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Research paper

Factors affecting the emission of pollutants in different types of transportation: A literature review

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ABSTRACT

Given the importance of the environment around the world and its accelerating destruction brought on by the increase in emissions resulting from the growing use of various forms of transportation, this paper shall aim to eliminate this research gap via a thorough investigation of the literature. These goals include the effect of greenhouse gases emitted by the transportation industry on the environment, the impact of pollutants on transportation mode choice, a study of the obstacles to reducing pollution in transportation, and the presentation of solutions and suggestions. In the research, papers related to this topic in various transportation industries, including road, rail, marine, air, and multimodal transportation, and the variables affecting the control of greenhouse gas emissions in any mode of transportation were collected. Afterward, fundamental analysis was carried out, conclusions drawn, and the presentation of suggestions and solutions in this area addressed. Reducing greenhouse gases in transportation is a challenge that requires examining numerous influential variables and factors. The studies presented in this research are expected to be useful, especially for the energy activists, researchers, and policymakers who would like to conduct long-term studies of pollutants in the transportation industry and the variables influencing the control of greenhouse gas emissions.

1. Introduction

Given the increasing significance of the environment on the global scale and the increasing trend in its destruction, attention to environmental considerations in the planning process has nowadays been raised as a global necessity (Bristow et al., 2008). The rise in greenhouse gases is not only considered the primary driver of global warming (Chen and Hao, 2015; Dulal et al., 2011), but it also increases the number of deaths due to cardiovascular and respiratory diseases. Furthermore, it causes adverse effects during pregnancy, such as a reduced birth weight, preterm birth, and congenital disabilities (Jiang et al., 2017). The trend in the studies shows that the level of greenhouse gas emissions in developing countries is higher than that of developed countries. This highlights the need for the developing countries to attempt to reduce future emissions (Dulal et al., 2011; Chandler et al., 2002). The compounds affecting global warming are divided into two groups (Peters et al., 2011): (1) compounds that have a short life-span in the environment and mostly affect the ozone layer (SO_2, NO_x, CO, NMVOC, etc.), and (2) compounds that endure in the environment and are known as greenhouse gases (CO_2, CH_4, and N_2O). The emissions from the various transport sectors entail a mix of gases and aerosols with very different characteristics and effects on the climate. In the assessment of the effects of current emissions on climate, we need to decide on the (1) time horizon and (2) impact parameter. The choice of the former goes beyond natural sciences and requires value judgments, and the choice of impact parameter that cannot be solely based on science, a trade-off between relevance and uncertainty. The design of a metric depends also on its application and the policy context within which it is intended to function (Fuglestvedt et al., 2010).

Transportation is the second-largest source of greenhouse gas emission in the European Union. Global data relating to the emission of greenhouse gases indicate that the main factors of global greenhouse gas emissions in 2015 were electricity generation (29%), transportation (27%), and production (21%). The considerable share of transportation in the global emission of greenhouse gases has turned into an area of study and concern. The attempts to reduce carbon emission will be challenged by predicting a 25% increase in the GDP in the transportation sector by 2030 (Liu et al., 2015a; Timilsina and Shrestha, 2009). According to the estimation by the International Energy Agency, CO_2 emission is predicted to increase by 41% by 2030, which is greater than compared to be 9.3 billion tons numbers in 2007 (Van Fan et al., 2018).

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Moreover, Van Fan et al. (2018) believe that transportation has a share of about 32% in the production of CO_2 and about 27% in the total production of greenhouse gases. In the transportation sector, road transportation is the largest source of greenhouse gas emission in the EU (Morán and del Rio Gonzalez, 2007) since petroleum is the dominant fuel source. Road transportation constitutes 81% of the total energy consumption by the transportation sector (Chapman, 2007). In the EU, road transportation is responsible for producing more than 72% of greenhouse gases in the transportation sector. The road is followed by air transportation with 13.3%, marine with 12.8%, and rail transportation with about a 0.5% share in emissions. The rest is attributed to other modes of transport. Clearly, there is a huge difference between greenhouse gas production levels in road transportation and other modes of transportation in Europe (Van Fan et al., 2018). As for the production of CO_2, trains in Finland produce by far the least pollution. Depending on the route, the pollution created by short-haul flights is 1.6–2.6 times greater that of a car, 2.3 to 4.5 times that of a bus, and 2.9 to 17.7 times that of a train on the same route (Baumeister, 2019). Transportation activities conventionally include the costs of internal transportation. With increasing environmental concerns, the negative external costs of road, rail, marine, and air transport, including air pollution, environmental impacts, climate change, noise, and the devices that control them have drawn the attention of governments and procurement companies (Demir et al., 2015; Kreutzberger et al., 2003).

As stated earlier, transportation has adverse effects on the lives people, animals, and plants, and on the change in the ecosystem. Therefore, controlling and examining polluting factors, creating regulations, and considering policies for preventing issues are among the priorities of progressive societies. Greenhouse gas emissions must be decreased to limit the global warming to 2 °C by 2050. This decrease is a challenge for the transportation sector and requires examining various influential variables and factors (Jiang et al., 2017; Morán and del Rio Gonzalez, 2007). However, given the variety of previous studies, a comprehensive study considering the different types of transportation and a review and summary of the previous studies seems necessary. This issue is addressed in the present study, and a general overview of the effects of different kinds of transportation on the environment is presented. Furthermore, important suggestions and solutions are provided by examining the impact of pollutants on transportation mode selection, and obstacles to reducing pollution in transportation are listed as well.

1.1. Research questions

The production of greenhouse gases due to transportation constitutes a serious threat to humans. Given the significance of this issue, the present research attempts to answer the following questions:

RQ 1: Which factors and variables reduce and control greenhouse gases in different transportation modes?

RQ 2: What are the obstacles and challenges in decreasing transportation-related pollution?

RQ 3: Which types of transportation are suitable alternatives to hazardous transportation?

RQ 4: What solutions are there for simultaneously ensuring optimal transportation and reducing pollutants?

1.2. Contributions

The following issues have been addressed for the first time in this paper:

- Investigating the variables affecting the control of greenhouse gas emissions in different transportation modes: (1) planning and policymaking, (2) technology, (3) economy, and (4) demand.
- Examining the obstacles to reducing pollution in transportation based on the literature.
- Comprehensively summarizing the literature, trends in previous studies, and the most important and effective variables in the studies and proposing solutions for the optimal use of different transportation modes to reduce the emission of greenhouse gases.

1.3. Outline

This paper is organized into different sections. Section 2 reviews the literature, including the effect of greenhouse gases in the transportation industry on the environment, the effect of pollutants on transportation mode choice, and the obstacles to reducing pollution in transportation. Section 3 includes a discussion, and Section 4 concludes the paper and points to future research.

2. Literature review

The transportation sector has been considered the largest producer of greenhouse gases in the last 30 years, and attempts have been made to reduce the impact of these emissions on the environment (Kok et al., 2011; Ong et al., 2011; Kopelias et al., 2020). Transportation is responsible for 26% of all CO_2 emission in the world (Chapman, 2007). First, we will examine previous review studies and compare them with this research.

Demir et al. (2015) presented a review aimed at increasing awareness of the costs associated with external factors in road, rail, marine, and air transportation that must be eliminated using accurate pricing policies. Estimating external costs is done for various reasons: Designing economical pricing systems, facilitating the allocation of research and development budgets, and supporting the analysis of costs and the desired return on investment for different transportation modes and infrastructure. Moreover, Bickel et al. (2006) believe that many costly external factors, such as congestion, accidents, sustaining the environment, social and infrastructural costs, are either not at all reflected in the current prices or only partially reflected. Considering external factors in the reasonable pricing of transportation will improve the efficiency of the system.

The production of greenhouse gases in road transportation is a serious threat to urban air quality and results in global warming (Chapman, 2007; Kok et al., 2011; Ong et al., 2011; Kopelias et al., 2020) . The following topics have been studied in this area: the strategies for the possible reduction of emission (Dulal et al., 2011; Ong et al., 2011; Demir et al., 2014; Emberger, 2017), the relationship between noise in the environment and road traffic, the effects of the former on public health (Ong et al., 2011), and the policies aimed at changing the current adverse trends, such as reducing the use of private vehicles, reducing goods transportation via roads, reducing air traffic related to the transportation of cargo and passengers, reducing energy consumption in transportation, reducing accidents (Dulal et al., 2011; Emberger, 2017), studying fuel economy and CO_2 standards for road vehicles, and examining the fundamental differences between various policies and alternatives for reducing CO_2 (Kok et al., 2011; Demir et al., 2014), and increasing the use of alternative fuels by promoting electric vehicles, biofuels, natural gas, liquefied gas etc (Emberger, 2017; Navas-Anguita et al., 2019). Chapman (2007) believes that automobiles and airplanes are the main cause of greenhouse gas emissions in the transportation sector. He has investigated and evaluated the influential factors in reducing greenhouse gases, namely novel technologies such as alternative transportation fuels, which aim to eliminate dependence on petroleum and focus on policymaking and behavioral patterns. To achieve stability in greenhouse gas emissions from transportation, changes in behavior and urging policymakers to make policies and regulations are very important. In a review paper, Nakamura and Hayashi (2013) used the Comparative study on Urban Transport and the Environment (CUTE) to research the following 4 classes for various carbon reduction strategies: (a) technology (e.g., infrastructure planning, vehicle technologies, and alternative fuels), (b) regulations (e.g., transportation management, control, and services), (c) information (e.g., information presentation, raising awareness, and communication technologies), and (d) economy (e.g., pricing and taxes). Moreover, he has summarized the trends and effects of low-carbon transportation actions. Given the significance of CO_2 emission levels from marine transportation, which constitutes about 3% of annual greenhouse gas emissions, Bouman et al. (2017) investigated some promising points. They looked at technologies and operational methods, determined the reduction potential, and examined the policies and regulations for successfully reducing the emission of greenhouse gases. They believe that using current technology emissions can be reduced by more than 75% by 2050.

Several review papers address the state of emissions due to transportation and the development of the carbon market in China as the largest producer of greenhouse gases. The items studied in these papers can be considered as an example for other countries. These items include the following: examining the public health consequences of decisions, policymaking, technology, and transportation infrastructure in China (Jiang et al., 2017), investigating the frequency and intensity of accidents and damage related to traffic (Jiang et al., 2017), analyzing China's status in the international market (Hua and Dong, 2019; Liu et al., 2015b), studying the factors affecting the establishment of a carbon market by the Chinese government (Liu et al., 2015b), examining the development of mandatory and voluntary carbon trade (Liu et al., 2015b), studying the challenges of and obstacles to the commercialization of carbon (Hua and Dong, 2019; Liu et al., 2015b), and resolving carbon market issues such as carbon pricing, allocation of carbon emission quotas, identification of methods for measuring a unit of carbon quota, gradual increase in the sale ratio of carbon quota, sources of covering carbon emissions, and legal and political systems (Hua and Dong, 2019). In a review study Yang and Luo (2020) provided suggestions to introduce policy suggestions for some countries whose carbon financial researches are not deep enough, and also significant theoretical references for scholars. Moreover, they analyzed various aspects of the carbon financial market. Von Blottnitz and Curran (2007) evaluated bioethanol systems with conventional fuel based on life cycle assessment (LCA). Given the different hypotheses and system boundaries, Lee et al. studied a wider range of environmental effects, such as resource depletion, global warming, ozone depletion, acidification, erosion, human health and the environment, and smoke formation, among others.

Compared to other review papers, the innovation of our research in the area of the effect of the carbon market on the transportation industry makes the research important and useful, as summarized in Appendix A. The current paper attempts to fill a gap by a thorough inspection of the literature, including the following: (1) the effect of transportation-induced greenhouse on the environment, (2) the impact of pollutants on transportation mode selection, (3) the obstacles to reducing pollution in transportation, and (4) related suggestions and solutions. For a better appreciation of the topic, the research was divided into three groups: (1) the environmental effects of transportation in six parts (road, rail, marine, air, multimodal, and summary), (2) the impact of pollutants on transportation mode selection, and (3) the obstacles to reducing emissions in transportation.

2.1. Environmental effects of transportation

The results show that the transportation sector currently constitutes 23% of the total emissions in the 27 EU member countries due to its dependence on fossil fuels. If the current trend continues, transportation is expected to have a 50% share in the total emissions in the EU by 2050 (Emberger, 2017). Huang et al. (2020) studied the adverse effects of transportation networks on the Asian elephant population. The rapid growth of transportation networks threatens the life of species with a wide geographical presence. Harris et al. (2018) and Bonachea et al. (2005) examined a proposed methodological plan for evaluating the effects induced by transportation infrastructures, such as highways and railways. Bristow et al. (2008) investigated effective factors, such as technology development, pricing, public transport, and soft actions for the private transportation of land passengers in the UK. The following are among the results of their study: (1) in the absence of behavioral changes and technological progress more serious goals for carbon reduction cannot be achieved, (2) actions related to price indexes for encouraging a decrease in motor vehicle usage and the development and purchase of more efficient vehicles and facilities for decarbonizing public transportation vehicles reduce carbon emissions have to be considered, (3) taxing can be used to directly restrict carbon-based fuels, and (4) measures can be considered for decreasing the number of trips and encouraging the usage of local facilities and public transportation.

Subsequently, the environmental impact of different transportation methods, such as road, rail, marine, air, and multimodal transportation have been investigated well. For each of these items, the variables effective in controlling greenhouse gas emissions from any type of transportation are as follows: (Bristow et al., 2008; Nakamura and Hayashi, 2013; Brand et al., 2012; Akbari et al., 2020)

- **Planning and policymaking:** (1) Management of regulations, laws, policies, and standards, (2) Transportation planning, and (3) Investment on alternative methods
- **Technology:** (1) Alternative fuels, and (2) Technology development
- **Economics:** (1) Economic growth, (2) Pricing, and (3) Tax policies
- **Demand: (**1) Management of supply and demand, and (2) Traveled distance

2.1.1. Environmental impact of road transportation

The road transportation sector is a major contributor to CO_2 emission with an approximate 70% share in emissions due to its dependence on fossil fuels (Emberger, 2017). In addition to cargo transportation on roads, which is the main cause of emissions, motor vehicles, buses, taxis, and intercity buses also play an important role (Chapman, 2007). In 2010, road cargo transportation was almost 9 times that of other transportation modes (Demir et al., 2015). Cargo transportation uses up almost 43% of the total energy consumed in transportation. In addition, cargo vehicles move slowly, causing considerable congestion on highways (Chapman, 2007). As Chapman (2007) showed, road cargo transportation normally constitutes less than half of the total road transportation. Organizations and policymakers reinforce their attempts to prevent the transportation of goods via highways (Anas and Lindsey, 2011). The negative effects of urban road transportation include the following: (1) the cost of greenhouse gas production (such as the costs of congestion, fuel consumption, accidents, and infrastructure damage), (2) the adverse impacts of pollutants on drivers and local people, (3) water pollution, (4) vibrations, and (5) urban image deterioration (Anas and Lindsey, 2011). Many policymaking tools can be employed to control the negative output of road transportation, but all these tools have their own limitations. In the following chapter, more variables and controllable factors are investigated.

2.1.1.1. Planning and policymaking. To achieve stability in greenhouse gas emissions arising from transportation, factors such as planning, regulation, and behavioral change policies are very important (Chapman, 2007; Akbari et al., 2020; Hickman et al., 2012; Chavez-Baeza and Sheinbaum-Pardo, 2014; Hasan et al., 2019; Javid et al., 2014). The strategies implemented to reduce the production of greenhouse gases consist of two general classes:

1. Urban planning, including the following: administrative rules and regulations management (ARM) (Akbari et al., 2020; Herold and Lee, 2017); appropriate planning for intracity and intercity public transportation, which prevents system delay, increases customer satisfaction, reduces and controls traffic, and combines customer products into one truck instead of several trucks (Bristow et al., 2008; Dulal et al., 2011; Kopelias et al., 2020; Demir et al., 2014; Bouman et al., 2017; Akbari et al., 2020; Anas and Lindsey, 2011; Hensher and Ton, 2002; Berrittella et al., 2007; Pradenas et al., 2013; López-Navarro, 2014; Gan, 2003; Chen et al., 2021; O'Toole, 2008); integrated transportation (Hasan et al., 2019; Hensher, 2008; Tamannaei et al., 2021; Poudenx, 2008; Hensher, 2002); vehicle routes for providing services to a group of customers (Pradenas et al., 2013; Tamannaei et al., 2021; Jemai et al., 2012); controlling road congestion (Dulal et al., 2011; Chapman, 2007; Emberger, 2017; Anas and Lindsey, 2011; Javid et al., 2014; López-Navarro, 2014; Rodrigues et al., 2015); building a culture for the use of bicycles and walking (Anas and Lindsey, 2011; Berrittella et al., 2007; Gan, 2003; Poudenx, 2008); investing in alternative methods (Demir et al., 2015; Kopelias et al., 2020; Herold and Lee, 2017; Hensher and Ton, 2002; Pradenas et al., 2013; Poudenx, 2008; Seo et al., 2021; Fragkos et al., 2021); improving transportation efficiency (Emberger, 2017; Poudenx, 2008); improving the efficiency of energy usage (Pradenas et al., 2013; Gan, 2003); improving cargo logistics (Pradenas et al., 2013; López-Navarro, 2014; Rodrigues et al., 2015); preventing the destruction of agricultural land and rangelands due to the development of transportation networks (Demirel et al., 2008); and considering the positive road slope in route planning for road cargo (a positive road slope can increase fuel consumption).
2. Policymaking and regulations in transportation, for example, carrying out further studies on standardization and issuing stricter rules in road transportation (Chapman, 2007; Demir et al., 2014; Akbari et al., 2020; Hasan et al., 2019; Tamannaei et al., 2021; Brand et al., 2013); creating restrictions in highways for carrying cargo in trucks and passenger cars (Bouman et al., 2017; O'Toole, 2008; Tamannaei et al., 2021; Poudenx, 2008; Corbett and Winebrake, 2007); restricting the issuing of licenses and imposing parking and congestion costs (Jiang et al., 2017; Hensher and Ton, 2002; Poudenx, 2008); reducing speeds limits in highways (Brand et al., 2012; López-Navarro, 2014; Poudenx, 2008; Corbett and Winebrake, 2007); restricting engine idle time (López-Navarro, 2014; Corbett and Winebrake, 2007); controlling fuel consumption (Seo et al., 2021; Timilsina et al., 2011); controlling and regulating demand and ensuring safe, efficient, and comfortable transportation (Dulal et al., 2011; Jiang et al., 2017; Emberger, 2017; Berrittella et al., 2007; Tamannaei et al., 2021); implementing practical plans aimed at separating the areas associated with greenhouse gas propagation from residential areas (Jiang et al., 2017; Hensher and Ton, 2002); implementing scrap and retrofit plans for old vehicles, especially heavy diesel vehicles (Jiang et al., 2017; Emberger, 2017); raising public awareness (Bristow et al., 2008; Demir et al., 2015; Nakamura and Hayashi, 2013; Akbari et al., 2020; Berrittella et al., 2007; Tamannaei et al., 2021; Chatterton et al., 2009); and improving public transportation and encouraging people to use public transportation instead of private vehicles (Dulal et al., 2011; Emberger, 2017; Nakamura and Hayashi, 2013; Anas and Lindsey, 2011; Hasan et al., 2019; Hensher and Ton, 2002; Berrittella et al., 2007; Pradenas et al., 2013; Tamannaei et al., 2021; Poudenx, 2008; Qin et al., 2019).
3. Although urban planning has a limited effect on reducing greenhouse gas emissions in the short run, due to the time required to create infrastructure, it can be very effective in the long run. Namely, the dependence on private vehicles would need to shift to public transportation and other environment-friendly modes of transportation (such as walking or cycling) (Dulal et al., 2011; Tamannaei et al., 2021). Improving public transportation is an effective strategy for reducing emissions and fuel consumption from a technical viewpoint.

2.1.1.2. Technology. Technological changes will play an increasing role in the reduction of greenhouse gas emission from transportation (Chapman, 2007; Akbari et al., 2020). The research on solutions for decreasing carbon emissions in the transportation sector is mainly focused on adopting alternative fuel sources with less carbon content via battery electric vehicles (BEV) (Navas-Anguita et al., 2019; Brand et al., 2012; Baptista et al., 2012; Yaqoob et al., 2021; Li et al., 2021; Azar et al., 2003; Chakraborty et al., 2020; Watabe et al., 2019; Boonpanya and Masui, 2021; Tong et al., 2015; Grahn et al., 2009), zero-emission vehicles (ZEV) (Herold and Lee, 2017; Wang et al., 2020a), alternative fuels (Chapman, 2007; Ong et al., 2011; Emberger, 2017; Brand et al., 2012; Herold and Lee, 2017; López-Navarro, 2014; Gan, 2003; Hensher, 2008; Fragkos et al., 2021; Corbett and Winebrake, 2007; Baptista et al., 2012; Yaqoob et al., 2021; Li et al., 2021; Azar et al., 2003; Grahn et al., 2009; Eyre et al., 1997; Trevisan and Bordignon, 2020; Salvi and Subramanian, 2015; Kay et al., 2014), hydrogen fuel cells (FCV) (Demir et al., 2014; Hensher, 2008; Azar et al., 2003; Watabe et al., 2019; Tong et al., 2015; Grahn et al., 2009; Salvi and Subramanian, 2015; Banister, 2011), biofuels (biofuels are known as mono-alkyl esters, which are obtained from vegetable oils or animal fat) (Ong et al., 2011; Emberger, 2017; Fragkos et al., 2021; Baptista et al., 2012; Yaqoob et al., 2021; Azar et al., 2003; Grahn et al., 2009; Chauhan et al., 2009; de Souza et al., 2013; Kaufman et al., 2010; Nabavi-Pelesaraei et al., 2017), natural gas vehicles, (NGV) (Ong et al., 2011; Yaqoob et al., 2021; Watabe et al., 2019; Tong et al., 2015; Grahn et al., 2009; Eyre et al., 1997; de Souza et al., 2013; Ghasemi-Mobtaker et al., 2020; Mostashari-Rad et al., 2021; Nabavi-Pelesaraei et al., 2019; Khanali et al., 2021; Nabavi-Pelesaraei et al., 2021; Saber et al., 2021), liquified gas (Ong et al., 2011; Emberger, 2017; Baptista et al., 2012; Yaqoob et al., 2021; Tong et al., 2015; Grahn et al., 2009; Eyre et al., 1997), hybrid fuel (Grahn et al., 2009; Nakata, 2000), fleet renovation (Emberger, 2017; Navas-Anguita et al., 2019; Berrittella et al., 2007), and infrastructure improvement, including the following: road, tunnel, and bridge networks (Demir et al., 2015; Rodrigues et al., 2015; Azar et al., 2003; Trevisan and Bordignon, 2020); reducing the vehicle weight (increasing the vehicle weight increases fuel consumption) (Demir et al., 2014; Jemai et al., 2012); technical development (Bouman et al., 2017; Akbari et al., 2020; Herold and Lee, 2017; Hensher and Ton, 2002; Berrittella et al., 2007; Seo et al., 2021; Brand et al., 2013; Anable and Bristow, 2007; Mohamed, 2016; Pavlovic et al., 2016), advanced public transportation systems (Emberger, 2017; Nakamura and Hayashi, 2013; Anas and Lindsey, 2011; Qin et al., 2019); using environment-friendly trucks in cargo transportation (Kabadurmus and Erdogan, 2020); improving routing (Bouman et al., 2017); developing communication technologies such as the Internet, email, and video conference (to enable people to telecommute) (Chapman, 2007); and using efficient tools and methods to reduce uncertainty in estimating greenhouse pollution (La Notte et al., 2018; Weiss et al., 2011).

The automotive industry contributes to improvement efforts by considering economic development, environmental regulations, and changes toward green technologies to respond to the associated challenge (Gan, 2003). Brand et al. (2012) believe that battery electric vehicles (BEV), which use electricity produced from natural gas, reduce pollutants by about 40% compared to vehicles that use conventional gasoline. However, gaseous hydrogen fuel cell electric vehicles (FCEVs) and compressed natural gas (CNG) vehicles produce pollutants similar to those produced by conventional gasoline and lead to a limited reduction of pollutants given the one-hundred-year global warming potential (Tong et al., 2015). Given the prioritization of policies, short-term speed limitations in the short-run (2010–2020), medium-term (2010–2030), and long-term (2010–2050) limitations on fuel and electric vehicles, it is electric vehicles that are known as the most effective strategy for reducing pollution. The approval of efficient energy technologies, such as electric vehicles, fuel cells, and hybrid buses using modern technology can decrease CO_2 emission by 25%–34% in urban areas (Ong et al., 2011; Anable and Bristow, 2007).

Encouraging people to buy more capable vehicles or hybrid electric vehicles will lower the cost and save energy (O'Toole, 2008). According to some studies, the use of zero-emission vehicles (ZEV) in Ontario in Canada helped to reduce emissions. This indicates that each truck inflicts annual damage to the environment equivalent to $8000. A 5% usage of ZEVs can reduce greenhouse pollutants in 2012 by up to 800 ktCO_2e, which will lead to combined savings of $89 million per year (Wang et al., 2020a). Eyre et al. (1997) believe that the cost of emission from the fuel cycle of vehicles, from highest to lowest, consists of gasoline or diesel, liquid fuels, and natural gas.

Hydrogen infrastructure for supplying fuel to vehicles has improved in the recent decade, from stations with limited access and limited working hours to customer-friendly retail stations open to the public. The amount of hydrogen distributed annually by retail stores has increased almost four times, from 27,400 kg in 2015 to more than 440,000 kg in 2017 (Kurtz et al., 2019). Nevertheless, to replace conventional fuel (diesel and gasoline) with alternative fuels (natural gas, LPG, biofuels, electricity, and hydrogen), comprehensive data on the technical and economic performance of production pathways for alternative fuels needs to be provided by energy planners, modeling experts, analysts, and policymakers. Navas-Anguita et al. (2019) performed a study of the production pathways for a broad spectrum of road transportation fuels, including datasets of investment costs, operation and maintenance costs, and evolution efficiency for more than 40 production pathways.

2.1.1.3. Economics. An effective factor in curbing pollution in road transportation are economic factors, such as the following the increase in the gross domestic product (GDP) (Dulal et al., 2011; Berrittella et al., 2007; Timilsina et al., 2011; Lakshmanan and Han, 1997; Lu et al., 2007), road pricing (Bristow et al., 2008; Demir et al., 2015; Nakamura and Hayashi, 2013; Bonachea et al., 2005; Anas and Lindsey, 2011; Hensher and Ton, 2002; Poudenx, 2008; Brand et al., 2013; Kay et al., 2014), fuel pricing (Demir et al., 2015; Berrittella et al., 2007; O'Toole, 2008; Nakata, 2000; Graham and Glaister, 2004; Tirkaso and Gren, 2020), pollutant pricing (Demir et al., 2015; Hickman et al., 2012; Brand et al., 2013; Boonpanya and Masui, 2021; Han et al., 2017), competitive pricing of the total social cost of different transportation modes (Demir et al., 2015; Bickel et al., 2006; Berrittella et al., 2007; Tamannaei et al., 2021; Brand et al., 2013; Nakata, 2000; Forkenbrock, 2001), considering tax policies (such as vehicle purchase tax, vehicle insurance tax, pollutant tax, fuel consumption tax, hazardous transportation tax, and pollutant rationing tax) (Bristow et al., 2008; Hensher and Ton, 2002; Berrittella et al., 2007; Hensher, 2008; Poudenx, 2008; Brand et al., 2013; Chakraborty et al., 2020; Nakata, 2000; Tirkaso and Gren, 2020; Han et al., 2017; Morrow et al., 2010; Jin et al., 2014; Huang et al., 2019; Yan and Crookes, 2009; Wing, 2007), pollutant quota allocation (Hua and Dong, 2019; Brand et al., 2012; Han et al., 2017; Huang et al., 2019), and carbon dioxide emission trading systems (ETS) (Hua and Dong, 2019; Brand et al., 2012; Hickman et al., 2012; Brand et al., 2013; Han et al., 2017; Jin et al., 2014; Huang et al., 2019; Kumarappan and Joshi, 2011).

However, population growth and the GDP growth rate per capita have led to rapid economic growth, which is the main driving factor in greenhouse gas emissions in transportation (Berrittella et al., 2007; Timilsina et al., 2011; Lakshmanan and Han, 1997). For instance, GPD growth causes a continuous rise in household income and, in turn, the number of vehicles (Hensher, 2008). The economic growth variable causes an increase in the demand for transportation and hence, a rise in greenhouse gases and carbon emission. Lu et al. (2007) evaluated the factors influencing the emission of CO_2 greenhouse gases from road vehicles in Germany, Japan, South Korea, and Taiwan in 1990–2002. The results showed that economic growth and vehicle ownership are the most important factors of the increase in CO_2 emission. Moreover, Dulal et al. (2011) believe that the ownership of private vehicles by millions of people in developing countries is possible more than ever with a rapid increase in population, expansion of the middle class in developing countries, and the availability of cheaper vehicles. Economic growth can be viewed from another perspective. Rapid economic growth is a key approach toward implementing actions associated with developing a low-carbon transportation system (Dulal et al., 2011).

More comprehensive policies, such as road pricing (Bristow et al., 2008; Dulal et al., 2011; Nakamura and Hayashi, 2013; Bonachea et al., 2005; Anas and Lindsey, 2011; Kay et al., 2014), cause heavy vehicles to change their behavior due to the pricing initiative (Bonachea et al., 2005). In addition, converting external costs to calculated internal costs involves the following: accidents (injuries, casualties, and damages), pollutants (air pollution and greenhouse gases), noise, and costs with no return, such as preparation, operation, and maintenance costs of available equipment. Analysis has shown that 13.2% of personal costs must be added to external costs to convert them to internal costs (Forkenbrock, 1999). Moreover, an increase in fuel prices leads people to purchase vehicles with better fuel (O'Toole, 2008), considering actions related to fuel price indexes, such as increasing the price of fuel (including gasoline and diesel) to promote reducing the use of private vehicles and substituting public vehicles. The flexibility of the demand for fuel consumption given the price of gasoline for car users is estimated to be -0.25 in the short term and -0.77 in the long term (Graham and Glaister, 2004; Tirkaso and Gren, 2020).

The tax policies on transportation-related fuels can also significantly reduce greenhouse gas emissions (Tirkaso and Gren, 2020). A literature review indicates that imposing a fuel tax (or eliminating fuel subsidies) directly affects fuel demand and petroleum imports and hence, the emission of CO_2 greenhouse gases. Morrow et al. (2010) argue in their study that since the transportation sector produces one-third of the total greenhouse gases in the United States, direct fuel tax can be the largest factor in reducing CO_2 emissions in this country. Given estimates on the previous trends of energy demand its future trends, and the emission of greenhouse gases in China's transportation sector, Yan and Crookes (2009) developed a detailed model to derive a reliable historical trend of energy demand and GHG emissions who determined that the tax is one of the most important factors for achieving the set goals. Greenhouse gas reduction policies involve various economic tools, from taxes and subsidies to income transfer plans and quotas based on the carbon content of goods (Wing, 2007).

2.1.1.4. Demand. The higher the demand for transportation, the higher the transportation quantity and cost, which leads to an increase in carbon emission (Sarkar et al., 2016; Zhang et al., 2019b). The following factors have been considered in the literature: (1) Controlling road traffic depends on supply and demand factors (Emberger, 2017; Poudenx, 2008; Zhang et al., 2019b), (2) Demand management to reduce transportation-related pollution (Dulal et al., 2011; Jiang et al., 2017; Demir et al., 2014; Emberger, 2017; Akbari et al., 2020; Berrittella et al., 2007; Pradenas et al., 2013; Brand et al., 2013; Qin et al., 2019; Wang et al., 2020a; Trevisan and Bordignon, 2020), (3) Controlling the need for travels, which reduces the use of motor vehicles, reduces traffic congestion, exposes fewer people to road hazards, and hence, decreases greenhouse gas emission (Dulal et al., 2011; Jiang et al., 2017; Emberger, 2017; Berrittella et al., 2007), (4) Appropriate urban planning regulates demand (Jiang et al., 2017; Qin et al., 2019), (5) The choice of sustainable transportation modes (Hensher and Ton, 2002; Gan, 2003), (6) Urban planning, residential density, and employment and their potential effects reduce travel demand and the dependence on motor vehicles (Dulal et al., 2011), (7) Speed control for a given route in travels reduces fuel consumption (Demir et al., 2014; Qin et al., 2019).

Controlling the factors affecting the number of travels decreases the emission of carbon (Bristow et al., 2008). The factors increasing the number of travels are as follows: Cargo or passenger transportation with less than the vehicle's capacity, not using public transportation, not using alternative vehicles with less environmental danger, and not considering routing or non-optimal routing. Ehmke et al. (2016) investigated the change in transportation infrastructure and a decrease in the number and length of travels via changes in the routing (Bouman et al., 2017; Ehmke et al., 2016). With an increase in the distance traveled by a vehicle, the fuel consumption and, therefore, the carbon emission increase (Demir et al., 2014; Lakshmanan and Han, 1997). In research, Demir et al. (2014), Emberger (2017), and Berrittella et al. (2007) concluded that long-distance road transportation is the worst transportation option. In contrast, local road transportation is the best option for short distances. Jevinger and Persson (2016) proposed a novel method termed dedicated distance proportional allocation (DDPA) from allocating greenhouse gas emission quotas in transportation. DDPA can be used for transportation routes with several loading/discharge points with emission allocated based on a combination of the limiting factors. For trains and airplanes, one passenger more or one passenger less does not have a significant effect. However, an additional passenger on the road can mean an additional vehicle (Trevisan and Bordignon, 2020).

2.1.2. Environmental effects of railway transportation

Among various transportation modes, railway transportation has been recognized as green transportation and produces less environmental pollution compared to other transportation modes. It is the healthiest mode of transportation in terms of the environment (Krezo et al., 2014). In terms of the carried ton-kilometer per utilized energy unit, railway transportation is a more effective transportation mode than the road. Nevertheless, railway is not as flexible as road transportation, resulting in extensive cargo transportation via trucks worldwide (Demir et al., 2015). To provide guidelines for the executives and consultants of railway transportation plans, Tabesh et al. (2017) identified all the activities and aspects that affect the environment. They examined the environmental characteristics resulting from railway construction, including physical, chemical, and biological environments, and comprehensively analyzed and identified the parameters of each environment. Then, they presented the methods for identifying these parameters. More variables and controllable factors are investigated in the following section.

2.1.2.1. Planning and policymaking. Among the strategies applied to reduce greenhouse gas emissions in the studies performed in this field are the following: Administrative rules and regulations management (ARM) (Akbari et al., 2020); appropriate planning, and scheduling and preventing system delay from increasing the satisfaction level of customers and encouraging them to use less hazardous transportation modes (Jemai et al., 2012; Kabadurmus and Erdogan, 2020; Zhang et al., 2019a); appropriate planning and scheduling for trains in the network (such as merging the trains, thoroughly utilizing rail capacity, and combining customer goods) (Jemai et al., 2012; Kabadurmus and Erdogan, 2020; Zhang et al., 2019a); planning for the number of trains present in each station, number of stops, and train waiting time in the station (Miandoab et al., 2020); vehicle routing for providing services to a group of customers (Jemai et al., 2012; Miandoab et al., 2020); creating an exclusive railway for cargo trains; using some of the capacity of the express railway to transport cargo with high added value (To, 2015); and improving the infrastructure, such as the rail network, tunnels, and bridges (Demir et al., 2015; Trevisan and Bordignon, 2020).

2.1.2.2. Technology. Some research has been conducted on the solutions for reducing carbon emissions in railway transportation innovations, which include the following: Technical development (Akbari et al., 2020; Chiba et al., 2021); improving locomotive technology (Boonpanya and Masui, 2021; Ehrenberger et al., 2021; Marin et al., 2010; Kim et al., 2011); alternative fuels (O'Toole, 2008; Trevisan and Bordignon, 2020; Kabadurmus and Erdogan, 2020; Krezo et al., 2014; Hassan and Nosheen, 2019; Gould and Niemeier, 2009; Fragiacomo and Francesco, 2017); changing the energy generation mix (CEG) (Ehrenberger et al., 2021; Xu et al., 2020; Kim and Van Wee, 2009); changing locomotives from steam types to diesel and electric types (Boonpanya and Masui, 2021; Ehrenberger et al., 2021; Hassan and Nosheen, 2019; Xu et al., 2020; Kim and Van Wee, 2009; Annadanam and Kota, 2019; Wang et al., 2019); hydrogen fuel cell locomotives (Marin et al., 2010); using NH3 (ammonia) in locomotives with hydrogen fuel (Hassan and Nosheen, 2019; Martinez et al., 2015); high-speed trains (Wang et al., 2019; Cascetta et al., 2020; Khan et al., 2018; Janic, 2003); bullet trains (Khan et al., 2018); and lightweight rails (Khan et al., 2018).

The railway industry in India has a major role due to its efficiency and large passenger and cargo transportation network. A considerable increase in locomotive transportation has occurred with the change of locomotives from steam to diesel and electric in the recent decades. Table 1 displays suggested environmental pollution factors for steam, diesel, and electric locomotives suggested by the Intergovernmental Panel on Climate Change (IPCC) and the European environmental agency (EEA). The default emission factors were taken from the IPCC and EEA guidelines. All the diesel locomotives were assumed to use diesel fuel with a density of 0.84 kg/l and NCV of 43 TJ/Gg. The steam locomotives were assumed to use the sub-bituminous coal with an NCV of 18.9 TJ/Gg. The emissions from the electric locomotives were estimated by considering the contribution of thermal power plants in power generation and the distribution losses. The electricity at the thermal power plants was assumed to be generated using

Table 1
Fuel emission factors for steam, diesel, and electric locomotives.
Source: Ehrenberger et al. (2021).

	SO_2	PM	CO	NOx	N_2O	CH_4	CO_2
Steam	900	108	931	173	1.5	2	96100
Diesel	2	32	249	1219	28.6	4.15	74100
Electric	820	3.4	8.7	209	1.5	1	94600

subbituminous coal having a net calorific value of 18.9 TJ/Gg,s and the fuel required was considered to be 0.72 kg/kWh (Annadanam and Kota, 2019).

Based on the CEG scenario, carbon emission will reduce substantially if less coal is used as the primary source of supplying electrical energy, and if electrification is performed with higher quality. In the UK, only 6.7% of all electricity is produced from coal (Xu et al., 2020). Investment in the high-speed train can effectively reduce domestic air transportation pollution (Wang et al., 2019). However, electrification of railway transportation is a promising alternative for reducing noise and greenhouse gas emissions, especially for trains operating in populated urban areas. Marin et al. (2010) have addressed the adverse effects of electrifying railway transportation and believe hydrogen fuel cell locomotives to be suitable alternatives. Hydrogen trains are more flexible than electric trains and need more space on the sides of the rails than diesel trains. The expenditures for rights of way for an electrified train affect the total predicted cost for the railway given the additional land needed for catenaries, substations, and related safety items. Martinez et al. (2015) analyzed the correction of two types of fuel (diesel and natural gas) on diesel locomotives. The use of natural gases increases the system's efficiency by an average of 60%, reduces fuel consumption, reduces CO_2 emissions by about 53.8%, and decreases NOx by about 97.7%, which can be attained through careful integration of the reformer unit. It has been shown that using natural gas leads to a better system and remarkable reductions in the production of greenhouse gases and fuel consumption. In addition, Martinez et al. (2015) examined the potential of a locomotive with the help of hydrogen using NH_3 (ammonia) as a direct alternative for fuel and hydrogen, which has led to a 53% reduction in greenhouse gas emissions and fuel consumption.

2.1.2.3. Economics. Since population growth and the rate of growth in per capita GDP lead to a rapid economic growth, which is the main driving factor in greenhouse gas emissions in transportation, economic growth is a powerful pollutant (Timilsina et al., 2011; Kabadurmus and Erdogan, 2020; Lakshmanan and Han, 1997; Khan and Khan, 2020). Moreover, railway transportation is known as an economic growth factor, but its environmental damage costs are not considered (Hassan and Nosheen, 2019). The economic factors affecting the reduction in pollution due to railway transportation include the following: (1) decision-making about the optimal pricing of railway cargo transportation (Tamannaei et al., 2021; Khan and Khan, 2020; Guo et al., 2020; Janic and Vleugel, 2012), (2) competitive pricing of the total social cost of different transportation modes (Demir et al., 2015; Forkenbrock, 2001; Kim et al., 2011), (3) fuel pricing (O'Toole, 2008; Graham and Glaister, 2004; Tirkaso and Gren, 2020), (4) pollutant pricing (Demir et al., 2015; Boonpanya and Masui, 2021), (5) economic growth following technological growth (in Italy, using high-speed trains has resulted in economic growth, market regulation, transportation availability, positive social effects, reduction in greenhouse gas emissions, and reduction in accident costs) (Cascetta et al., 2020; Khan and Khan, 2020), (6) discount plans for railway transportation in comparison with other modes (Kabadurmus and Erdogan, 2020), and (7) considering tax policies (Bristow et al., 2008; Tirkaso and Gren, 2020; Morrow et al., 2010; Yan and Crookes, 2009; Wing, 2007).

Limiting and pricing greenhouse gases as the main mechanism for controlling them will lead to a 4% reduction in total production, 3.4% in domestic consumption, and 1.2% in GDP compared to business as usual (BaU). Therefore, introducing reduction measures in the goods transportation sectors and making new investments in the transportation sector, such as the generation of low-carbon fossil-based energy and the development of novel technologies, increases generation, household consumption, and GDP (Boonpanya and Masui, 2021). The external cost of using HSR is 70% less than vehicles and 59% less than airplanes. Moreover, the carbon dioxide produced per person who travel with HSR during one year is about 700 thousand tons less per year than in road and air transportation (Cascetta et al., 2020).

2.1.2.4. Demand. The higher the demand for transportation, the higher the transportation quantity and cost, indicating an increase in carbon emission (Sarkar et al., 2016; Zhang et al., 2019b). The following factors have been considered in the literature: Controlling the need for travel due to supply and demand factors (Trevisan and Bordignon, 2020; Miandoab et al., 2020; Khan and Khan, 2020); controlling traffic congestion (Trevisan and Bordignon, 2020; Miandoab et al., 2020); travel demand management (TDM) (Akbari et al., 2020); planning for the average number of demands for using the train in stations, the number of planned or unplanned stops, and delay in the intermediate stations (Miandoab et al., 2020); controlling the distance range (Kim and Van Wee, 2009; Zhang et al., 2020); and further use of railway transportation in long distances with large demands (Kim et al., 2011; Kim and Van Wee, 2009). Railway can be an importer or exporter of carbon dioxide pollution depending on the demand in various economic fields, especially in civil and service areas (Du et al., 2019).

2.1.3. Environmental effects of marine transportation

About 90% of international transportation consists of marine transportation because it is one of the most suitable methods of carrying cargo in terms of cargo volume and economics. The main sources of marine pollution include the following: (1) ship propulsion system, (2) auxiliary power systems, which provide for the power needs of the ship during various operations, and (3) auxiliary boilers, which produce water and hot steam for use by the engine room and crew (Kontovas, 2014). Almost 3% of the total CO_2 emission comes from marine transportation (Emberger, 2017; Bouman et al., 2017). If a given load is carried by ship instead of an airplane, an approximate 90% reduction in CO_2 production per ton-kilometer will occur (Michaelowa and Krause, 2000). Containerships are among the most important producers of marine CO_2 with more than 70 million metric tons of fuel consumption and more than 230 million metric tons of CO_2 production, which is equivalent to 22% of the total CO_2 production by global shipping. Compared to bulk ships, oil tankers, and regular cargo ships, this number is 1.3, 2.2, and 2.5 times larger, respectively (Corbett et al., 2009). Almost 70% of shipping pollution occurs within 400 km of shores (Eyring et al., 2010). The port sector increasingly acts as the driving force behind carbon reduction policies in the marine sector (Mellin and Rydhed, 2011; Gibbs et al., 2014). More variables and controllable factors are investigated in the following section.

2.1.3.1. Planning and policymaking. Among the strategies applied to reduce greenhouse gas emissions in the studies performed in this field are the following: (1) lowering tool implementation complexity through stronger collaboration within global value chains and enhancing emission visibility through alliances with cargo-owners and regulators (Poulsen et al., 2018), (2) sharing experiences related to the results of methods of implementing various tools for reducing pollution by ports with respect to leaseholders, trucks, trains, and wharf ships (Poulsen et al., 2018), (3) incentive policies for controlling and reducing pollution for cargo owners (Poulsen et al., 2018), (4) managing ship speed with the aim of achieving less CO_2 emission (Kontovas, 2014; Corbett et al., 2009; Kontovas and Psaraftis, 2011; Wu et al., 2021), (5) optimal routing and scheduling aimed at reducing travel time (Peters et al., 2011; Jemai et al., 2012; Kontovas, 2014; Kontovas and Psaraftis, 2011), (6) controlling the load-carrying capacity (especially upon loading and unloading) (Kontovas, 2014; Styhre et al., 2017), (7) managing and controlling petroleum extraction from the sea (Peters et al., 2011), (8) using a strong regulation monitoring system and emission reduction control standards (Michaelowa and Krause, 2000), (9) management and planning of implementing effective factors (such as examining the capacities and technologies available to each port, controlling the speed within the wharf limits, studying the operational issues for controlling ship mobility especially for cargo ships and oil tankers, supplying alternative fuel and on-shore energy sources especially for containerships during loading and unloading, and improving harbor conditions) (Kontovas and Psaraftis, 2011; Styhre et al., 2017), and (10) energy consumption efficiency. Corbett et al. (2009) believes that a reduction in the ship speed results in 20% less CO_2 emission, which will cost $30 to $200 per ton of CO_2 for containerships. This decrease has been reported for 70% containerships, which will be achieved by halving the speed.

2.1.3.2. Technology. There are research works about the solutions for reducing carbon emissions in the transportation sector, be divided into several groups.

1. The first group mainly involves alternative fuel sources with less carbon content, such as marine gas oil (Bengtsson et al., 2012), hydrogen fuel cells (Gibbs et al., 2014; Cullinane and Cullinane, 2013; Ozturk et al., 2021), low-Sulfur fuels (Cullinane and Cullinane, 2013), biofuels (Bengtsson et al., 2012; Cullinane and Cullinane, 2013), nuclear power (Gibbs et al., 2014; Cullinane and Cullinane, 2013), wind and solar (Cullinane and Cullinane, 2013), and liquid natural gas (LNG). Although changes in fuel usually have a large impact on emissions, it requires changes in engine technology. However, some fuels can be used with minor changes in existing engines. According to previous studies, both diesel and biogas can be mixed with their petroleum-based counterparts and are considered suitable alternatives, especially for shipping. Nevertheless, using these alternative fuels has its own challenges (Bengtsson et al., 2012). Bengtsson et al. (2012) has evaluated the life cycle of two alternative routes for biofuels in the shipping industry, namely the diesel route and the gas route. The diesel route involves changing from heavy fuel oil to marine gas oil, and then, to biodiesel. In contrast, the gas route involves changing to liquefied natural gas, and then, to liquefied biogas. Experimental results have shown that the gas route exhibits better environmental performance than the diesel route. Moreover, the use of biofuels is a suitable solution for reducing the global warming effect due to shipping.
2. The second group consists of studies that mention ship technologies and ports. Changes in the body design and dimensions of ships (Gibbs et al., 2014); seawater scrubbers and filters (Cullinane and Cullinane, 2013); Selective Catalytic Reduction (SCR) (Cullinane and Cullinane, 2013); Humid Air Motor (HAM) (Cullinane and Cullinane, 2013); Shore-Based Power ('Cold Ironing') (Cullinane and Cullinane, 2013); changes in the port infrastructure (Demir et al., 2015; Gibbs et al., 2014); and the use of novel tools and technologies to update the data required for pollution analysis (López-Navarro, 2014; Boonpanya and Masui, 2021; Styhre et al., 2017; Miola and Ciuffo, 2011) are actions that improve energy efficiency and reduce greenhouse gas emission.
3. The third group involves information technologies and includes the following: the computer program called Voyage and Vessel Optimization System (VVOS), which leads to a reduction in fuel consumption, optimal speed, and route management, which results in about 2%–4% saving in greenhouse gases without an increase in transit time (Ballou et al., 2008); Total energy and emissions analysis for marine systems (TEAMS) model, which can analyze six types of fuel conversion (including oil to residual oil, oil to regular diesel, oil to low-sulfur diesel, natural gas to compressed natural gas, natural gas to Fischer–Tropsch diesel, and soybean oil to biodiesel for pollutants such as CH_4, CO_2, N_2O, natural pollutants, CO, nitrogen oxides, sulfur oxides, and aerosols), leads to reduction in fuel consumption (Winebrake et al., 2007), and is a complex-activity-based methodology with the support of ship-to-ship communication systems and automatic identification system (AIS) that obtains a reasonable estimate of ship pollution (Song, 2014).

2.1.3.3. Economics. Given the increase in economic activities and international trade, marine transportation causes a rise in emissions in parallel with its own increase (Cullinane and Cullinane, 2013). Marine transit will increase due to the increase in marine space and the opening of shorter and hence, more profitable routes. One tool for controlling pollution reduction is imposing fuel tax, given that a fuel tax of $150 per ton reduces CO_2 emission by 20% to 30% (Michaelowa and Krause, 2000; Corbett et al., 2009). Based on an agreement with the implementation of various CO_2 emission reduction plans in Swedish ports, these plans have been ranked as follows: (1) imposing independent port costs for CO_2 emission: 97%, (2) implementing technical standards: 92%, (3) implementing CO_2 taxes: 84%, and (4) implementing the European Union (EU) commercial pollution plan: 74% (Mellin and Rydhed, 2011). Among the costs that must be considered is social cost tax collection, which includes the effect of pollution on human health, the environment, and the climate of coastal areas (Demir et al., 2015; Song, 2014).

2.1.3.4. Demand. The higher the demand for cargo and passenger transportation in ports, the larger the quantity and cost of transportation, which leads to an increase in the percentage of emission of greenhouse gases (Styhre et al., 2017). Tzannatos (2010) addressed the examination and accurate control of emission from passenger ship exhaust at the Port of Piraeus according to the demand in different seasons. The human population and the seasonal demand directly affect pollutants. With an increase in demand in the summer, the demand for passenger transportation increases, leading to maximum emission in this season. Saraçoğlu et al. (2013) conducted research on the emission of exhaust gases from ships in the Port of Izmir, the main port in Turkey, using a method based on ship activity (demand fuel type, ship speed, and ship type). They found that the ships in the Port of Izmir are an air-polluting factor in the city of Izmir and its surroundings.

2.1.4. Environmental effects of air transportation

Air transportation is considerably more damaging than the emission figures represent (Van Fan et al., 2018; Chapman, 2007;

Larsson et al., 2018; Yu et al., 2020; Ansell and Haran, 2020). In the EU, air transportation is responsible for 13.3% of greenhouse gas production in the transportation area (Van Fan et al., 2018). General aviation worldwide is responsible for 5% of greenhouse gas emissions and is still growing (Larsson et al., 2018). The aviation industry is the main source of greenhouse gas emissions at high altitudes, and due to high-altitude emissions, the greenhouse effect can be more than three times that of landfill gas (Yu et al., 2020). The aviation industry on the global level is almost totally dependent on carbon-based fossil fuels, especially kerosene. When fuel burns inside an airplane engine, the jet engine produces heat, noise, and a mixture of greenhouse gases. In addition to airplanes, ground access equipment in airports (such as buses and taxis), transportation equipment inside the airport (such as baggage carts), and the internal power generation system of the airport all cause the airport to be a remarkable source of gas production (Shaari et al., 2020; Baxter et al., 2020; Rondinelli and Berry, 2000). Due to the scale of the aviation industry, the annual global damage reaches more than one billion dollars in noise and ten billion dollars in climate change (Shaari et al., 2020). In the next section, more variables and controllable factors are investigated.

2.1.4.1. Planning and policymaking. Among the strategies applied to reduce greenhouse gas emissions in the studies performed in this field are the following: using alternative transportation methods (Simões and Schaeffer, 2005); using solutions termed end of pipe (EOP), such as control systems that reduce emissions without decreasing energy production activities (these solutions are usually more economic for the aviation industry) (Bollen and Brink, 2014); creating a monitoring system for the use of novel technologies (Wang et al., 2020b); planning for the resolution of numerous challenges concerning the commercialization and large-scale implementation of air transportation technologies (Ansell and Haran, 2020); government focusing on increasing fuel efficiency via planning for aircraft technology (Jovanovic and Vracarevic, 2016; Hassan and Mavris, 2020; Baharozu et al., 2017); optimizing routes and flights (Jemai et al., 2012; Yu et al., 2020; Lu and Wang, 2018); effectively leveraging route planning and fleet management (Jemai et al., 2012; Yu et al., 2020; Lu and Wang, 2018); policies focusing on a more accurate and efficient implementation of air transportation driving tools, which can reduce travel demand in addition to motivating the development and use of low-emission technologies (Jovanovic and Vracarevic, 2016; Hassan and Mavris, 2020; Lu and Wang, 2018); encouraging pilots to save fuel (Yu et al., 2020); providing passengers with information that can effectively improve their awareness (in this case, more passengers will pay for the environmental costs of their trip or travel in a more environmentally-friendly manner) (Lu and Wang, 2018); the government can regulate policies to encourage aviation companies to invest more resources to conform to international emission standards (Lu and Wang, 2018); giving priority to planning and policies for remote transportation due to its higher cost and fuel consumption compared to other modes of transportation (Baharozu et al., 2017); decreasing the route distance by optimizing the airspace structure and developing temporary routes (Jemai et al., 2012; Yu et al., 2020); coordinated developing of regional and large-scale network aviation (Yu et al., 2020); coordinated developing of passenger transportation and goods transportation (Yu et al., 2020); optimizing the runway–taxiway system (reducing the land taxi, etc. waiting time) (Yu et al., 2020); strengthening the carbon market and comprehensive management regulations (Yu et al., 2020; Lu and Wang, 2018); the government must control the market economy on a macro basis, such that it combines the economic policies with energy saving and emission reduction policies and fully uses market actions such as carbon emission trade and energy performance contract (Yu et al., 2020); and changing and introducing organizational processes or innovations in airport systems for participating in carbon reduction plans (which depend on public ownership, private ownership, and low-cost hubs usually identified with the lowest charge and taxes and the presence of low-cost airlines; private companies and low-cost hubs usually follow fewer environmental requirements) (Falk and Hagsten, 2020).

2.1.4.2. Technology. The most important reason for reducing carbon production efficiency in an airline has been changed with technology efficiency (Chapman, 2007; Wang et al., 2020b). Among the solutions applied to reduce greenhouse gas emissions in the studies performed in this field are the following: improving aviation operations and infrastructure (Demir et al., 2015; Singh, 2016); improving airplane engine performance (Baxter et al., 2020; Jovanovic and Vracarevic, 2016); using electrical carts (Baxter et al., 2020); using smart systems for optimizing the performance of the passenger terminal air conditioning (Baxter et al., 2020); designing light bodies for aircraft (Ansell and Haran, 2020; Singh, 2016); reducing the weights of airplanes via cabin material technologies (Lu and Wang, 2018); lightweight containers and cabin articles (Lu and Wang, 2018); CO_2-managed cabin Linke et al. (2020); hybrid laminar flow control (Linke et al., 2020); functional-driven moveables (depending on the technology combination, they can reduce fuel consumption in a secondary fleet of an airline by up to 7% and reduce NO_x emission by as much as 12%. Hence, by considering the effects of NO_x, H_2O, CO_2, and contrail cirrus, the impact of weather can be reduced by up to 7.7%) (Linke et al., 2020); improving the design of the combustion chamber (Baharozu et al., 2017); optimizing fuel consumption (Trevisan and Bordignon, 2020; Kabadurmus and Erdogan, 2020; Janic, 2003; Yu et al., 2020; Ansell and Haran, 2020; Baxter et al., 2020; Jovanovic and Vracarevic, 2016; Lu and Wang, 2018; Singh, 2016; Baumeister et al., 2020; Chao et al., 2019; Liu et al., 2020; Singh and Sharma, 2015); using systems that use solar cells as an energy source (Baxter et al., 2020); using auxiliary equipment with hydrogen fuel (Baharozu et al., 2017); alternative fuels such as vegetable kerosene (Simões and Schaeffer, 2005), hydrated alcohol (leads to roughly a 100% reduction in CO_2 production in the aviation industry) (Simões and Schaeffer, 2005), electrical power (Trevisan and Bordignon, 2020; Ansell and Haran, 2020; Baharozu et al., 2017; Baumeister et al., 2020; Liu et al., 2020; Pamplona and Alves, 2020; Schäfer et al., 2019). These measures have strongly reduced CO_2 emissions.

Moreover, due to the annual increase of 5% in air transportation demand, low-cost solutions such as a 0.3% decrease resulting from the optimization of air routes and a 0.2% decrease due to technology improvement will be incapable of countering the growth emissions. This necessitates the use of more costly solutions, such as fuel infrastructure modification. Although it has large financial and environmental savings in the long run, commercially producing new fuel is costly, and developing existing capacities to improve the fuel must not be underrated (Shaari et al., 2020). One alternative fuel solution is the use of electrical power in airplanes (Ansell and Haran, 2020; Baharozu et al., 2017; Baumeister et al., 2020; Liu et al., 2020; Pamplona and Alves, 2020; Schäfer et al., 2019). Designing electrical airplanes is the only path toward the zero-emission of greenhouse gases (Baumeister et al., 2020). In their research, Schäfer et al. (2019) examined the advancements in battery technology. These results include more energy, less cost, a reduction in CO_2 intensity, a reduction in direct CO_2 and non-CO_2 heating, noise reduction especially during the flight, and the total elimination of combustion. All-electric airplanes with a 800-watt-hour per kilogram battery packs can replace half of all airplane flights, reduce NO_x emissions in the airport zone by 40%, and reduce fuel consumption and direct CO_2 emission by 15%. Baumeister et al. (2020) studied the factors related to the emission level of CO_2 and real travel times (RTT) for First Generation Electric Aircraft (FGEA) using the door-to-door method on 47 routes with airplanes, trains, and automobile transportation modes. The emission level of greenhouse gases produced by electric airplanes are considerably reduced (down to that of trains) and finally reach zero. A comparison with land transportation modes shows that for distances up to 170 km, land transportation clearly performs better than electric airplanes (Baumeister et al., 2020).

In addition, information technology is capable of creating practical computer software to reduce emissions in air transportation, including the following: (1) broad-ranging integrated air traffic control system, which is inspired by the US's air traffic flow management system. This system is capable of simultaneously calculating the ideal altitude, speed, and route of the flight for individual airplanes and have a remarkable impact on optimizing fuel consumption up to 10% (Simões and Schaeffer, 2005), and (2) updating the air traffic control automation system, upgrading and improving existing communications, navigation, monitoring, and other systems in addition to strengthening the technical support of air traffic control for creating a practical flight plan and achieving the rational use of airspace (Yu et al., 2020). Technological improvement for reaching long-run environmental goals and operational advancements provides essential benefits in the short run (Wang et al., 2020b; Hassan and Mavris, 2020; Dessens et al., 2014).

2.1.4.3. Economics. A practical issue in commercial activities is air transportation, which is considered an indicator of public economic growth. For example, positive structural changes in Brazil, especially its high economic stability, are the main reason for the recent development in the air transportation sector of the country (Simões and Schaeffer, 2005; Saikawa et al., 2017). Studies have shown that in some areas of China, where economic development is faster, the government has constructed a large number of airports to respond to this issue, which has led to an increase in the number of airports and hence, an increase in pollution in these areas. Moreover, in areas where economic growth is slower, more equipped airports have been built than in areas with faster economic growth. This approach has an additional effect on the reduction in pollution in these areas (Hu et al., 2020).

One of the important tools for controlling emissions is imposing an air tax for fuel consumption (Simões and Schaeffer, 2005). Apart from the tax factor, important and effective is pricing fuel and carbon consumption and the increase in shipping rates (Yu et al., 2020; Chao et al., 2019). The price of oil-based airplane fuels and the corresponding rate of increase in carbon price are two important factors for determining whether the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) policies achieve emission reduction aims (Chao et al., 2019). Based on the conducted studies, the results show that the emission of 2050 carbon is inversely related to fuel price and directly related to the GDP rate. The GDP growth rate mostly leads to more travel demand. Implementing a plan of the CORSIA type can excite the demand for sustainable aviation fuels (SAF) and reduce carbon emission while maximizing airline profitability (Demir et al., 2015; Chao et al., 2019).

2.1.4.4. Demand. The higher the demand for passenger and cargo air transportation, the higher the pressure on the airport capacity, the lower the controllability of air traffic, the higher the congestion and more frequent delays, the higher the fuel consumption, and the higher the pressure of the air transportation on the environment in terms of noise, air pollution, and land occupation (Janic, 2003). An increase in demand and the rapid growth of air transportation in the future will increasingly lead to climate change. The focus of policies on more accurate and efficient implementation of the driving tools can reduce the demand for travels apart from motivating the development and using low-emission technologies (Trevisan and Bordignon, 2020; Jovanovic and Vracarevic, 2016). Using a travel demand prediction model to estimate the environmental effects, Pamplona and Alves (2020) show that the increase in air transportation demand also increases emissions. Furthermore, with a rise in personal income and low fares, a 4% increase in the demand is probable in the next two decades (Larsson et al., 2018). With an increase in fuel price, the price of tickets will rise, leading to a fall in passenger demand. In addition, a rise in GDP will lead to a rise in travel demand. However, a change in the fuel price has a more substantial effect on emissions compared to the growth rate in GDP (Chao et al., 2019).

Many long-distance trips are taken by air transportation. However, short-haul air journeys are also popular. According to previous studies, short-distance trips produce the most significant pollution per passenger of all air trips. The following are among the solutions for this challenge: (1) replacing air transportation with other transportation modes that produce much less pollution (this paper examines the potential of reducing greenhouse gas emissions by replacing air travels for distances shorter than 400 km with railway and road transportation modes) (Baumeister, 2019; Janic, 2003), (2) using electric airplanes for smaller distances (Baumeister et al., 2020), (3) encouraging the use of wide-body aircraft in popular domestic routes, and the use of low-fuel aircraft in long international routes (Yu et al., 2020), and (4) the possibility of replacing some of air passenger transport (APT) and short flights with equivalent high-speed railway (HSR) services. The corresponding effects are potential savings in the corresponding values and costs of social and environmental effects such as airport airside delays, noise and local and global greenhouse gas emissions (Janic, 2003, 2011).

From another perspective, Baxter et al. (2020) believes that the increase in the number of flights and passengers does not have a considerable effect on the emission of greenhouse gases providing control tools such as the following are used: improving the performance of aircraft engines, using auxiliary equipment with hydrogen fuel, using electric carts, using smart systems for improving the performance of passenger terminal air conditioning, and using systems that utilize solar cells as an energy source.

2.1.5. Environmental effects of intermodal transportation

Intermodal transportation is the intermediary between different industries. It drives production, and leads to economic, cultural, and social development. If suitable infrastructure exists for intermodal transportation, ships can be used for long marine routes, the railway can be used for long land routes, and road transportation can be used for short and special routes. This solution can effectively reduce the cost of transportation and reduce fossil fuel consumption, road accidents, increase the efficiency of the existing facilities and make it possible to provide transportation services throughout the country and other neighboring countries. The optimal combination of transportation methods with the simultaneous consideration of environmental hazards due to greenhouse gas emissions caused an increase in the carriage speed, reduced costs, and increased goods safety. Among its prominent features are the reduction in environmental hazards. By using low-emission transportation modes instead of high-emission ones, one can help reduce greenhouse gas emissions (López-Navarro, 2014; Kim and Van Wee, 2009).

2.1.5.1. Goals. Numerous studies have looked at the shift from high-risk transportation modes to intermodal transportation. The desired goals based on the previous studies are the following: intermodal transportation reduces energy consumption (López-Navarro, 2014; Kim and Van Wee, 2009); it encourages the rational use of infrastructure (López-Navarro, 2014); it reduces environmental effects by employing the high capacity of marine and railway transportation (López-Navarro, 2014; Kim and Van Wee, 2009; Kirschstein and Meisel, 2015); it uses the high flexibility in road transportation (López-Navarro, 2014); it reduces climate change (Baumeister, 2019; Kreutzberger et al., 2003; Janic, 2003), and noise pollution (Baumeister, 2019; Kreutzberger et al., 2003; Janic, 2003).

2.1.5.2. Solution. Based on previous studies, the following solutions have been considered: (1) reducing the share of hazardous transportation via policymaking (Winebrake et al., 2008), (2) the European Commission (2001) considers the internalization of external transportation costs to be an important motivation tool for intermodal transportation: "The integration of external costs must encourage the use of methods with less impact on the environment." (Kreutzberger et al., 2003), (3) increasing the coverage of external costs using taxes; the costs and subsidies in fair and efficient pricing (all the transportation costs are paid for by the transportation users) (Kreutzberger et al., 2003), (4) replacing railway transportation with trucks in markets for medium or long distance, using road transportation for short distances, or using intermodal transportation (because, in competitive terms, railway services are less efficient than road transportation, and this replacement will cause an approximate 30% reduction in emission savings) (Tamannaei et al., 2021; Janic and Vleugel, 2012; Kirschstein and Meisel, 2015; Tao and Wu, 2021), (5) encouraging pricing policies for the conversion to intermodal transportation (Kim and Van Wee, 2009), (6) using intermodal methods based on energy demand (Kirschstein and Meisel, 2015), (7) using short sea shipping (SSS), an advantage of SSS compared to transportation is its low fuel consumption (López-Navarro, 2014), and (8) an increase in environmental pressure (either by environment-aware consumers and producers or by governmental policy) may cause an increase in the use of railway transportation near coasts and shipping ports for long distances and the use of truck services for intermodal transportation and short distances (Winebrake et al., 2008).

2.2. The effect of pollutants on the selection of transportation

One of the major decisions that companies must make regarding transportation, is transportation mode because each mode has different characteristics, which will lead to different economic and environmental performances (Waller et al., 2008; Leal Jr. and Márcio de Almeida, 2011; Hoen et al., 2014; Konur and Schaefer, 2014). The choice of transportation mode has an important role in reducing carbon emission in the transportation and logistics system since making good decisions in this area has a remarkable impact on economic and environmental performance (Waller et al., 2008; Tsamboulas et al., 2007). One important factor affecting this decision-making is the awareness about carbon emission levels in different transportation modes. In the following, the opinions of researchers on this issue are examined (He et al., 2013).

Given the conducted studies, which transportation modes lead to the control of greenhouse gas emissions?

According to the latest information on the emission level of greenhouse gases in the transportation sector, the main factor is greenhouse gas production in road transportation, which currently makes up for 70% of total production (Morán and del Rio Gonzalez, 2007; Ong et al., 2011; Emberger, 2017; Javid et al., 2014; Han et al., 2017; Annadanam and Kota, 2019). In addition to cargo transportation on roads, which is the main cause of emissions, motor vehicles, buses, taxis, and intercity buses also play an important role (Chapman, 2007). Comprehensive index R*j* is based on the three indicators of (1) capacity, (2) responsibility, and (3) potential:

$$R_j = W_A A_j + W_B B_j + W_C C_j \quad (1)$$

where R_j is the index for road transport mode j, A_j is the ratio of the average fuel consumption of mode j to the industry average, B_j is the ratio of the annual average travel distance of mode j to the industry average, C_j is the ratio of vehicle possession for mode j to total vehicle possession, and W_A, W_B, and W_C are the respective weights of the indicators. This comprehensive index was calculated in a Chinese research that discovered that mini trucks have the biggest index — 16%, while light trucks have the smallest, 10.9% (Han et al., 2017). Cargo transportation uses almost 43% of all transportation energy (Chapman, 2007). Apart from road transportation, the aviation industry is the main source of greenhouse gas emission in high altitudes. The greenhouse effect due to high-altitude emissions can reach three times that of landfill gases (Van Fan et al., 2018; Chapman, 2007; Demir et al., 2015; Larsson et al., 2018; Yu et al., 2020; Ansell and Haran, 2020; Shaari et al., 2020; Baxter et al., 2020). Due to the scale of the aviation industry, the annual global damage reaches more than one billion dollars in noise and ten billion dollars in climate change (Shaari et al., 2020). Moreover, marine transportation can carry large quantities of goods by ship at long distances via oceans, lakes, canals, or rivers at the lowest external emission costs (Demir et al., 2015; Kontovas, 2014). Almost 3% of the total CO_2 emission comes from marine transportation (Emberger, 2017; Bouman et al., 2017). The railway, being the green transportation, causes less environmental pollution compared to other transportation modes (Demir et al., 2015; Krezo et al., 2014). The railway transportation system is an industry that is expected to reduce the emission of greenhouse gases and contribute to the long-term reduction strategy. In the European Union, road transportation is responsible for producing more than 72% of greenhouse gases in the transportation sector, followed by air with 13.3%, marine with 12.8%, and rail transportation with about 0.5% share in emissions. The rest belongs to other modes of transport (Van Fan et al., 2018).

Moreover, the emission produced by one airplane at a short distance is 1.6 to 2.6 times that of traveling by a private vehicle, 2.3 to 4.5 times that of traveling on a bus, and 2.9 to 17.7 times that of traveling by train on the same route (Baumeister, 2019). This indicates the very large difference between the levels of greenhouse gas production in road and air transportation and those in other transportation modes. According to most of the research cited in Section 2.1, different transportation modes can be ranked in terms of emission in descending order as follows: road, air, marine, and railway transportation (Van Fan et al., 2018; Chapman, 2007; Ong et al., 2011; Emberger, 2017; Javid et al., 2014; Herold and Lee, 2017; O'Toole, 2008; Rodrigues et al., 2015; Han et al., 2017; Krezo et al., 2014; Kim et al., 2011; Kim and Van Wee, 2009; Annadanam and Kota, 2019; Cascetta et al., 2020; Janic and Vleugel, 2012; Du et al., 2019; Michaelowa and Krause, 2000; Poulsen et al., 2018; Cullinane and Cullinane, 2013; Simões and Schaeffer, 2005; Tao and Wu, 2021; van Ierland et al., 2000; Erdogan et al., 2020; Filimonau et al., 2014; Avetisyan, 2018).

Among the characteristics of railway and marine transportation are inexpensive transportation and applicability to bulky goods. Nevertheless, it must be considered in decision-making that these modes are always not available and places. In 1991, the European Commission adopted a policy for promoting the replacement of cargo transportation with railway and marine transportation as part of its agenda (Bouman et al., 2017; Tao and Wu, 2021). In addition, one policy in line with the Kyoto Protocol is a conversion from road and air transportation to marine and railway transportation, which is environmentally friendly (Rodrigues et al., 2015; Kim et al., 2011). Transporting one ton of cargo using the railway produces only 20% of the CO_2 produced by transporting it by road, and with an increase in the distance, the railway will become a more attractive option (Chapman, 2007). It is predicted that if transport switches from road to the railway, NO_x and CO_2 will decrease by 58% and 50%, respectively (Annadanam and Kota, 2019). For instance, the marine route from Rotterdam to Geneva is 4 times longer than the corresponding road route. The greenhouse gas emission of ships is much less, but aerosols' production and nitrogen oxides are much more than those of road vehicles (Van Fan et al., 2018).

Air transportation is also not economical for replacing road transportation due to its high price and limited capacity unless is used for sensitive, valuable, and luxury goods (Avetisyan, 2018). According to previous studies, it is short-distance air trips that produce the largest pollution per passenger. On the other hand, many of them can be replaced by other modes of transportation. By replacing air travels less shorter than 400 km long with road and railway routes, emissions will be considerably reduced (Baumeister, 2019). High-speed rail (HSR) has better environmental performance than air passenger transport (APT) (Janic, 2003). The emission factors related to cargo transportation indicate that containerships and cargo trains produce much less greenhouse gases (GHG) than air cargo and trucks (To, 2015). If a given load is carried by ship instead of an airplane, an approximate 90% reduction in CO_2 production per ton-kilometer will occur (Michaelowa and Krause, 2000). By replacing air and road transportation with trains and marine transportation, greenhouse gas emissions will be substantially reduced (Filimonau et al., 2014).

One of the best environmentally friendly options is intermodal transportation. Moreover, the difference in the emission between the intermodal road/marine option and the intermodal road/rail option is negligible. According to the Dutch study "Aagrunol Project", the emission of CO_2 with the barge option is always less than that with the railway option, whereas the emission of C_xH_y, CO, NO_x, and aerosol is higher (Kreutzberger et al., 2003). Intermodal transportation also reduces energy consumption, encourages the rational use of infrastructure, and reduces the environmental effects by using the high capacity of marine and rail transportation. In addition, it makes use of the higher flexibility of road transportation (López-Navarro, 2014; Kim and Van Wee, 2009). Hence, a logical solution for carrying cargo in long routes is converting the transportation mode to rail and marine transportation (Krezo et al., 2014; Annadanam and Kota, 2019; van Ierland et al., 2000). In addition, road transportation can be used in short routes due to its high flexibility (van Ierland et al., 2000). Table 2 presents a summary of the prioritization of different transportation modes based on their emission intensity.

2.3. Examining the obstacles to reducing pollution in transportation

The reduction of greenhouse gases in different societies faces obstacles and challenges. In the following, a number of these obstacles are addressed based on the research works studied in this paper:

- The lack of an efficient carbon and pollutant trade market (Liu et al., 2015b; Yang and Luo, 2020; Herold and Lee, 2017).
- Invalidity of quota allocation (Hua and Dong, 2019; Liu et al., 2015b; Herold and Lee, 2017).
- Correction of the constitution and the lack of a legal framework, service agency, and well-developed supervision system (Hua and Dong, 2019; Liu et al., 2015b; Yang and Luo, 2020; Herold and Lee, 2017).
- Shortages such as the absence of carbon price (Hua and Dong, 2019; Liu et al., 2015b). To sum up, the existing research works in carbon finance are not sufficiently deep, and many topics can be further discussed (Yang and Luo, 2020; Herold and Lee, 2017; Michaelowa and Krause, 2000).
- The increase in the cost of transportation and the price of goods is due to policy-making in the area of carbon commercialization (Hua and Dong, 2019; Hoffmann, 2010).
- The laws concerning carbon commercialization promote competition in the export of transportation services from developed countries. In contrast, they have a negative effect on the export and price of transportation services from developing countries, which have a higher emission rate in transportation. This approach has led to the objection of developing countries (Avetisyan, 2018; Hoffmann, 2010).
- The opposition of monopolies in hazardous transportation such as road and air transportation (Cullinane and Cullinane, 2013; Hoffmann, 2010).
- Resolving the obstacles to speed control of vehicles, such as the following: Increase in delay, increase in congestion, prolonging of the carrying process (Corbett et al., 2009), increase in cargo and passenger customer dissatisfaction with policies such as (1) the rise in fuel prices and taxes leading to an increase in the price of goods and services, (2) limitation and rationing in some industries leading to delays in travel time and good and service delivery, and (3) encouraging customers to use a specific type of alternative transportation and public transportation leading to the mistaken passenger assumption of a reduction in social services (O'Toole, 2008; Graham and Glaister, 2004).
- The double policies promote the development of public transportation while encouraging the purchase of private vehicles (Gan, 2003; La Notte et al., 2018) (state subsidies in line with supporting and encouraging the purchase of private vehicles to ensure the positive activity of vehicle manufacturers have negative effects on pollution and social culture) (Gan, 2003).
- The governments have relatively low motivation for increasing fuel efficiency and alternative fuels (Jovanovic and Vracarevic, 2016).
- The less advanced state of low-risk transportation such as railway transportation compared to other methods (Kim et al., 2011).
- Like other renewable energy sources, biofuel is used in the areas of heat, heat process, and economy in the most economical state. However, for biofuel, there are challenges such as (1) lack of agricultural space for producing the required oil seeds, (2) optimal economic technology for producing biofuel from oil seeds, (3) appropriate catalyst for increasing the amount of fuel obtained from the oil seeds, (4) storing biofuel, (5) confirming the emission characteristics of biofuel in the transportation sector (Azar et al., 2003; Chauhan et al., 2009).
- The challenges that electric airplanes will face include battery safety and charging time issues (Baumeister et al., 2020).
- Lack of strong tools to calculate the exact amount of emission (Nakamura and Hayashi, 2013; Herold and Lee, 2017; La Notte et al., 2018; Styhre et al., 2017; Song, 2014).
- Uncertainty in estimating greenhouse pollution due to transportation (Herold and Lee, 2017; La Notte et al., 2018; Miola and Ciuffo, 2011; Song, 2014).

Table 2
Prioritization of different transportation modes based on emission intensity.

Authors	Pollution generation according to the type of transportation (in descending order)					Description
	Road	Air	Marine	Railway	Multimodal	
Van Fan et al. (2018)	1	2	3	4	–	rail and marine methods are more efficient than road and air methods
Avetisyan (2018)	1	2	3	–	–	The marine method is more efficient than air and road methods
Filimonau et al. (2014)	1	1	–	2	–	The rail method is more efficient than air and road methods
Krezo et al. (2014)	–	–	–	4	–	The rail method is more efficient than other methods
Annadanam and Kota (2019)	1	–	–	2	–	The rail method is more efficient than the road method
Bouman et al. (2017)	1	–	–	2	–	The rail method is more efficient than the road method
Chapman (2007)	1	1	–	2	–	The rail method is more efficient than air and road methods
van Ierland et al. (2000)	1	–	–	2	–	The rail method is more efficient than the road method
O'Toole (2008)	1	–	–	2	–	The rail method is more efficient than the road method
Cascetta et al. (2020)	1	2	–	3	–	The rail method is more efficient than air and road methods
Kabadurmus and Erdogan (2020)	–	1	–	2	–	The rail method is more efficient than the air method
Michaelowa and Krause (2000)	–	1	2	–	–	The marine method is more efficient than the air method
Janic (2003)	–	1	–	2	–	The rail method is more efficient than the air method
Kabadurmus and Erdogan (2020)	2	1	3	3	–	rail and marine methods are more efficient than road and air methods
López-Navarro (2014)	1	–	2	2	3	Rail, marine and multimodal methods are more efficient than road method in long distances
Winebrake et al. (2008)	1	–	2	2	3	Rail, marine and multimodal methods are more efficient than road method in long distances
Kreutzberger et al. (2003)	1	–	2	2	–	Rail, marine and multimodal methods are more efficient than road method
Corbett and Winebrake (2007)	1	1	2	2	3	Rail, marine and multimodal methods are more efficient than road and air methods
To (2015)	1	1	2	2	–	Rail, marine and multimodal methods are more efficient than road and air methods
Khan et al. (2018)	1	2	3	3	–	rail and marine methods are more efficient than road and air methods
Janic and Vleugel (2012)	1	–		2	–	The rail method is more efficient than the road method
Kim et al. (2011)	1	–	2	2	–	rail and marine methods are more efficient than the road method
Kim and Van Wee (2009)	1	–		2	2	The rail-based hybrid method is more efficient than road method
Rodrigues et al. (2015)	1	–	2	2	2	Rail, marine and multimodal methods are more efficient than road method
Herold and Lee (2017)	1	–	–	2	2	Rail and multimodal methods are more efficient than road method

- Lack of flexibility in low-risk transportation industries such as railways and shipping compared to road and air transportation, including the following: (1) road transportation is door-to-door, but door-to-door transportation is impossible for rail and marine transportation, (2) long loading and unloading times in rail and marine transportation, (3) a long time required for cargo transportation since some parts of the railway has not been electrified yet; therefore, transportation using diesel locomotives decreases the train's speed (Kim et al., 2011).

3. Discussions and implications

Given the potential research between environmental attitudes and transportation behavior, this section investigates the trend in the studies and presents solutions for reducing emissions in the transportation sector by using a comprehensive summary of the papers studied in the literature review section. The table in Appendix A is a comprehensive summary of 200 papers examining the environmental effects of different transportation methods, such as road, rail, marine, air, and intermodal transportation. The tables in Appendices A–E summarize the solutions presented in the previous section for road, rail, marine, air, and intermodal transportation. Four variables – (1) planning and policymaking, (2) technology, (3) economy, and (4) demand – have been investigated for road, rail, marine, and air transportation. Subsequently, we will address the most important factors related to said variables. Fig. 1 shows the importance of the variables and the number of their instances in the studies for different transportation modes. Fig. 2 displays the percentage of instances of different transportation modes in the studies. Fig. 3 represents the percentage repetition of the variables in the studies, and Fig. 4 shows the number of instances of the most important factors relating to each variable in 4 transportation modes.

According to Figs. 1 and 2, most of the studies concern road (60%), air (26%), rail (28%), marine (22%), and intermodal (7%) transportation. As mentioned before, in the European Union, road transportation generates more than 72% greenhouse gases in the transportation sector, followed by air with 13.3%, marine with 12.8%, and rail transportation with about a 0.5% share in emissions. The rest belongs to other modes of transportation (Van Fan et al., 2018). This shows the large difference between the level of greenhouse gas production in road transportation with that of other modes of transportation in Europe. In this area, more studies have been conducted compared to other modes of transportation. However, this does not mean that other transportation modes are unimportant. Rather, they require further examination. Also, according to Figs. 1 and 3, the highest percentage of instances of said variables in the studies are related to (1) technology (67%), (2) planning and policymaking (53%), (3) economics (37%), (4) demand (29%). This indicates high importance of the technology variable. Bouman et al. (2017) believe that the emissions can be reduced by more than 75% by 2050 using the current technology. Technology provides environmental goals in the long run and operational advancements in the short

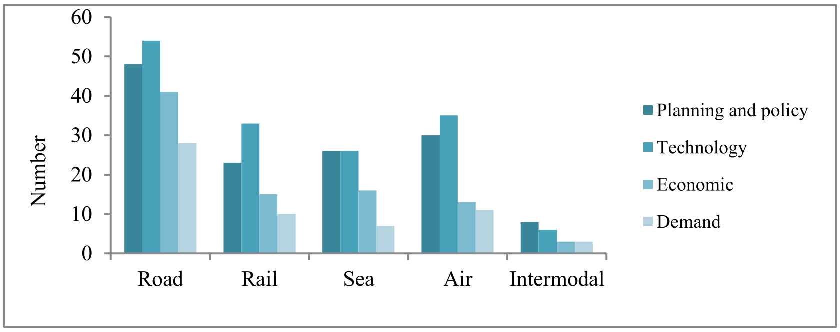

Fig. 1. The importance of the variables and the number of repetitions of them in the studies for different transportation modes.

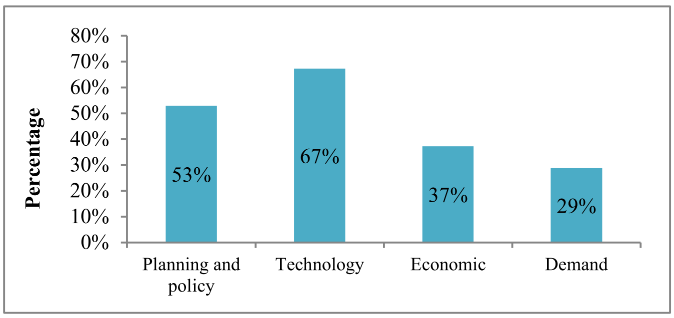

Fig. 2. The repetition of different transportation modes in the studies.

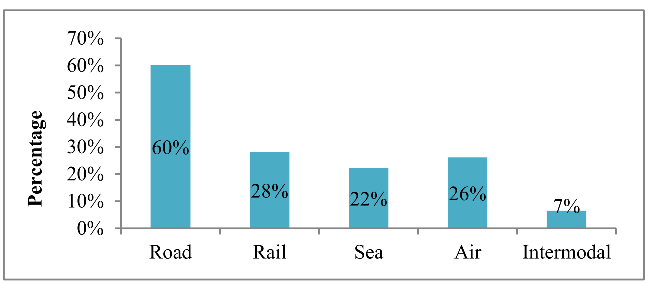

Fig. 3. The percentage of repetition of different transportation modes in the studies.

run (Chapman, 2007; Shaari et al., 2020; Wang et al., 2020b; Hassan and Mavris, 2020; Baumeister et al., 2020). As long as investment and behavior change policies are not made, technological advancement might be the only way of countering environmental damages (Chapman, 2007). To reduce carbon emissions in transportation, relevant authorities must simultaneously consider technology efficiency and the use of novel technologies (Wang et al., 2020b). Moreover, the planning and policymaking variable is very important for achieving stability in greenhouse gas emissions from transportation (Chapman, 2007; Akbari et al., 2020; Hickman et al., 2012; Hasan et al., 2019; Javid et al., 2014).

Numerous methods exist for reducing the production of greenhouse gases. The solutions suitable to each factor for decreasing greenhouse gases are as follows:

1. The solutions related to the management area are as follows: Strict monitoring of the implementation of laws (Jiang et al., 2017; Akbari et al., 2020; Herold and Lee, 2017; Demirel et al., 2008; Michaelowa and Krause, 2000; Wang et al., 2020b); appropriate planning and scheduling and preventing system delay (Dulal et al., 2011; Peters et al., 2011; Kopelias et al., 2020; Demir et al., 2014; Bouman et al., 2017; Akbari et al., 2020; Anas and Lindsey, 2011; Hensher and Ton, 2002; Berrittella et al., 2007; Pradenas et al., 2013; López-Navarro, 2014; Gan, 2003; O'Toole, 2008; Jemai et al., 2012; Kabadurmus and Erdogan, 2020; Zhang et al., 2019a; Kontovas, 2014; Kontovas and Psaraftis, 2011); preventing the destruction of agricultural lands due to the development of transportation networks (Demirel et al., 2008); separating GHG-emitting areas from residential areas (Jiang et al., 2017; Hensher and Ton, 2002); implementing scrapping and reinforcement plans for older vehicles (Jiang et al., 2017; Emberger, 2017); and sharing the experiences concerning the results for the methods of implementing different reduction tools (Jemai et al., 2012; Yu et al., 2020; Lu and Wang, 2018).
2. The use of alternatives for high-risk transportation includes the following: Rail and marine transportation are the best replacements for road and air transportation (Bristow et al., 2008; Van Fan et al., 2018; Chapman, 2007; Emberger, 2017; Berrittella et al., 2007; López-Navarro, 2014; O'Toole, 2008; Tamannaei et al., 2021; Krezo et al., 2014; Kim et al., 2011; Kim and Van Wee, 2009; Annadanam and Kota, 2019; Wang et al., 2019; Janic and Vleugel, 2012; Michaelowa and Krause, 2000; Simões and Schaeffer, 2005; Tao and Wu, 2021; van Ierland et al., 2000; Avetisyan, 2018).
3. The use of the road and air transportation in intermodal transportation, short (road) distances, transport of goods with less time limit and in locations with lack of rail, and marine transportation access (Chapman, 2007; Baumeister, 2019; Emberger, 2017; López-Navarro, 2014; O'Toole, 2008; Corbett and Winebrake, 2007; Kim et al., 2011; Annadanam and Kota, 2019; Khan et al., 2018; Khan and Khan, 2020; Janic and Vleugel, 2012; Tao and Wu, 2021; van Ierland et al., 2000).
4. Creating an exclusive railway for cargo trains, using some of the capacity of express railways for carrying cargo with high added value, and focusing on the high-speed railway (To, 2015; Xu et al., 2020; Wang et al., 2019).
5. Improving the quality of peripheral railway services and marine ports as an alternative, such as storing, and collecting cargo at railway stations and reducing the fare and giving discounts for long-distance cargo can improve the quality of access points in the service network (Kim et al., 2011).
6. Planning and evaluating changes in the network, such as extending the highway capacity, improving the facilities for intermodal transfer, natural or human-made disasters, improving the infrastructure for predicting future cargo transportation needs, or the effect of taxes or other policies (Corbett and Winebrake, 2007).
7. Planning for public transportation vehicles as an alternative for private vehicles, such as the following: Planning and

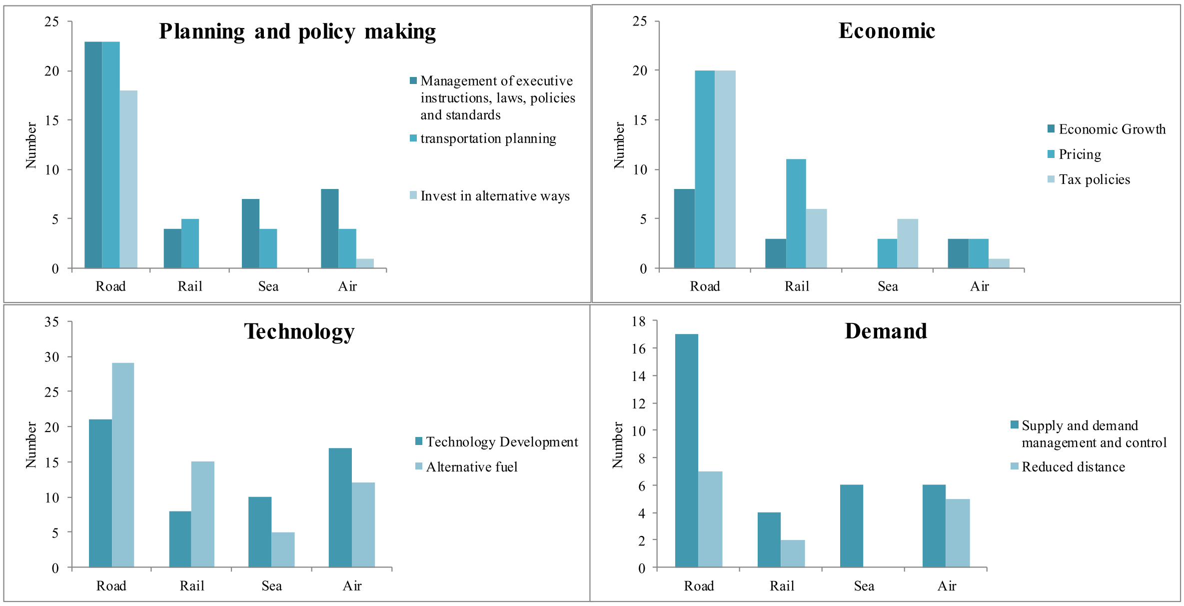

Fig. 4. The number of repetitions of the most important factors relating to each variable in the four transportation modes.

scheduling public transportation to prevent delays and reduce the system traffic in order to increase the customer satisfaction level (O'Toole, 2008; Corbett and Winebrake, 2007); investment for building advanced public transportation systems (Emberger, 2017; Nakamura and Hayashi, 2013; Hensher and Ton, 2002); creating public transportation methods capable of competing with private vehicles and providing better environmental performance (Hensher and Ton, 2002; Poudenx, 2008); optimal network routes that minimize emission, cost, travel time, or lead to other goals (Corbett and Winebrake, 2007); considering facilities for decarbonizing public transportation vehicles (Bristow et al., 2008; Emberger, 2017); moving public transportation vehicles on crowded routes, e.g., metro and bus (O'Toole, 2008); creating facilities, developing public transportation in cities, and enabling easy commute (O'Toole, 2008; Waygood and Avineri, 2016); using smaller public transportation vehicles at times of lesser commute and in regions with less demand (O'Toole, 2008); culture building and public education regarding the environmental hazards of transportation (Nakamura and Hayashi, 2013; O'Toole, 2008; Kabadurmus and Erdogan, 2020; Styhre et al., 2017; Lu and Wang, 2018; Waygood and Avineri, 2016); using media to raise awareness about the impact of pollutants and the advantages of carbon offsetting plans, which can help passengers to have a positive attitude toward changing the travel behavior (Lu and Wang, 2018).

8. Culture building and public education regarding the environmental hazards of transportation (O'Toole, 2008; Lu and Wang, 2018; Erdogan et al., 2020; Waygood and Avineri, 2016).
9. Using media to raise awareness about the impact of pollutants and the advantages of carbon offsetting plans can help passengers have a positive attitude toward changing travel behavior (Lu and Wang, 2018).
10. The creation of incentive plans and policies to convince monopolies in high-risk transportation (Cullinane and Cullinane, 2013; Hoffmann, 2010); incentive plans for ports, managers, and staff, for fulfilling obligations and capacities and using available technologies (Styhre et al., 2017); making policies to encourage airline companies to invest more resources for conforming to international emission standards (Lu and Wang, 2018); encouraging pilots to save fuel (Yu et al., 2020); persuading people to buy less-polluting vehicles (O'Toole, 2008); encouraging passengers to use public transportation or less hazardous transportation (O'Toole, 2008; Tamannaei et al., 2021; Waygood and Avineri, 2016); encouraging people to use bicycles and walk (Gan, 2003); giving discounts to reward customers or transportation industries with less pollution; and the presentation of incentive plans by governments, which simultaneously punish high carbon emission and reward low carbon emission (Brand et al., 2013).
11. Exerting political pressure on governments with the aim of changing their behavior regarding pollutants (Chapman, 2007; Falk and Hagsten, 2020); focusing on long-term technological solutions (Chapman, 2007); raising awareness among managers and authorities concerning the implementation of regulations and the disadvantages of disobeying them (Styhre et al., 2017); the need for invasive policy-making (especially the policies of pricing and technology in the form of increased carbon efficiency in vehicles) (Kay et al., 2014).
12. Making control policies for the owners and manufacturers of vehicles, such as the following: Imposing time limits and cost in highways for carrying cargo with trucks (O'Toole, 2008); reducing the weight of vehicles (Demir et al., 2014; Jemai et al., 2012); controlling the speed of vehicles (for example, reducing the speed of containerships can have a remarkable effect of up to 70% on CO_2 emission; nevertheless, the costs of this speed reduction are the largest obstacle in the way, which can be removed by adding ships to this system) (Demir et al., 2014; Jemai et al., 2012; Corbett et al., 2009; Styhre et al., 2017); decreasing cargo volume (Demir et al., 2014; Jovanovic and Vracarevic, 2016); new toll roads (Hensher and Ton, 2002); taxes for gas-guzzlers (Hensher and Ton, 2002); implementing changes in fares (Hensher and Ton, 2002); changing parking policies (Hensher and Ton, 2002); taking actions for and introducing low-consumption vehicles (Hensher and Ton, 2002).

13. Planning and policymaking for the carbon market, such as the following: universal pricing of carbon (Hua and Dong, 2019; Kay et al., 2014; Avetisyan, 2018); imposing universal taxes on GHG, directly limiting the use of carbon-based fuels via universal GHG taxes (Avetisyan, 2018; Ward et al., 2017; Voigt et al., 2014); allocating carbon quota (Hua and Dong, 2019); considering the mandatory carbon emission capacity (Dissanayake et al., 2020); limiting carbon to the carbon emission trade system (Dissanayake et al., 2020); creating an efficient and advanced international carbon trade market (Nakamura and Hayashi, 2013; Hua and Dong, 2019; Liu et al., 2015b; Herold and Lee, 2017); the lack of a comprehensive protocol, legal framework, service agency, and a supervision system for the carbon market (Nakamura and Hayashi, 2013; Liu et al., 2015b; Herold and Lee, 2017; Ansell and Haran, 2020); making incentive plans and policies for persuasion and increasing customer satisfaction and the cooperation of developing countries with high emission rates (Liu et al., 2015b); and plans for supporting market attractiveness through political intervention (Emberger, 2017).
14. Investment for creating, improving, and buying technology (Bristow et al., 2008; Ong et al., 2011; Kopelias et al., 2020; Emberger, 2017; Nakamura and Hayashi, 2013; Akbari et al., 2020; O'Toole, 2008; Seo et al., 2021; Fragkos et al., 2021; Baptista et al., 2012; Yaqoob et al., 2021; Li et al., 2021; Wang et al., 2020a; Banister, 2011; Chiba et al., 2021; Ehrenberger et al., 2021; Marin et al., 2010; Annadanam and Kota, 2019; Martinez et al., 2015; Gibbs et al., 2014; Cullinane and Cullinane, 2013; Ozturk et al., 2021; Ballou et al., 2008; Shaari et al., 2020; Jovanovic and Vracarevic, 2016; Baharozu et al., 2017; Singh, 2016; Baumeister et al., 2020; Hu et al., 2020).
15. Implementing intelligent transportation system (ITS) technologies (Emberger, 2017; Song, 2014).
16. Creating smart software for finding optimal routes in the network in various transportation modes (Corbett and Winebrake, 2007).
17. Using structural equation modeling to identify the key factors affecting the potentials for reducing GHG emission in transportation (Singh, 2016).
18. Developing and implementing new technologies and engines for road transportation (Emberger, 2017).
19. The development of communication technology such as the Internet, email, and video conference, which people can use to work from home instead of commute (Chapman, 2007).
20. Creating technologies for reducing the uncertainty in emission estimation (La Notte et al., 2018).
21. Creating facilities, investing, and strengthening the infrastructure related to alternative transportation for road and air transportation and fleet renovation, such as constructing railways in high-demand areas, purchasing wagons and locomotives, and constructing new roads (Emberger, 2017; Chen et al., 2021; O'Toole, 2008; Fragkos et al., 2021; Corbett and Winebrake, 2007; Trevisan and Bordignon, 2020; Singh, 2016; Hu et al., 2020).
22. A positive road slope can lead to increased fuel consumption and must be considered in route planning (Demir et al., 2014).
23. The use of the experiences of industrial countries, especially new technological innovations, by developing countries (there is no reason to repeat the past mistakes developed countries in transportation) (Gan, 2003)
24. Using alternative fuels for different transportation modes such as the following: electric vehicles (Annadanam and Kota, 2019; Ansell and Haran, 2020; Aryanpur and Shafiei, 2015; Azar et al., 2003; Baharozu et al., 2017; Baptista et al., 2012; Baumeister et al., 2020; Baxter et al., 2020; Boonpanya and Masui, 2021; Brand et al., 2012; Chakraborty et al., 2020; Ehrenberger et al., 2021; Emberger, 2017; Fragkos et al., 2021; Grahn et al., 2009; Hassan and Nosheen, 2019; Kim and Van Wee, 2009; Li et al., 2021; Liu et al., 2020; Navas-Anguita et al., 2019; Pamplona and Alves, 2020; Schäfer et al., 2019; Saikawa et al., 2017; Trevisan and Bordignon, 2020; Wang et al., 2019; Watabe et al., 2019; Xu et al., 2020; Yaqoob et al., 2021); hydrogen fuel cell (Demir et al., 2014; Hensher, 2008; Azar et al., 2003; Watabe et al., 2019; Tong et al., 2015; Grahn et al., 2009; Salvi and Subramanian, 2015; Banister, 2011; Marin et al., 2010; Gibbs et al., 2014; Cullinane and Cullinane, 2013; Baxter et al., 2020; Baharozu et al., 2017; Cuda et al., 2012); biofuels (Ong et al., 2011; Emberger, 2017; Navas-Anguita et al., 2019; Baptista et al., 2012; Azar et al., 2003; Grahn et al., 2009; Chauhan et al., 2009; de Souza et al., 2013; Kaufman et al., 2010; Bengtsson et al., 2012; Cullinane and Cullinane, 2013); natural gas (Ong et al., 2011; Emberger, 2017; Navas-Anguita et al., 2019; Yaqoob et al., 2021; Watabe et al., 2019; Tong et al., 2015; Grahn et al., 2009; Eyre et al., 1997; de Souza et al., 2013); hybrid fuel (Grahn et al., 2009; Nakata, 2000); liquid gas (Ong et al., 2011; Emberger, 2017; Navas-Anguita et al., 2019; Baptista et al., 2012; Yaqoob et al., 2021; Tong et al., 2015; Grahn et al., 2009; Eyre et al., 1997; Cullinane and Cullinane, 2013); marine gas oil (Bengtsson et al., 2012); low-sulfur fuels (Cullinane and Cullinane, 2013); nuclear power (Gibbs et al., 2014; Cullinane and Cullinane, 2013); wind and solar (Cullinane and Cullinane, 2013; Baxter et al., 2020); using NH_3 (ammonia) in hydrogen-powered locomotives (Hassan and Nosheen, 2019; Martinez et al., 2015); vegetable kerosene (Simões and Schaeffer, 2005); hydrated alcohol (results in about 100% reduction in CO_2 in the aviation industry) (Simões and Schaeffer, 2005).
25. Creating the technologies required for alternative fuels, including the primary sources, production technologies, storing, transportation, and distribution (Salvi and Subramanian, 2015).
26. Using end of pipe (EOP) technology, such as control systems, reduces emissions without undermining production activities (Bollen and Brink, 2014).
27. Lack of accurate instruments for measuring emission (Demir et al., 2014; Nakamura and Hayashi, 2013; Herold and Lee, 2017).
28. Large-scale control of market economics by the government such that it combines economic policies with energy-economy and emission reduction policies (Yu et al., 2020; Singh, 2016).
29. Converting external costs to calculated internal costs involves the following: accidents, pollutants, noise, and irreversible expenditures, such as preparation, operation, and maintenance costs of general equipment (Nakata, 2000; Forkenbrock, 1999).
30. Road pricing (Bristow et al., 2008; Demir et al., 2015; Nakamura and Hayashi, 2013; Bonachea et al., 2005; Anas and Lindsey, 2011; Hensher and Ton, 2002; Poudenx, 2008; Brand et al., 2013; Kay et al., 2014); fuel pricing (Demir et al., 2015; Berrittella et al., 2007; O'Toole, 2008; Nakata, 2000; Graham and Glaister, 2004; Tirkaso and Gren, 2020; Yu et al., 2020; Chao et al., 2019); pollutant pricing (Demir et al., 2015; Hickman et al., 2012; Brand et al., 2013; Boonpanya and Masui, 2021; Han et al., 2017); competitive pricing of all the social costs of different transportation modes (Demir et al., 2015; Bickel et al., 2006; Berrittella

et al., 2007; Brand et al., 2013; Nakata, 2000; Forkenbrock, 2001; Kim et al., 2011); and optimal pricing of cargo transportation (Khan and Khan, 2020; Guo et al., 2020; Janic and Vleugel, 2012).

31. Collecting taxes from high-emission transportation industries: taxes on purchasing and insuring vehicles without environmental standards, pollutant tax, fuel consumption tax, high-risk transportation tax, pollutant rationing tax, and taxes on the social costs of emission (Bristow et al., 2008; Demir et al., 2015; Hua and Dong, 2019; Brand et al., 2012; Hickman et al., 2012; Hensher and Ton, 2002; Berritella et al., 2007; Hensher, 2008; Poudenx, 2008; Brand et al., 2013; Chakraborty et al., 2020; Nakata, 2000; Tirkaso and Gren, 2020; Han et al., 2017; Morrow et al., 2010; Jin et al., 2014; Huang et al., 2019; Yan and Crookes, 2009; Wing, 2007; Michaelowa and Krause, 2000; Corbett et al., 2009; Mellin and Rydhed, 2011; Song, 2014; Simões and Schaeffer, 2005).
32. Eliminating taxes and subsidizing low-emission transportation industries and goods owners for using low-emission transportation with the aim of preventing a rise in the price of goods (Liu et al., 2015b; O'Toole, 2008; Brand et al., 2013; Graham and Glaister, 2004).
33. Taking measures for reducing the number of travels and increasing the usage of local facilities (Bristow et al., 2008; Graham and Glaister, 2004; Jovanovic and Vracarevic, 2016; Singh, 2016).

To overcome such challenges, deep research and adopting laws and policies are required to prevent the occurrence of different issues in developing societies (Jiang et al., 2017; Morán and del Rio Gonzalez, 2007). It is worth noting that enacting laws and considering these policies is not an easy task. In the following, we will briefly examine some issues.

The use of alternative methods, such as replacing road and air transportation with intermodal, rail, and marine transportation, will lead to problems, such as a rise in unemployment (Cullinane and Cullinane, 2013; Hoffmann, 2010); the opposition of monopolies related to high-risk transportation (Cullinane and Cullinane, 2013; Hoffmann, 2010); long cargo transportation time (Kim et al., 2011); an increase in cargo and passenger customer dissatisfaction (O'Toole, 2008; Graham and Glaister, 2004); loss of invested capitals (O'Toole, 2008; Graham and Glaister, 2004; Cullinane and Cullinane, 2013; Avetisyan, 2018; Hoffmann, 2010); a decrease in social welfare (O'Toole, 2008; Graham and Glaister, 2004; Cullinane and Cullinane, 2013; Avetisyan, 2018; Hoffmann, 2010); and the mistaken belief by passengers in a reduction in social services due to encouragement of customers to use alternative transportation (O'Toole, 2008; Graham and Glaister, 2004). The following policies can be considered for overcoming these issues: (1) using road transportation for short distances (door-to-door), carriage of goods with small time limits, and intermodal road–marine and road–rail transportation in locations without rail and marine transportation access (Baumeister, 2019; Annadanam and Kota, 2019; Tao and Wu, 2021), (2) upgrading public transportation as a substitute for private vehicles (O'Toole, 2008), (3) preferring light and medium vehicles to heavy vehicles for carrying an identical load (Demir et al., 2014), (4) reducing the loading and unloading times in rail and marine transportation using new technologies, management, and optimal scheduling (Kim et al., 2011; Tao and Wu, 2021), (5) using high-speed trains (Janic, 2003), (6) improving the quality of secondary services in railways and marine ports (Kim et al., 2011), (7) decreasing the journey time via optimal routing (Peters et al., 2011; Kontovas and Psaraftis, 2011), (8) culture building and general education through media (Erdogan et al., 2020; Hoffmann, 2010), (9) creating control policies for the owners and manufacturers of vehicles (such as reducing the weight of vehicles, controlling the speed of vehicles, etc.) (Demir et al., 2014; Jemai et al., 2012; Styhre et al., 2017), and (10) using the pressure of pricing policies and tax collection (Demir et al., 2015).

Technologies related to alternative vehicles are effective in the long run, but changes in policies and alternative transportation taxes are critical for achieving short-term effects (Baptista et al., 2012). If the environmental laws are stricter, the tendency to use railway transportation will increase. Otherwise, road transportation is better due to comfort and high flexibility (van Ierland et al., 2000). Hence, a logical solution for cargo transportation in long distances is switching to the railway and marine transportation. Transporting one ton of cargo using the railway produces only 20% of that produced by transporting it via the road, and with an increase in the distance, the railway will become a more attractive option (Chapman, 2007). According to experimental studies (Tao and Wu, 2021), road transportation consumes 99.17% of the total energy and produces 98.84% of all WTW CO_2 emissions. The energy intensity and CO_2 emission for intermodal road–rail transportation are respectively 81.34% and 74.24% less than those of road transportation. Accordingly, reducing the energy intensity of semi-trailers and transferring container traffic from road transportation to intermodal road transportation effectively saves energy and reduces CO_2.

Moreover, unlike other transportation modes, the marine mode has the lowest consumption due to its lack of traffic and carrying large cargo volumes in one ship (Demir et al., 2015). Currently, 90% of goods are carried by ships globally, which will triple by 2030 (Chapman, 2007). A reduction in the speed of containerships can decrease their emissions by up to 70%. Nevertheless, the costs of this speed reduction are the most important obstacle, which can be addressed by adding ships to this system (Corbett et al., 2009). Providing alternative fuel and coastal energy sources can be an attractive option since this method leads to considerable savings in ships' fuel consumption, especially containerships during loading or unloading (Styhre et al., 2017). Another suggestion in this area is focusing on operational issues to minimize ship movement in ports (Styhre et al., 2017). Although implementing large-scale regulations requires investigations at levels much higher than port management, it can play a role in reducing GHG emissions depending on the capacities and technologies available at each port. Using cleaner fuels, such as gas, can curb ship emission by up to 90%. If a given load is carried by ship instead of by plane, an approximate 90% reduction in CO_2 production per ton-kilometer will occur (Michaelowa and Krause, 2000). If rail travel is substituted, emission can be brought down by up to 20% in each kilometer traveled (Chapman, 2007).

Air transportation is considerably more damaging than the emission figures suggest (Chapman, 2007). An increase in the number of airplanes will lead to delays in landing, an increase in greenhouse gas emission, and finally, to the development of airports (Chapman, 2007). The level of greenhouse gas emissions by electric aircraft has reduced considerably and reached that of trains. For distances up to 170 km, land transportation clearly performs better than electric aircraft. Among the challenges in this area are battery safety and charging time (Baumeister et al., 2020). Factors such as aircraft technology and design, aviation operations and infrastructure, socio-economic and policy measures, and alternative fuels and fuel properties are some of the main factors for reducing greenhouse gas emissions. The combustion level of aircraft fuel during operation depends on special factors. Most of the factors are controlled by operational planning and direct strategies by airline companies. The operational performance of an airplane is measured using parameters such as airplane range, fuel weight, payload, cruise speed, and crew weight. When the fuel cost increases, airline companies actively select advanced aircraft with a large improvement in fuel economy (Singh, 2016). The largest amount of fuel is consumed during ascent, i.e., [unclear sentence]. With an increase in flight time, large amounts of fuel must be carried, which increases the aircraft weight and, thus fuel consumption (Chapman, 2007).

The use of modern technology such as alternative fuel involves numerous problems, including the following: (1) the objection of developing countries due to the adverse effect on service exports and transportation costs (Avetisyan, 2018; Hoffmann, 2010), (2) insufficient motivation in governments for increasing fuel efficiency and alternative fuels (Jovanovic and Vracarevic, 2016), (3) the shortage of economically optimized technology for the production of alternative fuels (Azar et al., 2003; Chauhan et al., 2009), (4) storage issues (Azar et al., 2003; Chauhan et al., 2009), (5) confirming the emission characteristics of alternative fuels in transportation (Azar et al., 2003; Chauhan et al., 2009), (6) issues related to the infrastructure of alternative fuels (Kurtz et al., 2019). The following policies can be considered for overcoming these issues: informing developing countries about the external costs of emission (Avetisyan, 2018; Hoffmann, 2010); motivating governments with information policies (such as introducing, determining, and providing methods for reducing external costs, earning income via tax collection and pricing policies, and raising awareness about the disadvantages of pollution) (Demir et al., 2015); replacing external costs with investment to improve infrastructure and optimal technologies for alternative fuel; creating control and restriction policies for vehicle manufacturers (Demir et al., 2014; Jemai et al., 2012; Styhre et al., 2017); reducing taxes for the manufacturers and buyers of zero-emission vehicles (ZEV) (Herold and Lee, 2017; Wang et al., 2020a).

Changes in fuel require changes in engine technology. However, some fuels can be used with minor changes to existing engines. Both diesel and biogas can be mixed with their oil-based counterparts (Bengtsson et al., 2012). Nevertheless, to replace conventional fuel (diesel and gasoline) with alternative fuels, comprehensive data regarding the technical and economic performance of production pathways for alternative fuels are required by energy planners, modeling experts, analysts, and policymakers. Navas-Anguita et al. (2019) performed a study of the production pathways for a wide spectrum of road transportation fuels, including datasets of investment costs, operation and maintenance costs, and evolution efficiency for more than 40 production pathways. The carbon transportation model of the UK with low-carbon financial policies, such as vehicle purchase and insurance tax policies, has played the largest role in spreading low-carbon technology and reducing greenhouse gas pollutants. If designed carefully, they can prevent excessive tax collection while maintaining financial resources. Road taxes are very effective in reducing pollutants. However, while they increase the governments income in countering emissions, they negatively impact the number of vehicles and drivers and hence, on the primary production of pollutants (Brand et al., 2013).

4. Conclusion and recommendations

Given the importance of the environment around the world and the recognition of the transportation industry as the second-largest source of greenhouse gas emission with a 27% share in all the industries, controlling and examining the polluting factors, creating regulations, and considering policies for preventing issues are among the priorities of developing and progressive societies. Due to the significance of this issue and the research gap, this paper provides an overview of the effect of greenhouse gases generated by transportation on the environment, examines the impact of pollutants on the selection of transportation mode, determines the obstacles to reducing pollution in transportation, and makes related suggestions and solutions. Four variables have been investigated for road, rail, marine, and air transportation: (1) planning and policymaking, (2) technology, (3) economy, and (4) demand. Then, the factors, obstacles, and solutions of each variable have been addressed. To overcome such challenges, deep research and the creation of laws and policies are required to prevent excessive emission. It is worth noting that enacting laws and considering these policies is not an easy task. The studies presented in this research are expected to be useful, especially for those energy activists, researchers, and policymakers who would like to conduct long-term studies of pollutants in the transportation industry and the variables influencing the control of greenhouse gas emissions. Given the research gaps in the literature review, the following suggestions are made for future research:

1. Creating a comprehensive protocol to deal with the challenges of carbon market policy and emission reduction
2. Examining the issues in the pricing of road, cargo, pollutant, fuel, etc.
3. Investigating the issues in collecting road, cargo, pollutant, and fuel taxes, and preventing a rise in the price of goods and services
4. Examining solutions for dealing with the opposition of monopolies in high-risk transportation and developing countries with relatively higher emission rates in transportation
5. Higher focus on incentives
6. Improving low-risk transportation technology, such as rail and marine transportation
7. The need for a strong tool to calculate the level of emission accurately and reduce the uncertainty in estimating greenhouse pollution due to transportation

CRediT authorship contribution statement

Sajede Aminzadegan: Conceptualization, Methodology, Writing – original draft, Writing – review & editing. **Mohsen Shahriari:** Conceptualization, Methodology, Validation, Writing – review & editing. **Fahime Mehranfar:** Conceptualization, Methodology, Writing – review & editing. **Borna Abramović:** Conceptualization, Methodology, Validation, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary material related to this article can be found online at https://doi.org/10.1016/j.egyr.2022.01.161.

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