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An identification of models to help in the design of national strategies and policies to reduce greenhouse gas emissions.

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Abstract

In response to the rapid increase in global greenhouse gas (GHG) emissions, 196 countries have made a legal commitment to implement a strategy to decarbonize their economies, under the Paris Agreement, particularly with respect to the transportation sector. As part of their long-term climate actions, these countries are defining various *Avoid/Reduce*, *Shift* and *Improve* (A-S-I) strategies, aimed at reducing or avoiding unnecessary travel, promoting and shifting to public transport and active modes, and improving energy efficiency and vehicle technology. In this paper, we take a closer look at some of the regional and national strategies and policies to reduce GHG emissions in Europe, as well as the models and methods used to assist in policy development. Keeping in mind the limited guidance on concrete avoidance/reduction and transfer strategies mentioned in the climate actions, we list some of the land use and transport interaction (LUTI) models that can be used to improve climate change control at the urban scale. The aim of this paper is to gain a better understanding of how methods and tools can assist in decision making and policy development with respect to GHG emission reduction goals in the transportation sector.

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1. **Introduction**

Transportation is considered to be the fastest-growing sector in terms of GHG emissions (Georgatzi *et al.,* 2020); global greenhouse gas (GHG) emissions associated with the transport sector have been increasing rapidly worldwide, in association with accelerated urbanization, rising household income, and increasing energy consumption (Creutzig, 2016; Gota et al., 2018; Lamb *et al.*, 2021). Data from the International Energy Agency (IEA) show that 37% of GHG emissions from end-use sectors can be attributed to the transportation sector, which is associated with about 60% of total oil demand and uses about 90% oil derived products (liquid fuels or natural gas) as its final energy - with an additional smaller share (4%) from biofuels (IEA, 2022). Within this sector, road transport contributes to a great share of all transported related GHG emissions (Zhang and Fujimori, 2020), but its dependence on oil makes it the main contributor to continued and increasing CO_2 emissions and the resulting global warming (Peters *et al.*, 2020). In Europe, road transport also represents more than 70% of total emissions from the transport sector (Ovaere and Proost, 2022). Although during the COVID-19 pandemic global CO_2 emissions have reduced, they rebound in 2022 to 2019 levels (IEA, 2022).

Public and political concern with the effects of global warming, such as rising sea levels, increased extreme weather events, and impacts on biological diversity, has led to increased action to address these issues on a global scale. To combat climate change, the Kyoto Protocol was proposed as the first environmental treaty setting binding emission reduction targets for developed countries (UNFCCC, 1997), then entirely replaced by the Paris Agreement. Adopted in 2015, by 196 parties, the Paris Agreement is a legally binding international treaty on climate change aimed at achieving a long-term global warming temperature goal (to keep average temperature below 2ºC in relation to pre-industrial levels), through a 5-year cycle of climate actions (UNFCCC, 2016). At the heart of the Agreement are the so-called nationally determined contributions (NDCs) and long-term low GHG emission development strategies (LT-LEDS), submitted by each signatory country, which outline short and long-term climate actions to reduce GHG emissions and build resilience to rising temperatures.

Given the increasing contribution of the transportation sector to these emissions, actions to reduce emissions in this sector should be at the core of these NDCs, but only a small percentage of countries have specific GHG emission reduction targets for the transport sector. Most of the efforts are directed to passenger transport, with a minor share devoted to active modes, such as cycling and walking, and freight transport being relatively neglected in NDCs (Huizenga and Peet, 2017). Although freight transport accounts for 40% of the total CO_2 emissions in the transport sector, only a quarter of the currently submitted NDCs address this activity (Changing transport, 2022). Among these efforts, widespread electrification of passenger transportation has been identified as one of the key strategies for reducing GHGs from road transportation. This was particularly noticeable in 2020-2021, during the COVID-19 pandemic, where electric car sales increased by more than 40%, despite the decline in the global passenger vehicle sales, following multiple tax incentives and the increase in related infrastructure, e.g., availability of charging stations (IEA, 2022). The global COVID-19 pandemic restrictions led to a substantial decline in passenger and commercial vehicle travel, the largest since World War II (Stoll and Mehling, 2020), and a consequent reduction in global transportation CO_2 emissions of approximately 10% from 2019 levels (Forster *et al.*, 2020; Gensheimer *et al.*, 2021; Nguyen *et al.*, 2021). Changes in road transport accounted for half of the decrease in CO_2 emissions during confinement (Le Quéré *et al.,* 2020). The main drivers of this decline have been government policies that have impacted energy demand patterns, and the resulting disruptions in the global supply chain, with a slowdown in the flow of goods and services and changes in passenger mobility patterns, both domestic and international (Mathieu *et al.* 2020). The changes during this period also demonstrated the impact of local policies on changes in society's behavior regarding the use of transportation modes, i.e., reduced need to travel and decrease in the use of private vehicles. However, as these changes did not reflect structural changes in various economic sectors, including energy and transportation, with the lifting of the pandemic-related restrictions, this trend was quickly reversed and the growth trend resumed (Le Quéré *et al.,* 2020; IEA, 2022).

Although ambitious long-term carbon neutrality targets have been set at global level (2050-2070), the so-called neutrality targets, it is important to consider their implications at the national, regional, or local level (van Soest *et al.* 2021). In principle, most cities and regions have no legal obligation to reduce CO_2 emissions (Mueller and Reutter, 2022). In addition, planning desirable transport futures is complex and requires a good understanding of different interrelated aspects, such as societal and economic aspects, the energy mix, available technologies, and political, legal, and environmental policies, at multiple scales. It also requires understanding and anticipating local and regional transformative changes, including changes in individual and collective behavior (Creutzig, 2016), which have also proved crucial during the pandemic. Some of these future scenarios, emission reduction strategies and policies are developed using a variety of methods and tools, considering nested aspects at different scales. Without these methods and tools, the definition of emission targets may remain vague, leading to less cost-effective solutions in the long run.

The aim of this paper is to shed light on some of the key models used to develop baseline scenarios to define GHG emission reduction targets in Europe. First, we conduct a review on the main strategies used to curb GHG emissions by different countries. We then review existing continental or country-specific models to understand the measures taken by these countries at the national level, as well as the baseline scenarios, methods and tools applied to build national policies and strategies. Our ultimate goal is to understand how these models have been used to define GHG reduction targets in the transport sector and integrate this knowledge to enhance our methodology.

2. Strategies to reduce GHG emissions from transportation

Several strategies and policy instruments have been explored and implemented to address the impacts of transport on a changing climate, ranging from improving engine efficiency to introducing low-carbon fuels to reducing vehicle miles traveled (Andress *et al.*, 2011). In this paper, we discuss these different strategies based on the approach *Avoid/reduce, Shift, and Improve* (A-S-I), developed in the 90s to structure the development of policies to reduce GHG emissions from transportation and in response to the traditional strategy of acting on the supply side of transport to meet growth in demand (Bongardt *et al.*, 2019). In short, the A-S-I approach proposes, among other things, to influence demand by encouraging a change in user behavior through better land-use planning and increased choice of transportation modes, so that users adopt travel habits that favor more sustainable modes. It is therefore consistent with the goals of reducing GHG emissions, energy consumption and congestion.

The *Avoid/Reduce* component aims to improve the efficiency of the transportation system, all in all, by reducing or avoiding unnecessary travel, *i.e.,* the distance and number of trips. This is usually done by addressing issues related to urban planning (e.g., increase in the density of cities and development along public transit routes), transport service provision, and demand management. The *Shift* component focuses on shifting to more efficient or environmentally friendly alternatives (e.g., from cars to public or active modes of transportation, or from trucks to rail transportation), while providing the corresponding transport infrastructure, including safe bicycle lanes, and offering a variety of services, at an adequate frequency. Both *Avoid/Reduce* and *Shift* components rely primarily on behavioral and infrastructure changes and are generally considered by countries with more ambitious emission reduction targets (Gota *et al.*, 2018). Finally, the *Improve* component focuses on optimizing transportation infrastructure, vehicles and energy efficiency, and the operational efficiency of transport. Overall, the main measures are associated with the electrification of light and heavy vehicles and improved fuel efficiency (e.g., increasing the share of biofuels in the energy mix).

While recent strategies have relied primarily on technological changes or increased efficiencies, there is a growing understanding that a more complex system transformation is needed to achieve more sustainable and desired transport futures (Gössling *et al.*, 2018). Indeed, among all NDCs submitted under the Paris Agreement, 53% consider *Improve* measures alone, while *Avoid/Reduce* and *Shift* measures are considered, respectively, in 8% and 19% of NDCs. *Avoid/Reduce* and *Shift* measures are considered together in 8% of NDCs, while *Shift* and I*mprove* measures are considered together in 10% of the NDCs. Finally, all three measures are considered integrated in only 2% of NDCs (Changing Transport, 2022). Therefore, achieving decarbonization of the transportation sector, and consequently reducing its contribution to GHG emissions, will rely on an integrated combination of these three components (Gota *et al.*, 2018). For instance, in the province of Québec, in Canada, such an approach has been formally considered in the development of GHG emission reduction measures for 2030 and 2050 (MTMD, 2018). In Quebec, the work of the *Chair in Transportation Transformation* (orig. "*Chaire en transformation du transport*"), a cooperative effort between researchers at the University of Montreal and Polytechnique Montreal, uses such an approach to support government and companies' efforts to choose more integrated and cost-effective approaches to reducing GHG emissions.

2.1. The Avoid/Reduce measures

Avoid and *Reduce* measures have been mainly achieved through (a) land use and transportation policies, such as the introduction of carbon tax, (b) the reduction of travel distances, through optimized routing and increased occupancy rates, and (c) reduced trip frequencies. They include so-called "push" strategies to reduce or avoid car use, such as increased parking fees, regional tolls, and zones with specific speed limits that discourage private vehicle use (Batty *et al.*, 2015). In association with "pull" strategies, such as improved and more frequent public transport services, they may lead to a modal shift towards more sustainable means of transport, discussed further below in this article. Integrated urban planning and redevelopment, a focus on more compact urban forms, transit-oriented development, and investments in new infrastructure, such as high-speed rail systems, have also shown to encourage modal shift, including cycling and walking (IPCC, 2014).

The effectiveness of *Avoid* and *Reduce* measures requires a change in mindset, i.e., it is closely linked to changes in society's individual and collective behavior towards transportation (Ewing and Cervero, 2010; Ewing and Hamidi, 2015). As such, they are also more effectively applied at the local level, in line with the need to create more resilient and sustainable cities (UN, 2017; UN, 2022). Indeed, cities and their complex and dynamic nature have been identified as key agents in achieving sustainability goals when it comes to sustainable mobility. The shape of cities and their structure dictate the density of shared space and the activities within the city, determining the mobility of people and goods (Creutzig *et al.*, 2015). Research shows that small-scale population concentration and employment-housing balance, along with higher population density, can significantly reduce car travel and CO_2 emissions. However, accounting for GHG emissions in cities is not an easy task: they have significant indirect and variable carbon flows across administrative and urban boundaries, which has important policy implications (Dhakal, 2010). Implementing behavioral change is a challenge on the road to reducing emissions from the transportation sector (Lamb *et al*., 2021). Due to the difficulty of implementing behavioral changes, GHG mitigation has been primarily addressed through *Improve* measures. However, it is recognized that it is important to complement these with *Avoid* and/or *Shift* measures, which aim to orient user behavior towards cleaner, less GHG-emitting modes of transportation. Sun *et al.* (2021) demonstrate that emissions can be significantly reduced by more restrictive policies, such as those that encourage eco-driving, control motor vehicle use, and encourage transportation infrastructure development.

2.2. The Shift measures

Modal shift is considered an important option to reduce CO_2 emissions in dense urban areas and includes a shift to (a) public transport, (b) active modes of transport (e.g., cycling and walking), (c) car-pooling, and (d) ridesharing. As noted above, in combination with incentives that discourage or prevent car use, modal shift is encouraged by improved quality and attractiveness of public transport services and infrastructure. Public transport is one of the key tools to address sustainable mobility (Miller *et al.*, 2016). For freight transport, this includes a shift to cargo bikes and rail transport, as well as an improvement of transport infrastructure services. The latter comprises better interoperability with railway and an improved capacity of multimodal terminals (Pfoser, 2022).

Several studies addressed the importance of modal shift in reducing CO_2 emissions. McQueen *et al.* (2020) evaluated the potential for modal-shift from private vehicles to electric bikes in Portland, showing a reduction of 225 kg CO_2 per year, besides other benefits, such as improved human well-being and reduced urban noise. In their study they considered the upstream electricity generation required to charge these bikes. They concluded that the effectiveness of this technology in rural versus urban areas depends on travel distances and available infrastructure, i.e., in European countries these electric bikes would be more effective in rural areas, such as shown by Winslott, Hiselius and Svensson (2017), whereas in countries such as United States, their effectiveness is better proven in urban areas (MacArthur *et al.*, 2017). In the Netherlands, Sun *et al.* (2020) reported that the use of e-bikes leads to a reduction in the use of cars and conventional bikes, for short travel distances and in less dense areas.

Car-sharing schemes have been applied as a measure to induce a behavioral shift from private ownership and use of vehicles towards shared use of vehicles. A study by Amatuni *et al.* (2020) examined the impact of carpooling-induced modal shift on annual urban mobility related GHG emissions, while comparing emissions from private vehicle use with those from three carpooling scenarios in two North American and one European city. They concluded that the reduction in emissions (3-18%) is lower than most previous studies reported (37-50%), due to the rebound effects related to increased use of public transportation modes, such as bus or train, and the consideration of shared vehicle lifetime effect. Regarding the latter, they suggest that with the same passenger kilometer traveled distance, a better option would be to use ride-sharing schemes.

The degree of the effectiveness of *Shift* measures to achieve CO_2 emission reduction targets is still subject to debate. A better understanding of its interactions with other measures, such as land use planning, as well as its use as a targeted approach is needed to increase its application in urban areas (Müller and Reutter, 2022). In addition, it is important to understand the social, economic, and political local and regional context, recognizing user's behavior and needs (Batty *et al.*, 2015). More advanced transport models are needed to explore the full potential of interdependencies between existing policies and A-S-I measures (Müller and Reutter, 2022) and their effects on GHG emissions, but also on other issues, such as human health. The application of circular economy concepts may act in support of best practices in the transport sector (De Abreu *et al.*, 2022).

2.3. The Improve measures

Efforts to reduce GHG emissions from the transportation sector have relied heavily on *Improve* measures, i.e., on technology-oriented strategies, including the vehicle performance and fuel efficiency improvements, and the employment of digital technologies. Some authors argue that a shift to zero-carbon sources must be accompanied by the decarbonization of the energy sector (Zhang and Fujimori, 2020) and a complete shift away from fossil fuels (Jackson *et al.,* 2019). The transition towards more renewable energy systems remains challenging, as it demands economic costs, social changes, and resource availability (Bogdanov et al., 2019).

The electrification of vehicles, i.e., the shift from traditional internal combustion engines to electric vehicles, has been employed as one of the most promising strategies to reduce GHG emissions and increase conversion efficiencies (Zhang and Fujimori, 2020). During the COVID-19 pandemic, although the global sales of passenger vehicles have dropped, the same trend was not observed for electric cars, whose sales increased by more than 40%, but with a continuous shift to larger vehicles, such as SUVs: in 2021, the sales of electric vehicles doubled, in relation to 2020 (IEA, 2022). Indeed, data from the International Energy Agency indicates that the sales of electric cars has reached a record high in 2021, most sales concentrated in Europe and China (85%), with a lower share in the United States (10%) (IEA, 2022). In the latter, electrification of the vehicle fleet is one of the core strategies adopted by the government, thanks to battery improvements that researchers believe will reduce GHGs in 2050 by about 50% compared to 2020. The growing global trend towards electric vehicles is primarily supported by policy measures, such as government subsidies and incentives, as well as the development of necessary infrastructure, such as charging stations.

However, various factors can compromise the effectiveness of this solution in reducing GHGs emissions, such as the cost of this technology, battery weight, battery charging patterns, and available infrastructure. Firstly, the energy sources used for the electricity generation system and, therefore, the upstream emissions resulting from the production of this electricity needed to charge the batteries, is a key aspect to consider (Fernandez *et al*., 2019), as the efficiency in reducing GHG emissions depends on a country's carbon intensity of the electricity mix (Paltsev *et al.*, 2021). In this context, life cycle analysis is an important tool to be considered to accurately measure the contributions of vehicle electrification (Ou *et al.*, 2022). Second, it is important to consider the cost of batteries and charging infrastructure, as well as the scarcity of natural resources (Ou *et al.*, 2022). Indeed, the mass introduction of electric vehicles has been criticized because of potential rebound effects, unsustainable use of critical raw materials, and their definite contribution to overall urban sustainability (Müller and Reutter, 2022). A recently published report lays out a roadmap suggesting the use of hydrogen and hydrogen-based fuels vehicles in long-distance transport, as well as strong investment in clean energy for power generation and increased battery manufacturing capacity (IEA, 2022). Finally, a study conducted by Bueno (2012), concludes that the electrification of transport will not be effective if not accompanied by a densification of vehicle occupancy and a reduction in mobility in absolute terms.

3. GHG emission reduction policies for transportation

Following the Paris Agreement (UNFCCC, 2016), a range of different A-S-I measures have been put in place by governments around the world to tackle climate change, at local, regional, and national level. In this section, we identify the A-S-I approaches adopted in some European countries and how these measures are reflected in practical means, i.e. those that can be easily quantified, or simply presented generically.

In Europe, where transport is responsible for nearly 25% of total GHG emissions (De Angelis, *et al.* 2020), of which 71.7% is due to road transport (Pfoser, 2022), these measures include increasing the share of low- and zero-emission vehicles and alternative low-emission energy sources, and increasing the efficiency of the transport system, for example, through the implementation of smart mobility technologies and the multimodal passenger transport. The

European automotive industry is responsible for more than 7% of the EU's gross domestic product and for the creation of more than 6.5% of the jobs in Europe. The adoption of the European Green Deal communication (EC, 2019) and the recent adoption of the EU Strategic agendas for 2019-2024 (European Council, 2019) and 2025-2027 (EC-DGRI, 2024), aiming at a more socially fair, economically strong, and climate-neutral Europe are some of the strategies guiding actions towards the aimed reduction of GHG emissions in that continent. More recently, the European Commission has developed a package of legislative proposals for a green transition, entitled ***Fit for 55***, which revises and updates European Union legislation to reduce net GHG emissions by at least 55% by 2030 (below 1990 levels), focusing, among other things, on improving the health and well-being of citizens, increasing economic benefits for consumers, and strengthening competitiveness for the EU's automotive industry (European Council, 2022). For the transport sector, which is not covered by the EU Emissions Trading System, this reduction target is 40% and 13% compared, respectively, to 2005 and 2019 emission levels (EC, 2022). The proposed measures include, among others, the reduction of CO_2 emission targets for passenger cars and vans, which are responsible, respectively, for 12% and 2.5% (*i.e.,* for around 15%) of total EU emissions of CO_2 and, respectively, 44% and 9% of total road transport emissions (Ovaere and Proost, 2022). Alongside the tightening of CO_2 emission standards for new vehicles and the communication on 2030 Climate Ambition, Europe has also revised in 2021 the Alternative Fuels Infrastructure regulation (former EU Directive 2014/94), setting out a more detailed and binding methodology for the adoption of measures to facilitate a broad transition to zero-emission vehicles, such as increased and sufficient recharging stations (EU Communication COM/2021/559 final). The elements in this Directive are also in synergy with the Renewable Energy Directive (EU Directive 2018/2001), amended in 2021 (EU Communication COM/2021/557 final), which set obligations regarding the share of zero- and low-carbon sources of fuels in the transportation sector (e.g., a 13% increase in the target for the share of renewable fuels by 2030).

Under the European Climate Law, which regulates the goals set out by Europe in its Green Deal, each country sets their long-term energy and climate plans for 2030/2050, with specific strtategies and measures (Table 1). ***Germany***, in its Climate Action Plan 2050 (BMUB, 2016), outlines strategies to reduce GHG emissions from cars, light-duty and heavy-duty commercial vehicles, by 2030. In Germany, about 95.5% of the transport sector is based on fossil fuels, such as oil and gas (Table 2), except for rail transport, which is highly electrified. The transport sector contributes to 30% of the total energy consumption in Germany. The country aims to reduce the transport related GHG emissions in 2030 by 40-42% below 1990 levels, which were around 163 $MtCO_2eq$ (18% of Germany's total GHG emissions). Given the projected increase in vehicle kilometers by 2030 of 10% for passenger cars and 28% for heavy-duty vehicles (BMVI, 2016), Germany sets a benchmark for (a) alternative fuel vehicles, especially with the introduction of 15 million electric passenger cars by 2030, which would result in a budget of 52 $MtCO_2eq$ for passenger transport, (b) underlying infrastructure, and (c) a shift to carbon-neutral electricity generation (i.e., electricity generation based on renewable energy). However, the achievement of the above budget has been criticized in a recent study, which instead indicates a passenger transport budget of 64 $MtCO_2eq$ (Koska and Jansen, 2022). Reshaping and integrating the urban environment, implementing smart public transport networks and mobility services, and improving digitalization are also important points in the Action Plan, although the *Improve* measures mentioned earlier are at the heart of the Action Plan. Germany recognizes the need to develop smart and automated networks, remodel the urban environment, and improve infrastructure to promote modal shift. However, the Action Plan does not provide much detail on intermodal integration for passenger transport and how the government intends to increase the volume of rail passenger transport (BMUB, 2016). The largest share of passenger transport is concentrated in cars and motorized two-wheelers (76%), and it is not clear how integration or shift to other modes should be improved in the future. For freight transport, a 25% modal split share of rail freight is foreseen, but policy instruments for achieving this target are not detailed in the Action Plan. In the long-term, Germany recognizes the need to stimulate the development of new technologies, to shift away from fossil fuels.

France, through its National Low Carbon Strategy (SNBC), presents improving vehicle efficiency and increasing the share of electric vehicles (i.e., 35% of new electric vehicles and 10% plug-in hybrid vehicles in 2030), as well as the corresponding infrastructure as the main actions to achieve the emission reduction targets (Ministère de la transition écologique et solidaire, 2020). The country aims to reduce GHG emissions from the transport sector by 19% by 2030, below 1990 levels, which were around 122 $MtCO_2eq$ (30% of France's total GHG emissions), more than half due to private vehicles. The development of the national strategy considers a baseline scenario, developed through a modeling exercise that considers existing technologies. The GHG emission reduction guidelines contained in the SNBC are not prescriptive and provide recommendations for potentially achieving reduction objectives. France also plans to increase investment in the modal share of public transport, with a shift towards public transport and active modes, such as cycling (Ministère de la transition écologique et solidaire, 2020). Other clean mobility strategies include, such as in Germany, and in the long-term, an increase in the share of electric vehicles) and the corresponding infrastructure. For heavy-duty vehicles, the measures concentrate on a more balanced mix of fuels, including renewable gas, electricity, and biofuels. It should be noted, however, that most of the proposed measures in the national strategy are generic and not quantitative, serving mainly as guidelines (Table 1).

Outside Europe, the ***United Kingdom***'s Net Zero Strategy from the United Kingdom focuses on a mix of *Improve*, *Shift* and *Avoid/Reduce* measures (HM Government, 2021), although not as detailed as the German Climate Action Plan, and many measures are still in the process of final internal consultation. *Improve* measures, like those being taken in other countries, are at the heart of the Strategy and include a transition to electric vehicles and the phasing out of sales of new passenger cars with internal combustion engines (gasoline and diesel) from 2030 and motorcycles and buses from 2040. This transition should be accompanied by improved charging infrastructure in public areas. Shifting to other modes of transport is also mentioned in the Strategy, especially for freight, with increased investment in the rail network. Although the use of hydrogen is seen as a promising, the Strategy does not indicate the extent to which it will help reduce emissions. With such measures, the UK aims at reducing the domestic share of GHG emissions from transport, which represents 23% of the country's overall emissions. Among these, 55% (ca. 68 $MtCO_2eq$) are from passenger cars, while 16% (ca. 19 $MtCO_2eq$) are from heavy and light-duty vehicles (HM Government, 2021). In North America, Canada is among the world's largest per capita emitters of GHGs, with per capita emissions of approximately 19.4tCO_2 (Chancel *et al.,* 2022).

Just as a basis of comparison with Europe, the transportation sector is responsible for approximately 25% of ***Canada***'s total GHG emissions, with nearly half coming from cars and vans and nearly 35% from heavy duty trucks. Investments in decarbonization at the federal level are focused on electrifying light-duty vehicles, and improving related infrastructure (e.g., charging and refueling stations), as well as shifting to zero- or low-carbon energy sources. Incentives for improving the supply of zero-emission vehicles, and incentives for the purchase of these vehicles have been proposed to stimulate fleet electrification. In addition, the government has also increased investments in public transit and active transportation modes. To address the current climate crisis, each province in Canada has put in place its own decarbonization policy related to the sectors causing GHG emissions, including the transportation sector. More specifically, in the province of Quebec, the *Sustainable Mobility Policy 2030* sets out objectives related to the development of transportation services, promotion of mobility through electrification of the transport network and establishment of targets for transportation related GHG reductions (MTMD, 2018). This policy was designed to address three main issues: (a) social issues, such as equitable access to sustainable transportation, (b) environmental issues, associated, for example, with energy efficiency and pollution reduction, and (c) economic factors, related to the operation of the transportation system and progress is monitored by ten defined targets.

Table 1. Proposed A-S-I measures for road transport (G = generic; Q = quantitative) in the long-term low emission strategies. We display Canada as a basis of comparison with European countries.

Country	Avoid/Reduce		Shift measures		Improve measures	
France	• **Passenger transport**: Encourage remote work and increase the number of shared workspaces.	**G**	• **Passenger transport**: Increase modal shift (to active modes and public transport): from 3% to 12% (2030) and to 15% (2050), by creating bicycle paths, constructing pedestrian spaces, and increasing the transport options.	**Q/ G**	• **Passenger transport**: Improve the energy performance of passenger cars: 4L/100 km for internal combustion engine vehicles by 2030, and 12.5 kWh/100 km for new electric vehicle by 2050.	**Q**
	• **Passenger transport**: Limitation on the growth of passenger transport (up to 26%).	**G**	• **Passenger transport**: Promote car sharing, carpooling (development of tools and infrastructure to facilitate shared mobility), short routes, optimize the use of vehicles.	**G**	• **Freight**: Improve the energy performance of heavy-duty internal combustion vehicles: 21L/100 km for diesel, 15 kg/100 km for natural gas, and 129 kW/ 100km for electric vehicles.	**Q**
	• **Freight**: Limitation on the growth of freight transport (up to 40%)	**G**	• **Passenger transport and freight**: Investment in multimodal exchange hubs.	**G**	• **Passenger transport**: Increase the sales of electric cars or hydrogen-powered private vehicles to reach 35% of the fleet in 2030 and 100% in 2050.	**Q**
Germany	-	-	• **Passenger transport**: Tax on motor vehicle cars, based on CO_2 emissions (2-4 euros for each gram of CO_2 emitted per km).	**Q**	• **Passenger transport**: 15 million electric cars in 2030 (with incentives for the purchase of electric, fuel cell and hybrid electric vehicles).	**Q**
			• **Passenger transport**: Discounted ticket for public transport from 2023 (e.g., 9 euros/month ticket), including lower prices for long-distance rail travel and increased prices for air travel.	**Q**	• **Passenger transport and freight**: One million public charging points with non-discriminatory access installed in Germany by 2030 (100 thousand new public charging points/year by 2025), with funding from the government.	**Q**
					• **Passenger transport**: 1/3 of the kilometers travelled to take place based on electrical drivers or e-Fuels by 2030.	**Q**

Country	Avoid/Reduce		Shift measures		Improve measures	
					• **Passenger transport and freight**: Statutory regulations will require residential, corporate buildings big car parks to install charging infrastructure. • **Passenger transport and freight**: Expansion of rail network.	G G
Portugal	-	-	• **Passenger transport**: Strengthen the role of the public transportation system. • **Passenger transport**: autonomous and/or shared vehicles meet 1/3 | 1/2 of the demand for mobility	G Q	• **Passenger transport**: 36% of the mobility demand of private cars is met by electricity by 2030 and 100% by 2050 (replacement of internal combustion engine vehicles). • **Freight**: 70 to 88% of heavy-duty vehicles running on hydrogen and electricity, by 2030, and 100%, by 2050. The total mobility demand of light-duty vehicles is met by electricity.	Q Q
Spain	-	-	-	-	• **Passenger transport and freight**: By 2030, use of 28% renewable energy for transport.	Q
United Kingdom	-	-	• **Passenger transport:** Investment in cycling and walking: 100 – 1000 miles of segregated bicycle lanes / increase of low-traffic neighborhoods • **Passenger transport**: Investment on public transport system.	Q Q	• **Passenger transport and freight**: End the sale of conventional internal combustion engine vehicles from 2030 and introduce a zero-emission vehicle mandate for manufacturers: new car and van sales must be zero from 2024, and motorcycle and bus sales from 2040.	G
Canada	-	-	• **Passenger transport:** Investment in active and public transportation modes.	G	• **Passenger transport**: Transition to zero-emission vehicles (ZEVs) supported by rebates and investments in charging infrastructure (Goal: (at least 60% of all sales to be ZEVs by 2030 and 100% by 2035). • **Freight**: Regulation on heavy-duty vehicles to be developed, including the use of renewable and alternative fuels. • Development of CO_2 removal technologies.	Q G G

Overall, the measures taken in Europe focus mainly on improving energy efficiency and renewable energy, with an increased share of biofuels and electricity (Table 2), to replace fossil fuels (Capros *et al.*, 2018).

Table 2. Energy use and energy scenarios for transportation in Germany and France (Source: EC-JRC, 2022a).

		Total energy use for transportation (road, air, water)			
Country	**Energy type**	**2005 energy use**	**2019 energy use (current energy use)**	**2030 reference – projected energy use**	**2030 FF55 MIX – projected energy use**
Germany	Oil use	709 TWh (17.5% EU)	733 TWh (18.01% EU)	557 TWh (17.05% EU)	514 TWh (16.86% EU)
	Gas use	10 TWh (31.25% EU)	9 TWh (20% EU)	10 TWh (7.19% EU)	10 TWh (8.70% EU)
	Biofuel use	21 TWh (58.3% EU)	31 TWh (16.85% EU)	47 TWh (18.95% EU)	57 TWh (18.94% EU)
	Electricity	13 TWh (21.6% EU)	12 TWh (20.34% EU)	28 TWh (20.29% EU)	31 TWh (20.16% EU)
	Hydrogen and e-fuels	-	-	-	3 TWh (21.43% EU)
France	Oil use	592 TWh (14% EU)	567 TWh (13.93% EU)	448 TWh (13.71% EU)	421 TWh (13.81% EU)
	Gas use	-	2 TWh (4.44% EU)	12 TWh (8.63% EU)	11 TWh (9.57% EU)
	Biofuel use	7 TWh (19.4% EU)	37 TWh (20,11% EU)	32 TWh (12.90% EU)	36 TWh (11.96% EU)
	Electricity	10 TWh (16% EU)	10 TWh (16.95% EU)	25 TWh (18.12% EU)	28 TWh (18.30% EU)
	Hydrogen and e-fuels	-	-	1 TWh (100% EU)	2 TWh (14.29% EU)
EU	Oil use	4 058 TWh	4 069 TWh	3 266 TWh	3 049 TWh[a]
	Gas use	32 TWh	45 TWh	139 TWh	115 TWh
	Biofuel use	36 TWh	184 TWh	248 TWh	301 TWh
	Electricity	60 TWh	59 TWh	138 TWh	153 TWh
	Hydrogen and e-fuels	0 TWh	0 TWh	1 TWh	14 TWh
	Total EU	4186 TWh (total EU)	4 357 TWh (total EU)	3792 TWh (total EU)[b]	3 632 TWh (total EU)

[a] Reduction of 25% in EU fossil oil use, in comparison to 2019 use levels.

[b] Reduction of total energy consumption of 13% in comparison to 2019 consumption levels.

4. Transport modellings tools

To understand how these A-S-I measures were chosen, we first identify the models used to model GHG emissions in Europe and at national level, and then identify different land use transportation interaction models.

4.1. National scale modeling tools

In general, at national, regional, and local levels, it is unclear how GHG emission reduction targets are set and what evaluation and modeling tools are used to determine these targets. For the EU, a broader documentation is available to understand the path taken to define the current policy instruments. Behind the EU regulations and strategies is a model-based simulation and projection of the possible evolution of the EU energy system, its transport system and their GHG emissions (EC, 2020). The ***EU Reference Scenario 2020*** is based on existing policies, such as the EU regulation 2019/631, setting CO_2 standards for new passenger cars and light commercial vehicles, and the EU Directive 2019/1161 to promote clean and energy-efficient road transport vehicles, as well as on historical trends and existing GHG inventories, such as Eurostat energy balance data and country-level inventory submissions, in line with the Paris Agreement. Under this scenario, the EU aims to reduce the total energy consumption in EU transport by 13%, by 2030, compared to 2019 levels, and reduce the fossil oil consumption in EU transport by 38%, by 2050, in comparison to 2019 levels. To support the development of the policy instruments and measures in Europe, in line with these targets, the EU regularly projects the impacts of technologic and macro-economy on energy and transport systems, with the help of model-based simulations.

For the transportation system, the ***PRIMES-TREMOVE*** model is used to project the mobility demand of passengers and goods, the energy consumption, and emissions of the transportation modes (EC, 2020). The passenger transportation modes included in the model comprise powered two-wheelers, cars (conventional internal combustion engines and alternative powertrains), public road transport (bus), rail (trains, tram, and metro), maritime and aviation. For freight transport, the model comprises maritime and rail transport, as well as light and heavy-duty commercial vehicles. The projection of GHG emissions involves a complex interplay of models, including an energy system model (PRIMES) simulating energy consumption and supply, a macroeconomic general equilibrium model based on demographic and economic projections for EU countries (GEM-E3), and a model considering global energy and fuel prices and climate policy contexts (POLES-JRC). Containing two modules, oriented to the demand and supply for passenger transport activity, ***PRIMES-TREMOVE*** assesses the mobility of transport services and freight and derives ways to meet the transport demand, using optimum technology options and fuel mix. Aspects considered in the modeling, and associated with demographics and GDP, include digital technology, transport prices, use of alternative fuels, existing regulatory and economic measures, such as CO_2 standards, fuel subsidies and taxes, infrastructure, and other measures, such as eco-driving. The model results help evaluate policy options, such as fuel quality and blending regulations, CO_2 emission standards, taxation schemes on energy and vehicle pricing, as well as prices of infrastructure and public transport, in connection with two other tools: the ***Assessment of TRAnsport Strategies model ASTRA*** and the ***TRansport eUropean Simulation Tool TRUST***. ***ASTRA*** helps assess transport modes, including modal split, transport expenditure and volumes, while ***TRUST*** is used on the modeling the interplay between road, maritime and rail sectors, when it comes to infrastructure charging, transport information systems, and transport costs (EC-JRC, 2022b). Altogether, ***PRIMES-TREMOVE***, ***ASTRA*** and ***TRUST*** helped support the future guidelines for the development of the trans-European transport network.

Within ***PRIMES-TREMOVE***, to measure fuel consumption, pollutants, and CO_2 emissions from new passenger cars, allowing comparison between cars, the EU has developed and implemented the Worldwide Harmonized Light Vehicle Test Procedure (WLTP) in 2017, replacing the New European Driving Cycle (NEDC). The WLTP can be applied to traditional, hybrid and fully electric vehicles, but may be applied differently upon road traffic laws and the needs of each country. This lab-based procedure is also complemented by the Real Drive Emissions test (RDE), which measures pollutants (e.g., NOx and ultrafine particles) emitted by light-duty vehicles while driven on the road. Simulation conditions from NEDC and WLTP are also used in European scale simulation models, such as the ***CO2MPAS model***, to calculate CO_2 emissions, as well as energy and fuel consumption from passenger and commercial light-duty vehicles. After the adoption of the EU Regulation 2019/1242, setting targets to reduce average CO_2 emissions for new heavy-duty vehicles, the European Union developed the Vehicle Energy Consumption Calculation Tool (VECTO), in association with the European Heavy Duty Vehicle CO_2 and fuel consumption certification methodology (EC-JRC, 2018). This EU Regulation comprises an incentive mechanism for zero- and low-emission vehicles, with a super-credits system applied until 2024, and a benchmark-based crediting system from 2025 onwards, as well as exemptions for certain vehicles (e.g., construction trucks).

Although not officially used for building the EU Reference Scenario 2020, other models are also available at European scale, for different purposes, such as the ***DIONE fleet impact model*** and the ***NEAC European Transport Forecast Model*** (EC-JRC, 2022b). The ***DIONE fleet impact model*** has also been applied in Europe, as a tool to build scenarios of road transport, including the vehicle fleet composition, the driving patterns and the association with fuel consumption and resulting emissions. Although not formally used to develop the 2020 scenario, the ***DIONE fleet impact model*** has also been applied in Europe as a tool to develop road transport scenarios, including vehicle fleet composition and activity, driving patterns, in association with fuel consumption and resulting emissions. An economic component in the model also assesses the impact of policy development on the costs of vehicle ownership and the payback time in association with the efficiency of the technology. As with the ***PRIMES-TREMOVE model***, the spatial coverage of the ***DIONE fleet impact model*** is the EU Member States. The ***NEAC model*** is primarily used to project multimodal freight transportation flows, using data by transport mode and commodity type.

At the national level, many European countries use energy models developed under the IEA's Energy Technology Systems Analysis Program (IEA-ETSAP) to conduct their long-term scenario analysis and design their reference scenarios. The economic model generator, ***TIMES***, *i.e.*, ***The Integrated MARKAL-EFOM System***, has been applied to perform an in-depth analysis of energy and environmental dynamics, with the aim of exploring possible future scenarios (e.g., technology options) in the whole energy sector or in specific sectors (Loulou *et al.*, 2016). It simulates different scenarios by proposing, on the one hand, a least-cost solution scenario and, on the other, a second scenario based on political constraints (for example, the maximum amount of greenhouse gas emissions targeted). The model has as well been used in non-European countries, such as Armenia, New-Zealand, and Vietnam. Portugal has used the ***TIMES_PT*** energy-environmental-economic modeling tool to design the long-term low carbon scenarios under the Paris Agreement (Gouveia *et al.,* 2012). The TIMES_PT model presents, as an output, the optimal combination of energy supply and demand technologies in combination with final energy prices and costs, emissions, etc. It considers energy and material demand projections, policy constraints, the introduction of new technologies, national primary energy potentials (e.g., biomass, wind power, solar power capacity, etc.), and fuel prices to model the impact on transportation, industry, residential and commercial buildings, and agriculture. Other European countries using country-specific versions of TIMES include Belgium (***TIMES-BE***), Ireland (***TIM, TIMES Ireland Model***), Italy (***TIMES-RSE***), Norway (***TIMES_Norway***), Spain (***TIMES_Spain***) Sweden (***TIMES-City***), and Switzerland (***STEM, Swiss TIMES Energy systems Model***). TIMES has also been applied outside Europe, such as in New Zealand, in Serbia, and in the United Kingdom. The measures proposed in UK's Net Zero Strategy (HM Government, 2021) relies on the use of the ***UK MARKAL*** (or ***TIMES_UK***) multi-period linear optimization model to identify decarbonization pathways and assess potential technological changes in a cost-effective manner (Kannan *et al.*, 2007; Usher and Strachan, 2010). The model considers, among other things, energy demand, resource availability, policy constraints, technologies, and infrastructure.

Canada employed a suite of three international models, *i.e.*, ***GCAM*** (Global Change Analysis Model), ***EC-IAM*** (Environment Canada's Integrated Assessment model), and ***EC-MSMR*** (Environment Canada's Multi-sector, Multiregional Computable General Equilibrium (CGE) model), to build long-term low emission scenarios and assess their environmental, social, and economic implications (Environment and Climate Change Canada, 2021).

4.2. Land use transportation interaction (LUTI) models

At a regional and local scale, the so-called Land Use and Transportation Interaction (LUTI) models have been applied to improve urban planning, infrastructure measures and policy development, while linking land use and transportation patterns (Lopes *et al.*, 2018). These models are used to understand the spatial interrelationships and feedback loop between land use, transportation, human activities (e.g., residing, employment, shopping), and their consequent effects on user's travel behavior (e.g., travel time), decisions (e.g., mode of transportation), destination and route choices, and vehicle ownership, based on attractiveness and accessibility to services and locations, etc. (Wegener, 2004). In summary, they are used to support strategic planning process of transport modelling. For instance, greater availability of transport infrastructure and greater frequency of transport modes may lead to a reduction in car use and an increase in land prices (Lopes *et al.*, 2018). At the urban scale, they are important tools to understand the dynamics of the transportation system, in terms of land use and activities, and to support better decision making when it comes to implementing *Avoid/Reduce* and *Shift* measures to reduce GHG emissions. However, these models have not been explicitly applied in combination with the goal of achieving long-term emission reduction targets. In this paper, we make a compilation of some of the existing models, with the intention of highlighting the aspects considered in the basic components of these models (land use, transportation, and human activities), as well as the external factors and policies that can affect user behavior.

	ILUTE	IRPUD	ITLUP	LILT	MEPLAN	TRANUS	UrbanSim
Reference	(Miller & Salvini, 2001; Salvini and Miller, 2005)	(Wegener, 1982, Wegener, 2011)	(Putman, 1983, Putman, 1991)	(Mackett, 1983; Mackett, 1990; Mackett, 1991)	(Echenique, Crowther, Lindsay, 1969)	(de la Barra and Rickaby, 1982; de la Barra, 1989, de la Barra, 2021)	(Waddell, 2007; Waddell, 2011)
Model structure	Activity-based, microsimulation model	Spatial interaction-based model	Spatial interaction-based model	Spatial interaction-based model	Spatial input-output model with economic evaluation/ Utility-maximizing multinomial logit-based models	Spatial input-output model (land use) / Utility-maximizing multinomial logit-based model	Spatial input-output model / Discrete choice
Sub-models	-Transport -Land use -Economy -Demographics	-Transport (e.g., car ownership travel/demand), -Housing market (migration decisions, change of residence), -Labor market (labor mobility; change of job), -Ageing (technological, biological, and socioeconomic), -Public programs (related to activities included in the model), -Private construction (related to land and construction market: investment and location decisions for developers) -Non-residential construction and demolition.	Household allocation (DRAM – Disaggregate residential allocation model) and Employment allocation (EMPAL – Employment allocation model) Link with GIS (METROPILUS)	Land use model, car ownership sub-model	Land development (LUSB), land market (LUSA), transport demand (TASA), transport market (TASB), and spatial interaction/accessibility (FREDA)	Activities/ land use, Transport	Macroeconomic, Travel demand, Economic and demographic, Household and employment, Land price, Real estate development, Accessibility
Geographic basis	Grid-cells (zones, buildings)	User-defined zones	Census	User-defined zones	User-defined zones	User-defined zones	Grid-cells (land, houses/commercial buildings, and occupants)
Activities included		Residing, working, shopping, studying (education), recreation, health, and welfare (services/social).	Residing, working	Residing, working, shopping		Divided in sectors: households and productive sectors (agriculture, industry, mining, services)	Residing, working, shopping
Individuals/household differentiation	Individuals (marital status, age, sex, educational status) and household-based	Household-based (categories)	Household-based (four income categories)	Household-based	Individuals and household-based	Household-based	Individuals and household-based
Household location choice	Modeled	Modeled	Modeled	Modeled	Modeled	Modeled	Modeled
Household categorization	Disaggregate	Disaggregate (income, size, nationality, age)	Aggregate (four income categories / four types of employment)	Disaggregate (three income categories)	Aggregate, user-defined	Aggregate, user-defined (income or size)	Disaggregate (household income and size, number of workers, presence of children)
Real estate characteristics	Dwelling units, households, families, persons	120 household and housing types (dwelling units, households)	No explicit representation of buildings/ floor space	-	Aggregate, user-defined (acres, units of floor space)	Aggregate, user-defined (acres, units of floor space)	24 development types (acres, units of floor space)
Real estate development and prices	Modeled	Modeled	Not modeled	-	Modeled	Modeled	Modeled (prices and rents)

	ILUTE	IRPUD	ITLUP	LILT	MEPLAN	TRANUS	UrbanSim
Employment location choice	Modeled by sector and occupation	Modeled by zone and sector	Modeled by zone	-	Modeled	Modeled	Modeled by sector
Employment classification	Disaggregate, 16 sectors (e.g., agriculture) and 10 categories (e.g., public service)	Disaggregate, 40 industrial sectors	Aggregate (four types of employment / four income categories)	Disaggregate, 12 sectors	Aggregate, user-defined	Aggregate, user-defined	Disaggregate, 10-20 sectors (by industry and land use type)
Transport modes	Car, public transport	Car, public transport, walking/ cycling.	Car, public transport	Car, public transport, and walking.	Car, public transport, walking	Car, public transport, walking, motorcycles	Car, public transport, walking
Transportation networks	Modeling of integrated multimodal networks	Modeling of integrated multimodal networks	Modeling of unimodal network	Modeling of unimodal network	Modeling of integrated multimodal networks	Modeling of integrated multimodal networks	Modeling of integrated multimodal networks
Travel decision	Endogenous$^{(b)}$: choice depends on car ownership, network flows, transportation network, travel demand, location choice, activity schedules, etc.	Endogenous$^{(b)}$: choice depends on car ownership, trip rates, destination, mode, and route choice (in equilibrium to congestion in the network)	Endogenous$^{(b)}$: choice based on congested travel times	Endogenous$^{(b)}$: choice of car ownership depends on time and travel costs	Endogenous$^{(b)}$	Endogenous$^{(b)}$: travel model with combined mode-route choice	Exogenous transport modelling$^{(a)}$
Freight travel	Modeled	Not modeled	Not modeled	Not modeled	Modeled: truck, rail, etc.	Modeled: trucks (single purpose individual trip), ships and trains	Not modeled
Simulation of urban development	Dynamic process over time (from base year)	Market choices and time-dependent transitions modelled endogenously. Public policies exogenously	Exogenous forecasts of population and activity rates				Dynamic process over time and space
Simulation of land market	-	Interaction of demand and supply, based on investment and location	-	Interaction of demand and supply, based on accessibility and attractiveness of the zone	-	-	Interaction of demand and supply, based on prices of properties and rents
Simulation of housing market	Distinction between ownership and rental, based on vacancies and prices (Decision to sell or lease dependent on type of housing, location, number of units, price, quality, size)	Distinction between ownership and rental. Modeling of intraregional migration decisions of households (stochastic microsimulation)	Exogenous forecasts of household types	It handles demolition, changing occupancy rates and vacancies	-	-	Distinction between ownership and rental. Distinction of building type (affordability)
Simulation of labor market	Distinction between job supply, demand, application, and acceptance (modeled after the housing market)	Demand-driven, with a distinction between workers and unemployed individuals. It influences the rates of employment and unemployment and household incomes in the region	Exogenous forecasts of employment	-	-	-	-
Policies	Fiscal/pricing, regulatory, infrastructure, operational,	Fiscal/ pricing (e.g., tax laws on land, parking fees), infrastructure (e.g., change of land use and	Development charges, infrastructure (e.g., build roads, high-occupancy vehicles)	-	Fiscal/ pricing (e.g., property, development, tolls, parking,	Fiscal/ pricing (e.g., property, development, tolls, parking, gas, transit	Fiscal/ pricing (e.g., property, development), regulatory (e.g.,

	ILUTE	IRPUD	ITLUP	LILT	MEPLAN	TRANUS	UrbanSim
	etc.	zoning, motorway access), regulatory, housing, employment			gas, transit fares), regulatory (e.g., zoning, speed limits), infrastructure (land services, high-occupancy vehicles)	fares), regulatory (e.g., zoning, speed limits), infrastructure (land services, high-occupancy vehicles)	zoning, speed limit, traffic operation), infrastructure (e.g., services, dedicated transitways)

(a) Transport decisions based on external models or model is fed by external data.
(b) Travel decisions are based on the level of available services.

5. Discussion

In this paper we reviewed national action plans, identified models for calculating emissions in EU member states and identified some of the land use interaction models and their characteristics, which can help predict changes in transport and land use patterns.

Under the commitments of the Paris Agreement, an important first step has been taken to improve energy efficiency in key sectors such as energy, transport, and construction, the decarbonization of power systems in different countries, while increasing the use of renewable sources, and the introduction of low-carbon energy sources for transport. However, the design of decarbonization pathways under the Agreement depends not only on economic based *Improve* measures at the national level, but also on perceived regional and local opportunities, considering behavioral changes (i.e., *Avoid/Reduce* and *Shift* measures). The emphasis on *Improve* strategies over those using structural improvements and behavioral changes is because strategies involving new technologies can be implemented more quickly and results can be observed and measured more easily. But most of the changes induced by existing policies are aimed at improving rather than reducing travel or transforming the way people move. Modal shift and land use planning strategies are more difficult to achieve, requiring a long-term scenario and policy development, a more structured dialogue among different actors (e.g., stakeholders, public sector, society, etc.), and a coordination between different aspects (e.g., impacts on local communities and economy). Emission reduction strategies must be developed in an integrated manner considering other aspects, such as social, economic, and environmental aspects, and support the development of people in their communities.

The extent to which national policies are constructed based on modeling approaches is not yet clear, despite the example of Europe and Canada cited in this paper. Nor are the results of the models and the resulting policy decisions fully transparent. In this context, policy implementation varies according to the conditions (e.g., the energy matrix, the degree of implementation of certain measures) and resources of each country. This is particularly true at the local scale, i.e., urban areas, where policies can induce strong behavioral changes, leading to substantial potential emission reductions. Most of the LUTI models cited in this paper have been applied to only a limited number of cities, and some are currently calibrated for specific urban areas. An example of how *Avoid/Reduce* measures influenced a decrease in emissions was achieved during the pandemic period, where a significant decrease in emissions was observed as a result of local and regional passenger travel restriction policies and telecommuting incentive policies.

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