O'Brien and Aliabadi, 2020) (Hook et al., 2020) and ii) contribute to the development of efficient decision-making tools to implement teleworking enhancing and air pollution reducing policies (Horvath, 2010).

Studies analysing the impacts of teleworking on traffic-induced air pollution have been conducted worldwide, on scales ranging from a single company to multiple states (Atkyns et al., 2002) (Pérez et al., 2004) (Nelson et al., 2007) (Kitou and Horvath, 2008) (Woodcock et al., 2009) (Khan, 2010) (Fuhr and Pociask, 2011) (van Lier et al., 2012) (Giovanis, 2018) (The Shift Project et al., 2017) (O'Brien and Aliabadi, 2020) (Hook et al., 2020). These studies usually adopt a three-step methodology: first, data concerning population's behaviour and equipment in vehicle are gathered; then, behavioural data are used to evaluate mobility, trips, teleworking rates and subsequent reduced travelled distance; finally, vehicle fleet data are used in conjunction with reduction in travelled distance to evaluate reduction in emissions. Potential health benefits can then be computed on the basis of evaluated reduction in pollutant emissions and changes in mobility behaviour.

Depending on available data and tools, several approaches may be used to conduct the study. Behavioural and equipment data may be obtained either by exploring official databases, or by conducting specific surveys especially for the study. Travelled distance may be computed using direct monitoring of the individuals, or via mobility simulation models. Emission reduction may be directly computed or evaluated via state of the art emissions models such as ADMS-urban (Atmospheric Dispersion Modelling System – Urban) or COPERT (Computer Program to calculate Emissions from Road Transport). However, most of these studies, and especially the more accurate and complex amongst them, remain often unavailable for local stakeholders. In most cases, only official databases and simple or open-based computing tools are available for local services wishing to evaluate the potential efficiency or benefits of a teleworking enhancing policy.

There is indeed strong differences regarding available teleworking-related data across the world. While some countries possess accurate and regularly updated databases for all administrative scales, other possess only partial data, if any. In Europe, there is a lack of exhaustive, fully comparable, and recent statistics across the union. Telework is still considered as a "growing phenomenon" and its perception vary widely between countries (EurWORK et al., 2017). Before the COVID-19 pandemic and the subsequent surge in telework caused by lockdown policies, in average 9% of workers in the European Union used ICT outside of the employer's premises, with around 2% teleworking mainly from home (Eurofound et al., 2015), but this number can increase up to one-third of employees in some of the countries (EurWORK et al., 2017). Thus, several countries have just started gathering statistics on telework while others have stopped data collection "since telework has become such a natural part of the work routine" (EurWORK, 2010).

France is an interesting example of a country where official statistics remains scarce despite an increase in teleworking during the last decade. This is partly due to the legislation, which demand a specific agreement for the gathering of statistics at the individual scale and allow their use at an aggregated level only. Other parameters, such as the time-lag between behavioural change and administration adaptation may also play a role. Consequently, teleworking, behavioural and fleet data in France are often produced for punctual studies, relying on varioust methodologies, and conducted by structures belonging to different ministries or different administrative levels. Reports, when they exist, thus provide different and somewhat incompatible numbers. For example, the most recent available French statistics evaluated the national teleworking rate at “between 7 and 9% nationwide” in 2009 (CAS, 2009), in average 14.2% in 2015 (CGET, 2015) and in average 16.7% in 2017 (ANACT, 2017). In the meantime European statistics evaluated it to be about 23% in 2005, with less than 13% of regular teleworkers (EurWORK et al., 2017). No information exists for most other administrative levels.

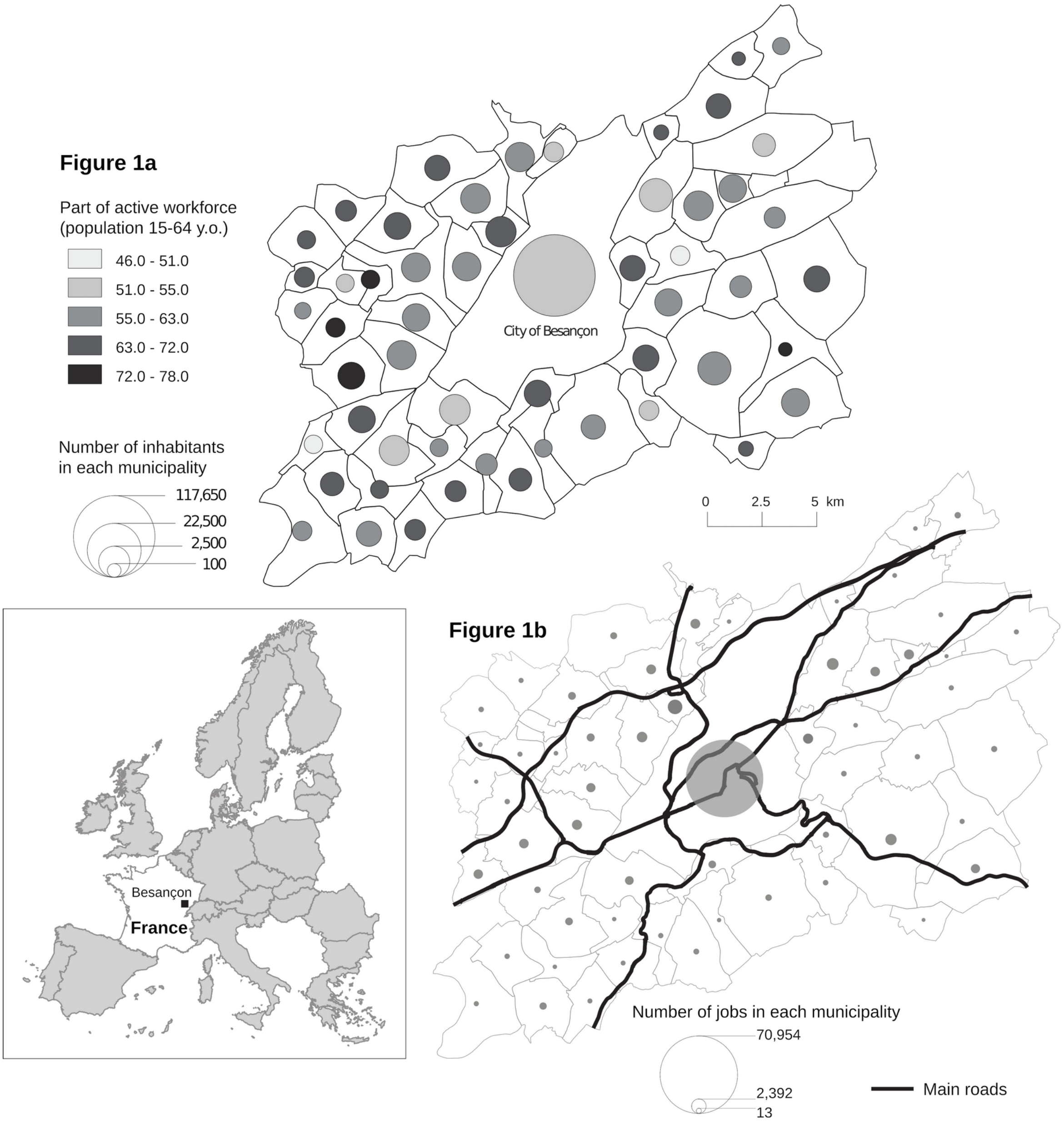
This general lack of high quality, easily accessible, fine scale data may be an important issue for stakeholders who aim to evaluate the environmental and health consequences of telework enhancing public policies. This is especially true for developing countries which combine high demographic progression with an increasing access to individual vehicles, high pollution levels, high health inequalities, and a lack of data and processing tools. This situation underlines the need for testing the consequences of using incomplete data and for developing techniques to compensate this issue. In this context, this paper aims to: i) evaluate the efficiency of telework as a potential lever for reducing atmospheric pollutant emissions in medium-sized European cities; ii) test several techniques to compensate for the lack of available data on individuals behaviour and vehicle fleet composition; and iii) identify the possible bias on calculated pollutant emissions resulting from the source and quality of data that describe the composition of the vehicle fleet. For this, we use the agent-based model MobiSim-MQ (Mobility Simulator – Daily Mobility) to simulate current daily mobility of individuals for a basic workday considering realistic planning policy scenarios that raise teleworking rates. The distance each individual travels by car in a simulation is then used to calculate resulting pollutant emissions. We test three different calculation methods that introduce different levels of details of individual’s vehicle equipment.

3. MATERIALS & METHODS

3.1. Study area and data

The study area (Lat: 47.237829, Long: 6.024054 – WGS84, Figure 1a&b) encompasses the city of Besançon (117 000 inhabitants in 2010), and 58 peripheral municipalities (60 000 inhabitants in 2010). Population density ranges from 57 inhabitants/km² (5 700 inhab/Ha) in the most peripheral municipalities, to 1 798 inhabitants/km² (179 800 inhab/Ha) in central Besançon (Figure 1).

Figure 1a&b. Map of Besançon's metropolitan area for the year 2008 showing for each municipalities a) the total population and the part of the active workforce in the total population; b) the main road network and the number of jobs in each municipalities. Data source: INSEE, 2014. Created using ESRI ArcGis 10.1



Following the trend observed in many medium-sized European cities, Besançon's city center is losing population (- 0.25% from 2007 to 2012) while the population in the peripheral municipalities remains stable (+0.08% in the same period). Because the city economy relies mostly on the tertiary sector, employment is largely concentrated in central Besançon (69%). In most other peripheral municipalities, the number of jobs is lower than the number of workers. Besides, a noticeable proportion of workers do not work in the municipality where they live. For instance, about 11 200 workers of the Besançon's municipality work in a peripheral municipality, while about 17 900 commuters from peripheral municipalities make the reverse path. Consequently, car-based commuting and road congestions are both increasing. No significant air pollution emitting infrastructures, such as heavy industries, airports, or major motorways, are present in the metropolitan area. Therefore, the main source for local environmental air pollution is the combustion of hydrocarbons due to road traffic on the 3 439 km of roadways. Due to this conjunction of factors, the city of Besançon is an excellent site for traffic-related pollution studies (Tenailleau et al., 2016) (Barba-Vasseur et al., 2017) (Mariet et al., 2018) (Brembilla et al., 2019).

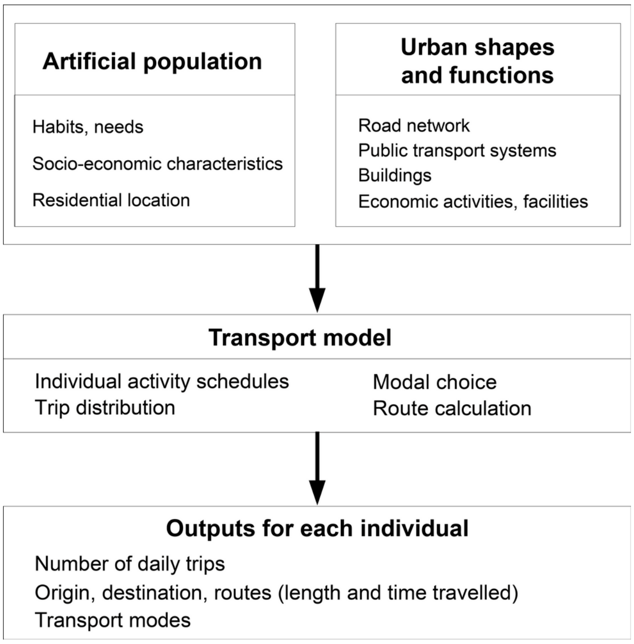
3.2. Simulating daily mobility trips of individuals using MobiSim-MQ

The choice of the simulation model MobiSim-MQ (Tannier et al., 2016) (Antoni et al., 2016) is based on two main arguments. First, this model is fully disaggregated whereas most traffic models are aggregated at the level of communities or neighbourhoods or traffic zones. Second, it is based on an artificial population of individuals that enables to model finely their demographic and social characteristics without needing detailed survey data (Hermes and Poulsen, 2012). Thereby MobiSim-MQ enables a high-resolution description of activity schedules, modal choices, and mobility patterns of individuals. It can also account for changes in population behaviour, which makes it highly suitable for studying the direct and indirect impacts of policies promoting teleworking, including the rebound effect implied by changes in non-work mobility patterns and habits.

Modelled entities in MobiSim-MQ are individuals forming an artificial population reconstructed from aggregated census data from the National Institute of Statistics and Economic Studies (INSEE - Table 1) (Antoni et al., 2017). This is necessary in France because of the unavailability of public individual-levels demographic data. This artificial population reflects the socio-economic composition of the population of the metropolitan area. Each modelled individual is characterized by a series of socio-economic attributes (age, gender, profession, marital status, etc.). Socio-demographic rules determine how individuals form households. Spatial rules locate dwellings within buildings. The urban environment is very finely represented: public transport systems with their timetables, roads with their speed limits, shops and facilities, places of employment, green and natural areas, etc. (Appendix A).

MobiSim-MQ operates on the basis of a classical four-stage traffic model (McNally, 2007) but the four stages are grouped two by two, thereby increasing the degree of interaction: the generation of activity schedules and their spatial distribution are interconnected processes determining individuals' daily mobility (Ben-Akiva and Bowman, 1998); determining the means of transport used and the routes taken are also two connected stages (Antoni et al., 2016). The modelling chain is as follows (Figure 2): (i) creation of an artificial population of individuals, households and dwellings; (ii) definition of activity schedules for each individual based on their socio-economic attributes (Table 2); (iii) attribution of activity places to each individual using a spatial interaction model; (iv) attribution of one mode of transport (walking and cycling, private car, or public transport) for each journey made by each individual using a generalized costs logit model.; and (v) calculation of routes used by each individual using Dijkstra’s classical shortest path algorithm applied to the generalized travel costs.

Figure 2. Simulation of daily mobility with MobiSim-MQ



In stage (iv) (attribution of one mode of transport), a generalized cost is calculated for each mode of transport considering each journey made by each individual. The calculation involves a series of parameters: a) the comfort index of each mode; b) the individual cost of time, which varies according to the hourly income of each individual under consideration (for children, the cost of time is a fixed value); c) for public transport, the price of the ticket; d) for car, the cost of distance per kilometre (only the length of the journey is taken into account for walking and cycling). The probability that an individual chooses a given mode of transport for a given journey is calculated on the basis of the minimum generalized cost that has been obtained by calculation. An additional parameter δ_{max} represents the maximum acceptable ratio of one generalized cost upon the minimum generalized cost of this journey. δ_{max} enables us to represent the choice of individuals being not fully rational (i.e. they can choose a mode that does not have the minimum generalized cost). In order to take network loading into account, individuals’ choices of transport modes are first made for empty networks, then a new computation is performed by including the loading of the networks.

3.3. Teleworking scenarios

No central administrative data source monitors the teleworking rate in French cities, and no recent survey has been conducted in Besançon by local administrations.

Consequently, the rate in the study area had to be evaluated on the basis of available occasional studies conducted at regional and national levels by other official services. First, local companies practising teleworking were identified using the 2010 Annual Social Declaration Database from the French Directorate for Legal and Administrative Information (DILA). This database allowed us to identify the number of companies concerned, the number of their employees, and their socio-occupational composition. From this, we can evaluate their local teleworking capability. The closest to date French Report on Teleworking, edited by the Directorate for Statistics of the French Ministry of Employment (DARES) provides nationally averaged teleworking rate per socio-occupational level. By coupling those two databases (DILA and DARES), we have estimated the probability of teleworking per socio-occupational level in Besançon (Table 3). The average teleworking rate of the global working population was evaluated at 7.35%. This 7.35% rate is below the national average, estimated at 13.00% from the DARES database. Although probably outdated, those data where the most recent available to date and correspond to those that may be used by officials for policy planning.

Teleworking is introduced into MobiSim-MQ on the basis of a first simulation performed without teleworking. Teleworkers are chosen randomly among the working individuals in the simulation performed without teleworking, according to the socio-economic distribution of teleworking in the population given by the closest available official French study (Table 3). Teleworkers may either stay at home or commute to the nearest teleworking site. Three types of teleworking sites have been defined: (i) co-working sites and business centres; (ii) Wi-Fi equipped public sites (hotels, cyber-cafés, pubs, etc.); and (iii) public sites that could be converted for hosting co-working areas (municipal buildings, post-offices, and unemployment agencies).

Two teleworking scenarios have been defined: i) the “balanced” scenario, representing the normal situation estimated from the DILA / DARES database (7.35% teleworking rate in the general population); and ii) the “increased” scenario, representing the consequences of an incentive policy aiming to raise the number of teleworkers in the study area up to the estimated average French value (13.00% teleworking rate in the general population). For this scenario, local socio-occupational teleworking rates have been equally increased for all types of activities, in order to maintain the same differences in teleworking rate according to the job types as in the balanced scenario. The two scenarios have been computed for a standard French workday.

3.4. Calculation of atmospheric pollutant emissions (three greenhouse gases and seventeen atmospheric pollutants)

Pollutant emissions have been calculated at the individual level according to: i) the total distance travelled by car in the day for each simulated individual, obtained from MobiSim-MQ; ii) the type of vehicle used by the individual; and iii) the emission rate of each considered pollutant. Here again, no official monitoring of the individual vehicle fleet composition exists in France at the city scale, and no data describing its exact composition in the Besançon metropolitan was available. Consequently, the national vehicle fleet composition was used as a standard for calculation. It was obtained from the Public Work Technical Study Centre (CETE - a technical directorate of the French administration) database, which gives the percentage of cars in the national fleet for three fuel types (petrol, diesel, and LPG & hybrids) and 41 categories of engine technology (Appendix B). However, this database lacks information on the distribution of those vehicles types according to the socio-professional status of individuals. In order to evaluate the impact of this missing information on the calculated pollutant emissions, three methods introducing increasingly detailed information regarding fleet composition were tested to attribute a vehicle and an emission value to each individual travelling by car in the simulations.

The identical vehicle method— On the basis of the CETE data giving statistical distribution of each engine technology among the national vehicle fleet, a single average vehicle was created and allocated to each car user. Emissions of pollutants for this identical vehicle correspond to the average of the emissions for vehicles of each engine technology weighted by the share of each engine technology in the national vehicle fleet.

The socio-occupational vehicle method— A Household Mobility Study conducted in Besançon (CAGB, 2005) gives the percentage of vehicles of each fuel type for each socio-occupational status (Table 4). On the basis of this study, a given average vehicle was defined for each socio-occupational status in order to account for the differences in fleet composition between socio-occupational categories. Emission rates for each socio-occupational vehicle correspond to the average of the emissions for vehicles of each fuel type weighted by the share of each fuel type in the vehicle fleet of the corresponding socio-occupational category.

The individual vehicle method— A vehicle of a given fuel type is randomly allocated to each individual according to the frequency of this fuel type among the vehicles owned by individuals having the same socio-occupational status. By individualizing vehicle attribution, this method enables us to better represent the variability of vehicle types in the population of the study area.

Emissions have been calculated for three greenhouse gases and seventeen atmospheric pollutants produced by vehicle fuel consumption: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), carbon monoxide (CO), non-methane volatile organic compound (NMVOC), nitrogen oxide (NO_X), ammonia (NH_3), polycyclic aromatic hydrocarbon (PAH), sulphur dioxide (SO_2), dioxins, furans, total particles (TSP) produced by both combustion and wear, lead (Pb), nickel (Ni), mercury (Hg), copper (Cu), chromium (Cr), cadmium (Cd), arsenic (Ar), zinc (Zn), selenium (Se). CO_2 due to lube oil has been included in the calculation. Carbon equivalents for CO_2, CH_4, and N_2O have been calculated using the Global Warming Potential (GWP) of each gas: x1, x56, and x280 respectively (IPCC, 2014). Emission rates have been obtained from the CETE and correspond to those presented in the European Monitoring and Evaluation Programme / European Environment Agency 2013 guidebook for air pollutant emissions inventory (EMEP/EEA, 2013). Pollutant emission rates that were not available from the guidebook were estimated, at the subsector level (for petrol-powered cars, diesel-powered cars, and Liquefied Petroleum Gas (LPG)), from data provided by the Technical Inter-occupational Centre for Atmospheric Pollution Studies

(CITEPA) 2013 OMINEA guidebook (Appendix B). Both those emission rates correspond to the emissions produced during a standard urban driving cycle, and to the closest available date from the 2010 teleworking data.

4. RESULTS

4.1. Impact of teleworking rate on distance travelled for each type of activity

An increase in the teleworking rate from 7.35% to 13.00% reduces total distances travelled by car by approx. 47 616 km (-2.33% - Table 5). This reduction varies according to the type of activity under consideration. For seven trip purpose upon eleven, the distance travelled by car decreases, from -19 084km to -496km, while it remains unchanged for two types of activity (job seeking and studying), and increases for two other types (+44km for social relation related trips and +0.12km when the trip purpose is coming back home). Not surprisingly, the activities showing the strongest reduction of kilometres travelled by car concern trips related to workplace and to home (Table 5). The modal shift from car use to walking and cycling is noticeable for most of them whereas the use of public transport increases only when the trip aim to reach home to telework after other non-work related trips (activity named “teleworking from home”).

The distribution of mode choice remains similar between scenarii for all purposes except those related to teleworking (Figure 3). Percentages of mode choice for different trip purposes show that car remains the main mode of transport except for reaching home to telework (here walking and cycling are the main modes). Average distance travelled to teleworking at home is usually extremely low (Figure 4). When the teleworking rate increases from 7.35% (balanced scenario) to 13% (increased scenario), a modal shift from car and public transportation toward walking and cycling occurs for eight trip purposes upon eleven. The main shift is observed for trips aiming to reach a teleworking center, for which car use decreases from 92% to 74% whereas walking and cycling increase from 5.8% to 22% and public transport from 2.47% to 4.23% (Figure 3). Concomitantly, whatever the transport mode under consideration, average distance travelled to teleworking center decreases noticeably (Figure 4).

Figure 3: Percentage of mode choice for each trip purpose regarding travelled distances.

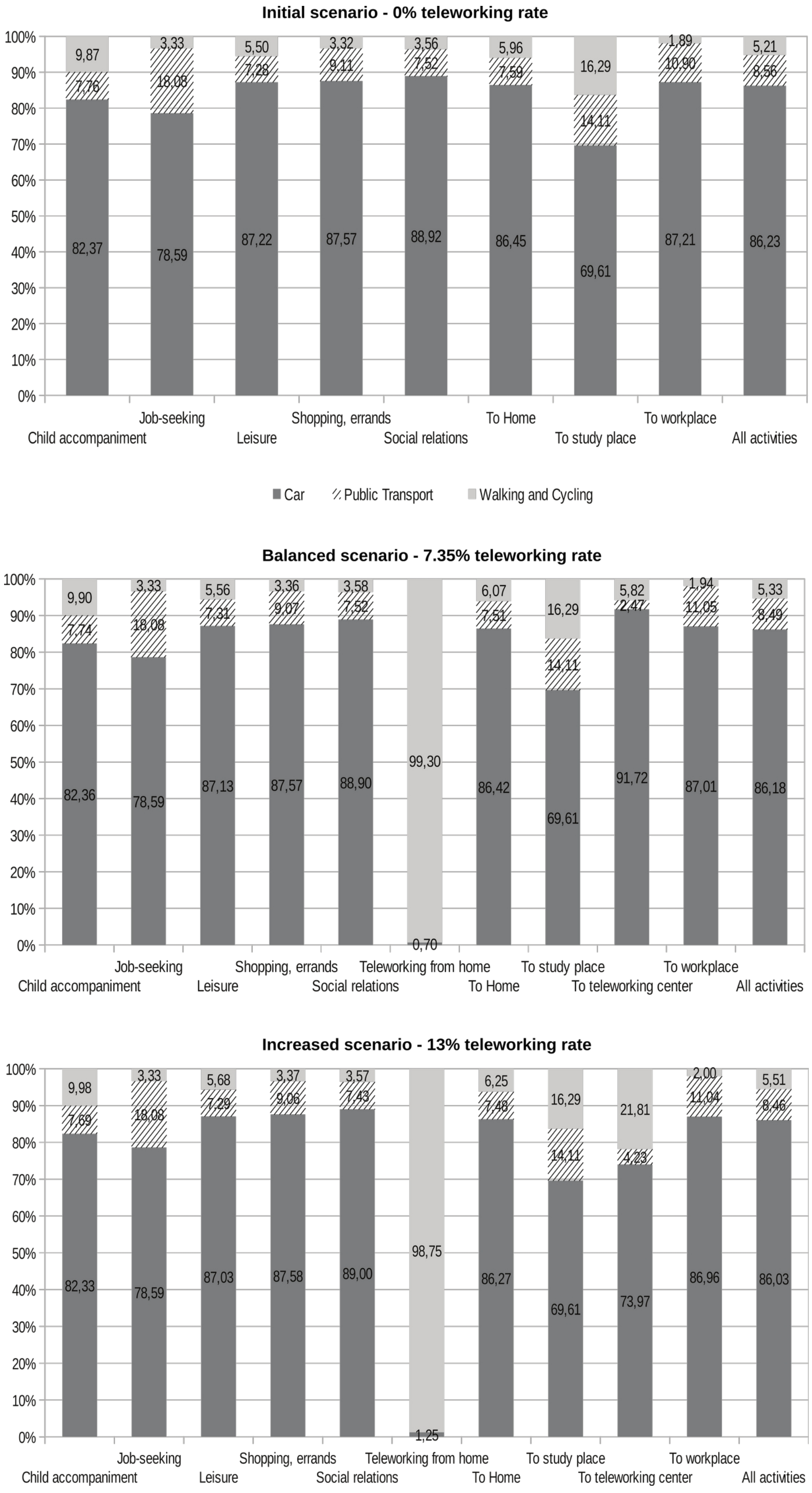
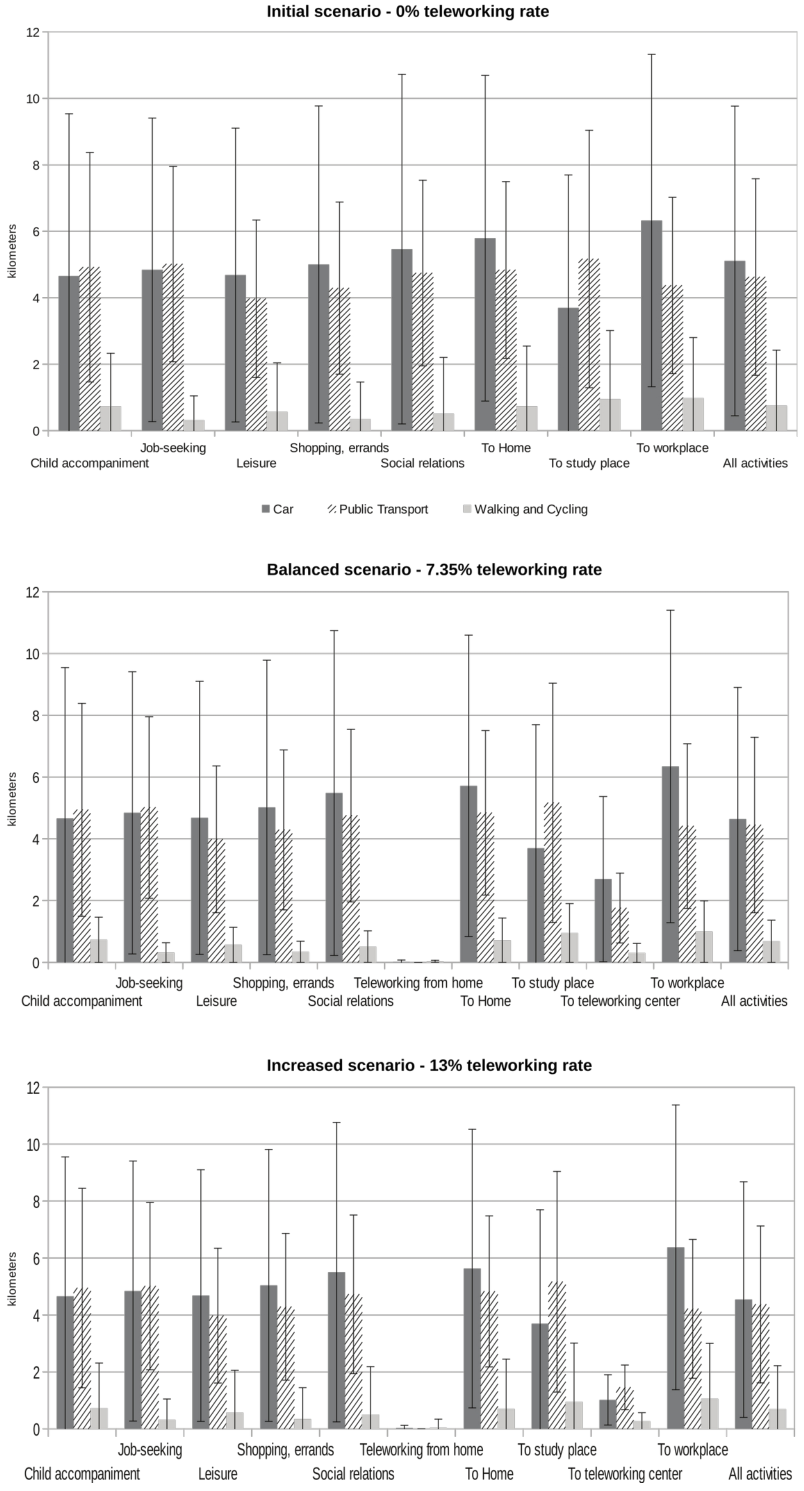


Figure 4: Average distances travelled for each trip purpose by each type of transport mode. Vertical black lines represent the standard deviation around the average.


Initial scenario - 0% teleworking rate

Balanced scenario - 7.35% teleworking rate

Increased scenario - 13% teleworking rate

4.2. Impact of the emission calculation method on evaluated atmospheric emissions

Calculated emissions varies strongly depending on the vehicle method used (Table 6). The socio-occupational vehicle method exhibits higher emissions than the identical vehicle method for all pollutants except NH_3 (11.95% / 12.13%) and Pb (10.44% / 10.66%) in both teleworking scenarios (balanced / increased) (Table 7). Marked variations appear between pollutants, with calculated emissions ranging from +363.48% / +362.11% (NOx) to -11.95% / -12.13% (NH_3). With the individual vehicle method, calculated emissions are higher than with the socio-occupational vehicle method for 14 out of 21 pollutants for both teleworking scenarios. Here again, marked differences appear between pollutants, with calculated emissions ranging from +137.93% / +139.61% (NO_x) to -70.95% / -70.87% (NH_3). Observed results are similar when comparing the individual vehicle method to the identical vehicle method: calculated emissions are higher for the same 14 pollutants and range from +1002.77% / +1007.25% (NO_x) to -74.42% / -74.40% (NH_3).

4.3. Impact of the raise of teleworking rate on air pollutant emissions

Results presented in Table 8 show that the changes in mobility due to an increase in teleworking rate, from balanced scenario (7.35%) to increased scenario (13.00%), leads to a reduction of road traffic pollutant emissions comprised between -2.14% and -2.60% depending on the computation method. This corresponds to a reduction of -0.38% to -0.46% in emissions per 1% rise in the teleworking rate.

With the identical vehicle method, the fall in road-traffic emissions is 2.55% for all pollutants and no variations appear between pollutants. With the socio-occupational vehicle method, the fall in road-traffic emissions varies from 2.57% for N_2O, SO_2, and NH_3 to 2.67% for NO_x, with an average reduction of 2.59% (0.46% per 1% rise in the teleworking rate). With the individual vehicle method, the fall in road-traffic emissions varies from 1.97% for dioxins & furans to 2.45% for Pb, with an average reduction of 2.15% (0.38% per 1% increase in the teleworking rate). The vehicle method also impacts pollutants differently: NO_x shows the greatest fall with the socio-occupational vehicle method (2.67%) but only the second lowest fall with the individual vehicle method (1.98%).

5. DISCUSSION

5.1. Impact of telework on atmospheric pollutant emissions

In this study, two teleworking scenarios characterized by very different teleworking rates have been simulated: the “balanced” scenario (teleworking rate fixed at 7.35%) and the “increased” scenario (13.00%). Our result indicates that a 5.65% rise in the percentage of teleworkers could contribute to an average -2.14% to

-2.60% fall in pollutant emissions due to car use (depending on the computation method).

While the chosen emission computation method appears to impact significantly the estimated quantity of emission (up to +1007.25%), it does not appears to impact estimated reduction in emissions between the two scenarios. Not surprisingly, the average decrease in emissions between the two scenarios is directly related to the decrease in travelled distances, which is in accordance with previous publications showing a similar relationship (Woodcock et al., 2009) (Khan, 2010) (Fuhr and Pociask, 2011) (van Lier et al., 2012) (Giovanis, 2018) (The Shift Project et al., 2017). This relationship is the core idea behind cutting emissions by increasing telecommuting. While obvious at first sight, this idea is actually slightly more complex: the impact of teleworking on air pollution actually depends largely on the interactions between behaviours of teleworkers, urban morphology, available transport modes, characteristics of owned car, driving cycles and traffic quality. Consequently, observed decreases in road-traffic pollutant emissions vary greatly among studies, from -0.15% (Khan, 2010) to -1.06% (Fuhr and Pociask, 2011) per percentage of increase in the teleworking rate (-0.38% in our study). To our knowledge only (Zhu and Mason, 2014) have found that, in the USA, CO_2 emissions due to teleworking increased by 5.9% between 2001 and 2009 while teleworking rates remained stable. Similarly, comparison of teleworkers and non-teleworkers daily trips in the UK, indicates that, for some social categories, trade-off effects resulted in an increase in CO_2 emissions (Cerqueira et al., 2020). According to the authors, and to other studies exploring the rebound effects of telework, this may be caused by teleworkers living further out from work and leisure places than non-teleworkers, which results in longer trips that counterbalance the reduction of the number of trips (Mokhtarian, 2002) (Zhu and Mason, 2014) (He and Hu, 2015) (Cerqueira et al., 2020).

This rebound effect actually covers two phenomena. The first phenomenon is the potential increase of the power consumption due to the over-use of computers, server farms, and domestic appliances, which could result in higher air-pollutant emissions depending on the type of energy used for electrical production (Gossart, 2015) (O’Brien and Aliabadi, 2020) (Hook et al., 2020). However, we did not account for this phenomenon in our study because of the absence of data on the power consumption, and because it is not directly related to road-traffic emissions. Moreover, as French electrical production relies for 91.3% on carbon-free technology, we could assume that this part of the rebound effect has negligible impacts on pollutant emissions in this context. The second phenomenon is the modification of mobility behaviours, where people may travel less by car to reach their work place, but may travel more or change their transport mode for non-work related purposes (purchases, leisure activities…) (Wang and Law, 2007) (Salomon and Mokhtarian, 2008) (O’Brien and Aliabadi, 2020) (Hook et al., 2020). Studies on the matter indeed indicates an unequal impact of ICT on mobility behaviour, depending on the abilities for ICT to substitute, complement or even increase the need for travels (Mokhtarian, 2002) (Salomon and Mokhtarian, 2008) (O’Brien and Aliabadi, 2020) (Hook et al., 2020). Most studies on telework indicate positive environmental impacts of telework despite the rebound effect; only a few suggests an actual negative or a neutral impact (O'Brien and Aliabadi, 2020) (Hook et al., 2020).

Changes in mobility behaviours, especially modal choices, have been accounted for in MobiSim-MQ modelling chain. Simulation results indicate a very low increase of the distance travelled by car (+44 km), which corresponds mostly to an increase in the distances travelled for "social relations" related trips (Table 5). The fact that this rebound effect of distances travelled by car is very small could be explained by the modal shift toward walking and cycling observed for nearly all activities (Table 5**,** Figure 3**,** Figure 4). Such a modal shift can be favoured by the specific spatial configuration of medium-sized European cities, where residential locations are closer to shops and services than in larger cities (Aguilera et al., 2016) or than in their American counterparts (Mokhtarian et al., 1995) (O'Brien and Aliabadi, 2020) (Hook et al., 2020). Indeed, in European cities, the "walking neighbourhood", defined as the area where subjects circulate to meet most of their daily needs, is often considered to encompass a 400m radius area around one's home (Forsyth et al., 2008) (Smith et al., 2010). To our knowledge, no other comparable study exists that could confirm the fact that an increase in teleworking induces a modal shift toward walking and cycling for work related purpose in the specific case of medium-sized European cities.

While our study does not aim to identify the factors influencing on workers' telecommuting and travel behaviour, both our results and literature results emphasize the need to account for these factors in future studies, and thus to develop a broader and more accurate knowledge on the matter. Differences in daily mobility habits, as observed between rural and urban populations, or American and European populations, may strongly impact the effect of teleworking on distances travelled and pollutant emissions. This element is to be kept in mind as it may be tempting, especially for stakeholders missing recent studies or local data, to directly compare study results without accounting for territorial specificities, differences in scales, time periods, methods, and concerned populations.

To our knowledge, the only other study conducted recently in France with a similar design was focusing on the consequence of teleworking in periurban areas. Its results are close to ours, with an estimated -1.3% to -4.5% total reduction of CO_2 emissions, depending on the financial investment in teleworking (The Shift Project et al., 2017). In general, few recent studies (post 2010) have been conducted in Europe (van Lier et al., 2012) (Guzman et al., 2016) (Giovanis, 2018), especially on city scales, despite the fact that the largest part of the European population (44%) lives in medium-sized cities and metropolitan areas ranging from 100 000 to 500 000 inhabitants (Giffinger et al., 2007). Thus new studies on the ecological and health impacts of teleworking in European medium-sized cities would be useful, especially considering that transportation services, urban morphology, mobility patterns, employment rates, traffic congestion and pollutant emissions in medium-sized cities differ noticeably from those of larger cities (Mokhtarian et al., 1995)

(Aguilera et al., 2016). This could also mean that the evaluated decrease in pollutant emissions may be lower than what might be expected for areas experiencing more dynamic socio-economic situations.

5.2. Impact of vehicle fleet data quality on computed air pollutant emissions

The three different methods chosen for calculating pollutant emissions aim to compensate for the lack of precise fleet composition data, and represent different levels of precision that could be easily computed by stakeholders in order to approach the reality of the fleet composition. Our results indicate that most often, the quantity of estimated emissions increases with the level of details of the vehicle fleet taken into account in the calculation. While the chosen method does not impact the general conclusion that may be drawn regarding the efficiency of telework enhancing policies, it strongly impact the estimated quantity of pollutants (up to ten times). Thus a strong attention should be paid to the choice of the emission calculation method when assessing planning polices or comparing the result of different studies, especially in view of an environmental or health objective. A ten time differences in pollutant quantity is not something to ignore when evaluating risks. The use of precise, high grade data thus appears to be of crucial importance for a reliable health and environmental impact assessment, especially when studying pollutants whose effects may be important even when levels of exposure are below the threshold set out in European legislation (PM, NO_x, GHG) (World Health Organization, 2016) (Jonson et al., 2017).

The three different vehicle methods used to affect emission rates to simulated individuals reflect different consideration for the complex relationship between socio-occupational status, teleworking rates and fleet composition. With the identical vehicle method, which reflect a situation where no data is available regarding the vehicle fleet composition, the emission rates are identical for all individuals and only the teleworking rates by socio-occupational status and the distance travelled by each individual impact the pollutant emissions. Conversely, with the individual vehicle method we were able to account for the distribution of vehicle fuel-type amongst socio-occupational status. The inclusion of this parameter results in great variations in calculated emissions. This reflects the core importance of the socio-occupational status, which impacts nearly all other variables: teleworking rate, vehicle's motorisation type, probability of using public transportation or walking, travelled distance, *etc.*. Here, we see and where able to account for the fact that the lower socio-occupational statuses (farmers, craftsmen/retailers, manual workers) are both the least susceptible to telework and the ones with the highest rate of diesel-fuelled vehicles in their fleets, while the highest socio-occupational statuses (executives & higher intellectual professions) are those teleworking the most, but also those with the highest rate of petrol-fuelled vehicles. Individual's purchasing power may also impact other important variables linked with pollutant emissions, such as the quality and recentness of the vehicle. These parameters were not accounted for in this study because available vehicle-fleet data were limited to the subsector level (fuel type) and thus lacked information about the distribution of vehicle recentness and engine (EURO) technology by socio-occupational status, but our results emphasize the need for gathering and using such information.

In France, fleet composition data are produced at the national and regional level, using occasional questionnaire studies only. The more recent available dataset allowing to identify vehicle type distribution according to socio-economic statuses dates from 2010. Thereby, we have chosen to focus the study on this date and to use the closest available datasets for both vehicle emissions and teleworking rates in order to ensure the consistency of the study. Despite the three-years gap between vehicle fleet data and the data about car emissions, we can consider that those datasets are compatible. Vehicle purchase is an important investment that limits rapid evolution of the fleet, and vehicle motorisation technology has not been subjected to major changes during the three years under consideration. Similarly, the closest in time available official dataset allowing to compute teleworking rates dates from 2004. Results presented in this study may thus differ to those relying on foreign or more specific data sources. However, these datasets remains the main official sources that will be used by local stakeholders for evaluating policy efficiency, which justify their use in this study as we aim to put ourselves in stakeholder shoes.

The lack of details in available databases reflects the low interest for telework amongst both French management and officials (Eurofound et al., 2015). Considering the recent promotion by the government of teleworking as a solution for reducing national carbon emissions (SNBC, 2015) and the increase of teleworking amongst the population due to the COVID-19 crisis, it is possible that the percentage of teleworkers surges over time and that an efficient monitoring of teleworking become implemented. Until then, the use of offsetting technics to compute teleworking rates and resulting emissions probably remains the only solution available for assessing the consequences of public policies.

5.3. Choice of the simulated scenarii

The ~2% reduction in air pollution was obtained with a scenario assuming a near-doubling of the pre-pandemic teleworking rate (the “increased” scenario). A recent survey conducted for the French government during the COVID-19 pandemic lockdown indicates that nearly 39% of workers, deemed “essential workers”, were not able to telework in any way, while 25% could telework “with difficulty”. Thus, 36% of the working population is eligible to daily telework (Lancrey-Javal and Hauser, 2020) (Blondel et al., 2021). Thus, we may consider that the 13% value of teleworking rate in the average working population obtained from the DARES 2010 database is a perfectly plausible scenario for a non-pandemic situation. Because no data was available to differentiate the evolution of teleworking rates according to the social groups, the increase in teleworking rates has been evenly distributed amongst groups in order to achieve a rate of 13% in the general population. Yet literature indicates the existence of strong inequalities in teleworking rate amongst socio-professional groups, and the main factors influencing the individual adoption of teleworking seem to be linked to individual social status : the ability to dematerialize activities, personal and professional access to ICT, flexible human resources practices, the urban morphology and the availability of efficient and cheap public transports, the social representation of individual car property, and above all the willingness to reduce commuting time (Mokhtarian, 2002) (Pérez et al., 2004) (Wang and Law, 2007) (Hynes, 2014) (Rau and Hynes, 2014) (Lachapelle et al., 2018) (Lin et al., 2018) (Akbari and Hopkins, 2019). The aforementioned survey confirms this: inability to telework was mostly due to the nature of the employment (67%), refusal by the employer (15%), lack of ITC equipment (9%), the need for face-to-face interactions with colleagues (7%), familial situation (6%) or fear for professional repercussion (4%) (Lancrey-Javal and Hauser, 2020). Consequently, it is highly plausible that teleworking enhancing policies would not result in an equal increase of teleworking rates amongst social groups, but would more probably result in an unequal increase, with upper socio-professional groups showing the highest increase in teleworking rate. We can thus consider that any general, equitable, and sustainable increase in telework would suppose a strong public investment in infrastructures, equipment, and incentives toward both industries and workers, as shown with Barcelona’s post-COVID teleworking policies (Bojovic et al., 2020). Not all territories may be able to support the potential cost of such a policy, which highlights the crucial question of its cost-efficiency, especially in the current context of austerity policies and economic downturn which impact both local and national governments (Grady and Goldblatt, 2012). This is especially true in the case of urban planning as the concerned policies can be very expensive (Macintyre et al., 2002) (de Snyder et al., 2011).

According to a recent report dealing with periurban mobility in France (The Shift Project et al., 2017), the national cost of enhancing teleworking in France would be 0.5bn€/year. When compared with other planning actions concerning good delivery, bicycle use, public transport services, and carpooling, telework appears to be the second most cost-efficient solution in terms of pollutant reductions per Euros of public investment, just after carpooling and before cycling. Nevertheless, it is important to keep in mind that those policies could interact, positively as well as negatively. For instance, an increase in teleworking can increase the modal shift to cycling, as suggested by our results, and subsequently improve public health from both air pollution reduction and increase in outdoor activities. But this modal shift may also increase accident risks in environments that lack bicycle lanes or adapted road network. In some contexts, increase in telework may also result in both a decrease in the need for public transportation, and a decrease in traffic congestion, which could lead to a de-funding of public transport and an increase in car use for small non-work related trips. Studies tackling these questions remain scarce and contradictory (Rietveld, 2011) (Elldér, 2020) (Ravalet and Rérat, 2019) (O’Brien and Aliabadi, 2020) (Hook et al., 2020). Last but not least, the reduced need for mobility may create conditions for a less social, more sedentary and unhealthy lifestyle in urban environments where travel distances between households and amenities are high (Rau and Hynes, 2014). Finally, despite leads indicating a benefit of telework on mental and physical health (Anderson et al., 2015) (Vega et al., 2015) (Tavares, 2017) (Windeler et al., 2017), the reduction in outdoor air pollution exposure may locally be compensated by an increasing exposure to indoor air pollution, where pollutant levels may exceed outdoor levels, while health impacts of several usual indoor contaminants remain poorly identified (Spiru and Simona, 2017). Resulting impacts of telework thus still need to be evaluated accordingly to the local environmental and social specificities, and positive as well as negative consequences must be considered.

6. CONCLUSION

Teleworking is a potential key lever to reduce road traffic and the resulting air pollution. Yet, literature in the field indicates that the effects of teleworking may noticeably vary according to the context: social habits, characteristics of the transport system, location of activities regarding the places of residence... Our study shows that, in the case of a typical medium-sized European city, an increase of +5.65% in teleworking reduces average air pollution and GHG emissions caused by car from -2.14% to -2.60%. As 44% of the European populations live in medium-sized cities, this research result supports the idea that promoting policies to enhance teleworking in those metropolitan areas could produce a positive cumulative effect that would globally reduce air pollution and GHG in Europe. Besides, higher reduction rates could probably be achieved in larger cities with stronger teleworking potential.

Observed reduction is not impacted by the quality of available fleet data, but this factor however strongly impacts the quantity of estimated emissions (up to +1007.25%), which is the actual key element for accurate health and environmental risk assessment. This plead for the monitoring and the use of fine-scale, high grade, regularly updated data on mobility behaviour and vehicle equipment amongst the different socio-economic statuses in order to better evaluate the efficiency of telework as a long term solution for both urban and climatic issues (O’Brien and Aliabadi, 2020) (Hook et al., 2020).

Proposed methodology, based on simulation, appears to be an interesting alternative. Distances travelled by individuals were simulated with MobiSim-MQ, which is original in its capacity to account for changes in individuals’ behaviour depending on both their socio-economic situation and the dynamic change in the local environment (rush hours, traffic congestion, etc.). This allows spatial and temporal changes to be explored at several levels of analysis, which is useful for testing prospective scenarios representing various urban and regional planning policies. The model remains largely perfectible, but still allows to partially compensate for the lack of precise updated data, and to understand introduced bias. This should, in term, help to guide stakeholder’s choices in the elaboration of public policies that may reduce harmful impacts of transportation on climate and health.

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Table 1. Socio-economic composition of the population in the city of Besançon and in the whole metropolitan area, for the year 2008. Children under 15 are omitted. Data source: INSEE, 2014.

	City of Besançon		**Whole metropolitan area**	
Activities in 2008	**number**	**%**	**number**	**%**
Population 15–64 y.o (workforce)	**82 559**	**82%**	**119 619**	**82%**
Active workforce	55 024	55%	82 386	57%
Clerical workers	13 560	14%	20 634	14%
Middle management and services	13 083	13%	20 582	14%
Manual workers	9 381	9%	14 327	10%
Executive & higher intellectual professions	9 391	9%	13 795	9%
Unemployed	7 653	8%	9 397	6%
Self-employed, retailers, chief executive officers	1 931	2%	3 432	2%
Farmers	25	0%	219	0%
Non-active workforce	27 534	27%	37 233	26%
Students	16 242	16%	20 310	14%
Housewives, househusbands, and disabled	6 357	6%	8 516	6%
Retired	4 935	5%	8 406	6%
Population older than 64 y.o	**17 595**	**18%**	**26 135**	**18%**
Working	368	0%	686	0%
Unemployed	17	0%	53	0%
Retired or disabled	17 210	17%	25 396	17%
Total population aged 15 y.o or more	**100 153**	**100%**	**145 754**	**100%**

Table 2. Activity schedules of the individuals in the simulation. The realization probability and the duration of each activity have been obtained from the statistical analysis of the Local Mobility Survey 2005 for the Besançon metropolitan area. Those survey data also inform us about the probability distribution of the starting time of each activity and the probability distribution of the duration of each activity. From these two distributions, a random draw within MobiSim is used to determine the starting time and the duration of each activity performed by each individual.

Activity	**Priority**	**Population concerned**	**Realization probability**	**Duration**	
				Average	**Standard dev.**
Work, all day	2	Workers	0.2500	8hrs40	1hr30
Work, mornings	3	Workers	0.3825	3hrs30	1hr
Work, afternoons	3	Workers	0.3675	3hrs10	1hr10
Study, all day	2	Students	0.2390	9hrs	1hr40
Study, mornings	3	Students	0.3957	3hrs30	1hr10
Study, afternoons	3	Students	0.3729	2hrs30	1hr20
Job-seeking	2	Unemployed	0.1700	2hrs	1hr40
Child accompaniment	5	Members of a household with children	0.4000	0hr10	0hr10
Shopping, errands	6	Workers and teleworkers	0.7400	0hr40	0hr40
		Non workers, Unemployed, retired	0.6500		
		Students	0.4600		
Leisure, daytime	7	Workers and teleworkers	0.2100	2hrs10	1hr45
		Non workers, unemployed, retired	0.1000		
		Students	0.2300		
		Retired	0.2000		
Leisure, evening	7	All individuals except children	0.1000	2hrs	1hr
Social relations	7	Workers and teleworkers	0.1800	1hr45	1hr40
		Non workers, unemployed	0.1100		
		Students	0.2100		
		Retired	0.2000		

Table 3. Probability of being a teleworker, for an individual working all day in a preliminary simulation, according to activity. Application of national frequencies per activity obtained from the Report on Teleworking in France, edited by the directorate for statistics of the French ministry of employment (DARES 2004).

Type of teleworking	Activity	Probability
Teleworking at home	Executive & higher intellectual professionals	0.097
	Middle management and service professionals	0.023
	Clerical workers	0.009
	Manual workers	0.001
Teleworking outside home	Executive & higher intellectual professionals	0.201
	Middle management and service professionals	0.090
	Clerical workers	0.027
	Manual workers	0.006

Table 4. Vehicle fleet composition for each socio-occupational status in the urban agglomeration of Besançon. Data source: CAGB, 2005.

	Petrol %	Diesel %	LPG & Hybrid %
Population 15–64 y.o (workforce)	**52.6%**	**45.6%**	**1.8%**
Active workforce	55.1%	43.7%	1.2%
Clerical workers	57.0%	43.0%	0.0%
Middle management and services	56.0%	43.0%	1.0%
Manual workers	56.0%	42.0%	2.0%
Executive & higher intellectual professions	57.0%	41.0%	2.0%
Unemployed	49.0%	49.0%	2.0%
Self-employed, retailers, chief executive officers	46.0%	54.0%	0.0%
Farmers	25.0%	63.0%	12.0%
Non-active workforce	47.7%	49.4%	2.9%
Students	38.0%	60.0%	2.0%
Housewives, househusbands, and disabled	66.0%	28.0%	6.0%
Retired	56.0%	42.0%	2.0%
Population older than 64 y.o	**55.9%**	**42.1%**	**2.0%**
Working	49.4%	47.9%	2.7%
Unemployed	49.0%	49.0%	2.0%
Retired or disabled	56.0%	42.0%	2.0%
Total population aged 15 y.o or more	**53.2%**	**45.0%**	**1.8%**

Table 5 : Evolution of the travelled distances (in km) due to an increase in teleworking rate from 7.35% to 13.00%, considering different transport modes and activities.

Trip purpose	Car km	Walking & cycling km	Public Transports km	All modes km
Child accompaniment	-496,2	29,7	-97,0	-563,5
Job-seeking	0,0	0,0	0,0	0,0
Leisure	-725,3	119,0	-72,1	-678,4
Shopping, errands	-612,7	-1,5	-120,6	-734,8
Social relations	44,1	-14,1	-96,9	-66,9
Teleworking from home	0,1	-4,5	240,3	235,9
To Home	-19084,6	324,8	-1740,2	-20500,0
To study place	0,0	0,0	0,0	0,0
To teleworking center	-3246,6	767,4	-4499,7	-6978,9
To workplace	-18994,5	-273,2	-2412,9	-21680,6
All activities	**-43115,7**	**947,5**	**-8799,0**	**-50967,2**

Table 6. Atmospheric pollutant and greenhouse gas emissions calculated for each teleworking scenario and each *vehicle* method.

Scenario	Distances travelled	Vehicle method	Carbon eq.	CO_2	CH_4	N_2O	SO_2	NO_x	NM VOC	CO	NH_3	TSP	As	Cd	Cr	Cu	Hg	Ni	Pb	Se	Zn	PAH	Dioxins & Furans
	km		t	t	kg	kg	kg	kg	kg	kg	kg	kg	g	g	g	g	g	g	g	g	g	g	mg
Balanced	1 851 587	*Identical*	346.05	340.85	35.80	11.42	7.22	407.51	393.41	2 857.17	87.19	78.27	3.80	1.58	3.61	487.96	0.95	4.11	223.08	0.82	910.12	3.98	1.36
7.35%		*Socioprof*	478.92	473.32	36.86	12.60	7.75	1 888.72	400.48	2 884.07	76.77	119.32	4.90	1.65	4.88	621.46	0.97	5.36	199.78	0.97	1 001.52	6.10	3.01
		Individual	661.25	655.57	34.61	13.34	5.79	4 493.88	267.38	2 196.62	22.30	192.13	6.35	1.54	6.92	791.06	0.61	6.99	135.22	1.12	1 054.49	10.16	5.39
Increased	1 808 471	*Identical*	337.81	332.73	34.95	11.15	7.04	397.81	384.05	2 789.16	85.11	76.40	3.71	1.54	3.52	476.34	0.93	4.01	217.76	0.80	888.45	3.88	1.33
13.0%		*Socioprof*	466.42	460.97	35.90	12.27	7.55	1 838.33	390.11	2 809.41	74.79	116.21	4.77	1.61	4.75	605.29	0.94	5.22	194.67	0.94	975.63	5.94	2.93
		Individual	647.51	641.96	33.88	13.04	5.67	4 404.76	261.77	2 150.50	21.79	188.05	6.22	1.51	6.77	774.37	0.60	6.85	131.92	1.09	1 031.36	9.94	5.29

Table 7. Differences in atmospheric pollutant and greenhouse gas emissions between the three *vehicle* methods.

Scenario	Vehicle method	**Carbon eq.**	**CO$_2$**	**CH$_4$**	**N$_2$O**	**SO$_2$**	**NO$_x$**	**NM VOC**	**CO**	**NH$_3$**	**TSP**	**As**	**Cd**	**Cr**	**Cu**	**Hg**	**Ni**	**Pb**	**Se**	**Zn**	**PAH**	**Dioxins & Furans**
	comparison	**t**	**t**	**kg**	**kg**	**kg**	**kg**	**kg**	**kg**	**kg**	**kg**	**g**	**g**	**g**	**g**	**g**	**g**	**g**	**g**	**g**	**g**	**mg**
Balanced 7.35%	*Identical vs. Socio-occ**	+38.40%	+38.87%	+2.95%	+10.29%	+7.40%	+363.48%	+1.80%	+0.94%	-11.95%	+52.45%	+28.79%	+4.37%	+35.18%	+27.36%	+1.18%	+30.38%	-10.44%	+17.37%	+10.04%	+53.32%	+38.40%
	Socio-occ vs. Individual‡	+38.07%	+38.50%	-6.10%	+5.91%	-25.23%	+137.93%	-33.24%	-23.84%	-70.95%	+61.02%	+29.68%	-6.59%	+41.91%	+27.29%	-36.35%	+30.48%	-32.31%	+15.74%	+5.29%	+66.63%	+38.07%
	Identical vs. Individual†	+91.08%	+92.34%	-3.33%	+16.81%	-19.70%	+1002.77%	-32.04%	-23.12%	-74.42%	+145.47%	+67.01%	-2.51%	+91.84%	+62.12%	-35.59%	+70.12%	-39.38%	+35.84%	+15.86%	+155.48%	+91.08%
Increased 13.0%	*Identical vs. Socio-occ**	+38.07%	+38.54%	+2.71%	+10.08%	+7.19%	+362.11%	+1.58%	+0.73%	-12.13%	+52.10%	+28.50%	+4.15%	+34.88%	+27.07%	+0.97%	+30.08%	-10.60%	+17.12%	+9.81%	+52.97%	+120.65%
	Socio-occ vs. Individual‡	+38.83%	+39.26%	-5.62%	+6.28%	-24.86%	+139.61%	-32.90%	-23.45%	-70.87%	+61.82%	+30.33%	-6.25%	+42.56%	+27.93%	-36.05%	+31.15%	-32.24%	+16.26%	+5.71%	+67.34%	+80.64%
	Identical vs. Individual†	+91.68%	+92.94%	-3.06%	+16.98%	-19.45%	+1 007.25%	-31.84%	-22.90%	-74.40%	+146.12%	+67.47%	-2.36%	+92.29%	+62.57%	-35.43%	+70.61%	-39.42%	+36.15%	+16.09%	+155.99%	+298.58%

*comparison obtained by subtracting the emissions calculated with the identical vehicle method from those obtained with the socio-occupational vehicle method

†comparison obtained by subtracting the emissions calculated with the identical vehicle method from those obtained with the individual vehicle method

‡comparison obtained by subtracting the emissions calculated with the socio-occupational vehicle method from those obtained with the individual vehicle method

Table 8. Differences in atmospheric pollutant and greenhouse gas emissions between the "*increased*" and the "*balanced*" scenarios.

Vehicle method	**Travelled distances**	**Carbon eq.**	**CO$_2$**	**CH$_4$**	**N$_2$O**	**SO$_2$**	**NO$_x$**	**NM VOC**	**CO**	**NH$_3$**	**TSP**	**As**	**Cd**	**Cr**	**Cu**	**Hg**	**Ni**	**Pb**	**Se**	**Zn**	**PAH**	**Dioxins & Furans**	**Average**
	km	**t**	**t**	**kg**	**kg**	**kg**	**kg**	**kg**	**kg**	**kg**	**kg**	**g**	**g**	**g**	**g**	**g**	**g**	**g**	**g**	**g**	**g**	**mg**	
Identical vehicle	-2.33%	-2.55%	-2.55%	-2.55%	-2.55%	-2.55%	-2.55%	-2.55%	-2.55%	-2.55%	-2.55%	-2.55%	-2.55%	-2.55%	-2.55%	-2.55%	-2.55%	-2.55%	-2.55%	-2.55%	-2.55%	-2.55%	-2.55%
Socio-occupational vehicle	-2.33%	-2.61%	-2.61%	-2.61%	-2.57%	-2.57%	-2.67%	-2.59%	-2.59%	-2.57%	-2.61%	-2.60%	-2.58%	-2.60%	-2.60%	-2.59%	-2.60%	-2.56%	-2.59%	-2.59%	-2.60%	-2.65%	-2.60%
Individual vehicle	-2.33%	-2.08%	-2.08%	-2.10%	-2.24%	-2.08%	-1.98%	-2.10%	-2.10%	-2.30%	-2.12%	-2.11%	-2.22%	-2.15%	-2.11%	-2.13%	-2.10%	-2.45%	-2.16%	-2.19%	-2.19%	-1.97%	-2.14%

Appendix A: Information and data used for the simulation with MobiSim, and for pollutant emission computation.

Required information	Data sources
City configuration	
Buildings (*polygons*)	BD Topo® IGN, 2010
Road and path network (*lines*)	BD Topo® IGN, 2010
Shops and services; schools; places of employment; leisure locations (*points*)	BD SIRENE INSEE, 2012
Public transport stations (*points*): buses, trams, and regional trains	Entered manually from plans supplied by the Community Services of the Urban agglomeration of Besançon
Population	
Sociodemographic data on individuals, households, and housing	INSEE, 2009 population census
Teleworking	
Number of teleworkers per activity in each municipality of the agglomeration	Computed from DILA, 2010 Annual Social Declaration Database and DARES, 2004 Report on Telework in France
Mobility	
Public transport timetables	Entered manually from bus, tram and regional train documents provided by transport authorities (Ginko bus services, French National Railway Company (SNCF))
Functional characteristics of road sections (capacity, speed limit, direction of travel, bends, gradients)	Entered manually and GIS calculations

Appendix B. Composition of the French national vehicle fleet by car technology, and associated pollutant emission factors.

Subsector	Technology	% in the 2009	CO_2‡ g/km	CH_4‡ mg/	N_2O† mg/	SO_2‡ mg/	NOx† mg/	NM VOC† mg/	CO† mg/	NH_3† mg/	TSP‡ mg/	As‡ µg/	Cd‡ µg/	Cr‡ µg/	Cu‡ µg/	Hg‡ µg/	Ni‡ µg/	Pb† g/	Se‡ µg/	Zn‡ µg/	PAH‡ µg/	Dioxins & pg/km
Petrol 0.8-1.4 l	ECE 15/00-01	0.16	170,0	30,0	10,0	1,2	1910,	2190,	29600,	2,0	38,7	1,9	0,8	1,8	249,5	0,5	2,1	0,0	0,4	465,0	1,9	0,7
Petrol 0.8-1.4 l	ECE 15/02	0.07	170,0	30,0	10,0	1,2	2120,	2060,	21700,	2,0	38,7	1,9	0,8	1,8	249,5	0,5	2,1	0,0	0,4	465,0	1,9	0,7
Petrol 0.8-1.4 l	ECE 15/03	0.43	170,0	30,0	10,0	1,2	2300,	2060,	21100,	2,0	38,7	1,9	0,8	1,8	249,5	0,5	2,1	0,0	0,4	465,0	1,9	0,7
Petrol 0.8-1.4 l	ECE 15/04	4.53	170,0	30,0	10,0	1,2	2070,	1680,	13100,	2,0	38,7	1,9	0,8	1,8	249,5	0,5	2,1	0,0	0,4	465,0	1,9	0,7
Petrol 0.8-1.4 l	Open Loop	0.00	170.0	30.0	10.0	1.2	1530.	960.0	11300.	2.0	38.7	1.9	0.8	1.8	249.5	0.5	2.1	0.0	0.4	465.0	1.9	0.7
Petrol 0.8-1.4 l	PC Euro 1 -	6.24	170.0	30.0	10.0	1.2	426.0	467.0	4880.0	92.2	38.7	1.9	0.8	1.8	249.5	0.5	2.1	0.0	0.4	465.0	1.9	0.7
Petrol 0.8-1.4 l	PC Euro 2 - 94/12/EEC	7.47	170.0	30.0	6.0	1.2	229.0	206.0	2420.0	104.3	38.7	1.9	0.8	1.8	249.5	0.5	2.1	0.0	0.4	465.0	1.9	0.7
Petrol 0.8-1.4 l	PC Euro 3 - 98/69/EC I	8.03	170.0	30.0	2.0	1.2	90.0	89.0	2070.0	34.2	38.7	1.9	0.8	1.8	249.5	0.5	2.1	0.0	0.4	465.0	1.9	0.7
Petrol 0.8-1.4 l	PC Euro 4 - 98/69/EC II	5.99	170.0	30.0	2.0	1.2	56.0	48.0	690.0	34.1	38.7	1.9	0.8	1.8	249.5	0.5	2.1	0.0	0.4	465.0	1.9	0.7
Petrol 1.4 - 2.0 l	PRE ECE	0.00	170.0	30.0	10.0	1.2	2530.	2800.	37300.	2.0	38.7	1.9	0.8	1.8	249.5	0.5	2.1	0.0	0.4	465.0	1.9	0.7
Petrol 1.4 - 2.0 l	ECE 15/00-01	0.03	170.0	30.0	10.0	1.2	2530.	2190.	29600.	2.0	38.7	1.9	0.8	1.8	249.5	0.5	2.1	0.0	0.4	465.0	1.9	0.7
Petrol 1.4 - 2.0 l	ECE 15/02	0.01	170.0	30.0	10.0	1.2	2400.	2060.	21700.	2.0	38.7	1.9	0.8	1.8	249.5	0.5	2.1	0.0	0.4	465.0	1.9	0.7
Petrol 1.4 - 2.0 l	ECE 15/03	0.11	170.0	30.0	10.0	1.2	2510.	2060.	21100.	2.0	38.7	1.9	0.8	1.8	249.5	0.5	2.1	0.0	0.4	465.0	1.9	0.7
Petrol 1.4 - 2.0 l	ECE 15/04	1.92	170.0	30.0	10.0	1.2	2660.	1680.	13400.	2.0	38.7	1.9	0.8	1.8	249.5	0.5	2.1	0.0	0.4	465.0	1.9	0.7
Petrol 1.4 - 2.0 l	PC Euro 1 -	2.37	170.0	30.0	10.0	1.2	485.0	530.0	3920.0	92.2	38.7	1.9	0.8	1.8	249.5	0.5	2.1	0.0	0.4	465.0	1.9	0.7
Petrol 1.4 - 2.0 l	PC Euro 2 - 94/12/EEC	2.64	170.0	30.0	6.0	1.2	255.0	251.0	2040.0	104.3	38.7	1.9	0.8	1.8	249.5	0.5	2.1	0.0	0.4	465.0	1.9	0.7
Petrol 1.4 - 2.0 l	PC Euro 3 - 98/69/EC I	4.26	170.0	30.0	2.0	1.2	97.0	119.0	1820.0	34.2	38.7	1.9	0.8	1.8	249.5	0.5	2.1	0.0	0.4	465.0	1.9	0.7
Petrol 1.4 - 2.0 l	PC Euro 4 - 98/69/EC II	3.32	170.0	30.0	2.0	1.2	61.0	65.0	624.0	34.2	38.7	1.9	0.8	1.8	249.5	0.5	2.1	0.0	0.4	465.0	1.9	0.7
Petrol >2.0 l	ECE 15/00-01	0.02	170.0	30.0	10.0	1.2	3900.	2190.	29600.	2.0	38.7	1.9	0.8	1.8	249.5	0.5	2.1	0.0	0.4	465.0	1.9	0.7
Petrol >2.0 l	ECE 15/02	0.02	170.0	30.0	10.0	1.2	2700.	2100.	21700.	2.0	38.7	1.9	0.8	1.8	249.5	0.5	2.1	0.0	0.4	465.0	1.9	0.7
Petrol >2.0 l	ECE 15/03	0.07	170.0	30.0	10.0	1.2	3520.	2100.	21100.	2.0	38.7	1.9	0.8	1.8	249.5	0.5	2.1	0.0	0.4	465.0	1.9	0.7
Petrol >2.0 l	ECE 15/04	0.10	170.0	30.0	10.0	1.2	2900.	1679.	13400.	2.0	38.7	1.9	0.8	1.8	249.5	0.5	2.1	0.0	0.4	465.0	1.9	0.7
Petrol >2.0 l	PC Euro 1 -	0.43	170.0	30.0	11.0	1.2	467.0	430.0	3410.0	92.2	38.7	1.9	0.8	1.8	249.5	0.5	2.1	0.0	0.4	465.0	1.9	0.7
Petrol >2.0 l	PC Euro 2 - 94/12/EEC	0.20	170.0	30.0	6.0	1.2	242.0	196.0	1670.0	104.3	38.7	1.9	0.8	1.8	249.5	0.5	2.1	0.0	0.4	465.0	1.9	0.7
Petrol >2.0 l	PC Euro 3 - 98/69/EC I	0.42	170.0	30.0	2.0	1.2	91.0	88.0	1500.0	34.2	38.7	1.9	0.8	1.8	249.5	0.5	2.1	0.0	0.4	465.0	1.9	0.7
Petrol >2.0 l	PC Euro 4 - 98/69/EC II	0.40	170.0	30.0	2.0	1.2	59.0	48.0	534.0	34.3	38.7	1.9	0.8	1.8	249.5	0.5	2.1	0.0	0.4	465.0	1.9	0.7
Diesel 1.4 -2.0 l	Conventional	0.85	159.0	1.5	0.0	1.1	546.0	159.0	688.0	1.0	75.0	1.9	0.7	3.0	231.5	0.1	2.0	0.0	0.4	442.0	5.7	0.5
Diesel 1.4 -2.0 l	PC Euro 1 -	3.64	159.0	1.5	3.0	1.1	690.0	47.0	414.0	1.0	75.0	1.9	0.7	3.0	231.5	0.1	2.0	0.0	0.4	442.0	5.7	0.5
Diesel 1.4 -2.0 l	PC Euro 2 - 94/12/EEC	4.17	159.0	1.5	5.0	1.1	716.0	35.0	296.0	1.0	75.0	1.9	0.7	3.0	231.5	0.1	2.0	0.0	0.4	442.0	5.7	0.5
Diesel 1.4 -2.0 l	PC Euro 3 - 98/69/EC I	14.44	159.0	1.5	7.0	1.1	773.0	20.0	89.0	1.0	75.0	1.9	0.7	3.0	231.5	0.1	2.0	0.0	0.4	442.0	5.7	0.5
Diesel 1.4 -2.0 l	PC Euro 4 - 98/69/EC II	17.35	159.0	1.5	10.0	1.1	582.0	14.0	92.0	1.0	75.0	1.9	0.7	3.0	231.5	0.1	2.0	0.0	0.4	442.0	5.7	0.5
Diesel >2.0 l	Conventional	1.01	159.0	1.5	0.0	1.1	870.0	159.0	688.0	1.0	75.0	1.9	0.7	3.0	231.5	0.1	2.0	0.0	0.4	442.0	5.7	0.5
Diesel >2.0 l	PC Euro 1 -	1.29	159.0	1.5	3.0	1.1	690.0	70.0	414.0	1.0	75.0	1.9	0.7	3.0	231.5	0.1	2.0	0.0	0.4	442.0	5.7	0.5
Diesel >2.0 l	PC Euro 2 - 94/12/EEC	1.63	159.0	1.5	5.0	1.1	716.0	100.0	296.0	1.0	75.0	1.9	0.7	3.0	231.5	0.1	2.0	0.0	0.4	442.0	5.7	0.5
Diesel >2.0 l	PC Euro 3 - 98/69/EC I	3.25	159.0	1.5	10.0	1.1	770.0	37.0	89.0	1.0	75.0	1.9	0.7	3.0	231.5	0.1	2.0	0.0	0.4	442.0	5.7	0.5
Diesel >2.0 l	PC Euro 4 - 98/69/EC II	2.60	159.0	1.5	10.0	1.1	582.0	14.0	92.0	1.0	75.0	1.9	0.7	3.0	231.5	0.1	2.0	0.0	0.4	442.0	5.7	0.5
LPG	Conventional	0.01	178.0	9.6	0.0	5.9	2360.	1050.	6832.0	2.0	36.0	1.9	0.7	1.5	247.2	0.0	2.0	0.0	0.4	460.0	0.5	0.0
LPG	PC Euro 1 -	0.01	178.0	9.6	20.0	5.9	414.0	723.0	3570.0	88.0	36.0	1.9	0.7	1.5	247.2	0.0	2.0	0.0	0.4	460.0	0.5	0.0
LPG	PC Euro 2 - 94/12/EEC	0.02	178.0	9.6	8.0	5.9	180.0	342.0	2480.0	100.7	36.0	1.9	0.7	1.5	247.2	0.0	2.0	0.0	0.4	460.0	0.5	0.0
LPG	PC Euro 3 - 98/69/EC I	0.27	178.0	9.6	4.0	5.9	90.0	120.0	1790.0	33.8	36.0	1.9	0.7	1.5	247.2	0.0	2.0	0.0	0.4	460.0	0.5	0.0
LPG	PC Euro 4 - 98/69/EC II	0.20	178.0	9.6	4.0	5.9	56.0	100.0	620.0	33.8	36.0	1.9	0.7	1.5	247.2	0.0	2.0	0.0	0.4	460.0	0.5	0.0

Data sources: *CETE Normandie Centre, 2010. COPCETE v3; † EME./EEA, 2013 Air pollutant emission inventory guidebook; ‡ CITEPA., 2013 Rapport OMINEA (Methods and Organisation for National Atmospheric emission Inventory): Inventaire des émissions de polluants atmosphériques et de gaz à effets de serre en