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Article

Assessing the Value of Information Technology for the Decarbonization of Freight Transport

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Abstract In its first part, the paper gives a summary of the levels of emissions resulting from each mode of transport by use of statistics at the European and global levels. It also summarizes the main measures and policies that have been put forward for the reduction of freight transport greenhouse gas (GHG) emissions. To facilitate the subsequent analyses, these measures and policies are classified into four categories, i.e., affecting the "demand" for freight transport services, shifting freight to less or no carbon-intensive modes, improving the energy efficiency of existing freight vehicles, and transitioning to "clean" fuels including electricity and hydrogen. For each of these categories, their current or potential use of information technology (IT) applications is presented, and key examples of such applications are mentioned. In the final part, a multicriteria analysis is performed with the help of two expert panels which are asked to assess, on a 5-level Likert-type scale, the extent of IT use in each of the four categories. The results show an important or very important contribution of IT in all categories except "improving the energy efficiency of current vehicles". The highest contribution (with scores higher than 4) appears to be in the category "shifting freight to less carbon-intensive modes".

Keywords transport decarbonization; freight transport; information technologies; climate change; green transport; electrification; freight decarbonization; multicriteria analysis

1. Introduction

In the autumn of 2019, the European Commission (EC) announced its overwhelming strategic goal to become the world's first climate-neutral continent. This announcement came as part of its "European Green Deal" package which was codified in the European Climate Law which has set a legally binding target of achieving net-zero greenhouse gas (GHG) emissions by 2050 [1]. An "umbrella" Commission Communication, together with a package of 17 Commission proposals for the revision of climate and energy legislation—called the "Fit for 55" Package—was launched on 14–16 July 2021 with the aim to reduce by at least 55% the GHG emissions by 2030 compared to the 1990 levels. By approving and accepting this legislation, all 27 European Union (EU) Member States committed to turning the EU into the first climate-neutral continent by 2050. Today, seven years before 2030, these pledges do not seem likely to be achieved as many EU-member countries seem unable or unwilling to meet their obligations to introduce measures to curb GHG emissions stating as their main reason for their expenditures to fighting the COVID pandemic, the impacts of the energy crisis and other supply chain disruptions due to the war in Ukraine, etc.

The share of GHG emissions from the transport sector in the EU is at the level of 25% of GHG emissions from all sectors [2]. The share of transport CO_2 emissions is even larger—at the level of 28% of the total CO_2 emissions—making transport the largest CO_2 emitter among all EU economic sectors. These percentages are larger in other world regions, the highest being in the US which, by emitting almost 30% of the global transport-related CO_2 emissions, is the biggest producer of transportation GHG emissions worldwide followed closely by the Asia-Pacific region which may even surpass the US if the high growth levels of China continue [3]. The share of freight transport in the total transport-related CO_2 emissions in the EU is a relatively small percentage. In 2017, 44% of all transport-related CO_2 emissions came from the circulation of passenger cars, 9% from light commercial vehicles, 19% from heavy-duty vehicles, and 4% from each of the air and maritime transport sectors (the remainder is from other transport related

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activities such as logistics operations within terminals, police supervision of traffic, and so on) [4]. These percentages remained roughly the same over the decade 2011–2021 [2], but the demand for freight transport services in the EU is expected to increase by approximately 30% by 2050 compared to 2015 [5]. According to [2], the road transport sector is by far the largest GHG emitter in the transport sector (in 2019 it accounted for 71.7% of all transport GHG emissions including domestic transport and international, while 14% was from water navigation, 13.4% from aviation, 0.4% from railways, and 0.5% other) [6]. This percentage of road transport emissions is expected to drop in the coming years because the great majority of the measures and policies that have been or will be applied by EU governments are likely to be focused on the road transport sector. On the contrary, in the maritime and aviation sectors their percent contributions to GHG emissions are likely to increase as we move toward 2030 because these sectors are expected to grow rapidly (especially the aviation sector). According to Eurocontrol, air traffic activity and flight numbers in Europe are expected to return to 2019 levels by the end of 2023 and then increase rapidly on a yearly basis [7]. According to the European Environmental Agency, without the implementation of additional measures, as foreseen in the "Fit for 55" package, the EU transport emissions in 2030 could reach a level of around 9% above the 1990 levels [2].

As regards the share of freight transport work (domestic and international), it is noted that in 2021 maritime transport in the EU accounted for more than two-thirds (67.9%) of freight transport work (in terms of ton-kms traveled). The second largest freight transport mode was road with a share of close to one-quarter (24.6%). So, maritime and road transport represented 92.5% of total freight transport work in the EU in 2021. The rest was shared by rail transport (5.5%), inland waterways (1.8%), and air (0.2%) as reported in [8]. This freight transport modal split has roughly remained constant throughout the last decade (2011–2021) with minor and insignificant variations even during the COVID years. The relevant range of figures is 68–70% maritime; 23–24.5% road; 4.5–5.5% rail; and 1.8–2.2% inland waterways (Figure 1 in [8], data code "tran_hv_ms_frmod"). Focusing on inland freight transport, the road represents much more than two-thirds of the total transport work (it was 76.7% in 2017 and 77% in 2020) with the remaining, shared between rail (17%) and inland waterways (6%). So far, the results from almost three decades of relevant EU legislation have failed to achieve a significant shift of freight from road to rail in spite of the fact that the European Commission had identified this shift as one of its main objectives in its first 10-year Transport White Paper in 1992. In 2001, it confirmed the importance of revitalizing the rail sector to attract more traffic from the road and in its 2011 White Paper set a target of shifting 30% of road freight, transported further than 300 km, to other modes such as rail or waterways by 2030, and more than 50% by 2050.

This paper examines the role that information technology (IT) can play and its significance in the successful application of relevant measures and policies for the eventual reduction and elimination of GHG emissions (especially of CO_2) in the freight transport sector (all modes). This is in effect the current research gap that exists, i.e., that we need to define this role and contribution as IT is one of the enablers of any decarbonization policy. By shedding light on this role and contribution, this paper will provide considerable value-added to policymakers and academics alike.

The paper first presents in a summary way the main measures and policies that have been proposed so far and foreseen, to achieve the goal of "net-zero" carbon efficiency in the freight transport sector by 2050. It classifies these measures and policies into four categories and for each one, it examines the role that IT can play in materializing the foreseen reductions in a successful way. Then a "quantification" is attempted, i.e., to assess how big or how important is this role of IT. This is done by use of a Multi-Actor Multi-Criteria Analysis (MAMCA) technique by using two groups of experts, one consisting of IT consultants and one of relevant stakeholders. A Delphi process is used to score the impact and importance of IT use and contribution in each category of measures. The research questions that this paper addresses are: What is the role and contribution of IT in reducing freight transport GHG emissions and to what extent can we quantify this role in a structured and objective way?

2. Measures and Policies Put Forward to Reduce Freight Transport GHG Emissions

There are numerous publications of measures and policies put forward to reduce GHG emissions by the transport sector in Europe [1,2,5,9–12]. Besides the many publications and EC's regulations, decisions, and reports, several other independent bodies have published similar suggestions and proposals [3,4,13–15]. Towards the end of 2019, the European Academies Science Advisory Council—EASAC (an independent source of science advice that brings together the National Academies of Science of the EU Member States, as well as Norway, Switzerland, and the UK) published a study on the potential measures and their feasibility for decarbonizing the European road transport sector [11]. The study also developed a framework for analyzing and implementing future transport decarbonization measures. This section attempts to present in a summary way and eventually "classify" the multitude of measures and policies that have been proposed so far for decarbonizing the freight transport sector in Europe. This means that we will be referring, practically, to measures and policies for decarbonization in the transport sector because many of these actions are aimed at both freight and passenger transport.

2.1. Horizontal Measures for Both Freight and Passenger Transport

Tighter standards for fuel economy and emissions, along with greater use of electric or other renewable fuel vehicles, are the most cited measures when considering the reduction of emissions in both passenger and freight transport. The reduction and eventual elimination of the carbon content of current vehicle fuels, for all types of vehicles including ships or aircraft, is the most urgently sought technological and policy goals. Reducing the carbon content of existing fuels can be achieved in the short term by mixing or substituting fossil fuels with less polluting alternatives such as methane, natural gas, or other renewable fuels such as biofuels. For road transport, currently, approximately 5% of existing internal combustion engines (ICEs) run on methane (mainly buses). Methane comes also from fossil sources, but it is less polluting and is known to the large public as liquefied petroleum gas (LPG). Other possibilities include using various biofuels such as biodiesel (which can be blended with fossil diesel) or bioethanol (which can be blended with gasoline). Over the past decade, these possibilities have contributed approximately 7% to transport fuels in the EU [16]. However, as these conventional biofuels are produced from crops which could instead be used for human food or animal feed, their future use and potential as transport fuels is limited. In addition to existing biofuels, the EU Renewable Energy Directive contains a list of 17 feedstocks which can be used to produce advanced biofuels and sets an overall target of 14% for renewable transport fuels in the EU by 2030 [10]. The use of biofuels in the freight transport sector is likely for applications which lack alternative low-carbon solutions with competitive costs, such as aviation, long-haul shipping, and long-haul heavy-duty vehicles.

The wide use of carbon-free energy vectors is the key option for the medium to long term. This mainly involves green electricity in electric vehicles i.e., Battery Electric Vehicles (BEV), Plug-in Hybrid Electric Vehicles (PHEV), and green hydrogen in Fuel Cell Electric Vehicles (HFCEV). The EU market for BEVs is growing fast with a fast-increasing number of battery charging facilities, especially along inter-city road networks. The most important point of concern is the provision of the electric power needed to charge the batteries of the future fleet of BEVs. When batteries must be charged more quickly, then "superchargers" with powers of up to 120 kW are needed and this is especially important for electric freight vehicles. Such public charging stations require new infrastructure and more funding, which for European countries is being provided by the EU Connecting Europe Facility, together with loans from the European Investment Bank (EIB, 2023) [17] as well as national sources. As the numbers of battery BEV grow, new policies will be needed to share the costs of providing public vehicle charging infrastructure in a fair way, and smart charging systems with time-dependent tariffs to manage the supply of electric power during the day. Smart charging is feasible only with the use of IT applications both at the level of the users as well as at the level of the power generators and distributors so that they can balance power demands with variable supplies from wind and solar generation without exceeding the capacity of electricity networks.

A game changer, especially important for long haul freight transport by road, maritime, or air, will be the introduction of hydrogen as a fuel in fuel cells but also as a direct fuel in hydrogen ICEs where its performance has been studied for many years. The gravimetric energy density of hydrogen is higher than that of batteries, so the driving range of hydrogen vehicles is typically longer than that of BEV while filling a fuel tank with hydrogen can be done much more quickly than re-charging a battery. However, the efficiency of burning hydrogen from source to wheel is 2–2.5 times lower than that of BEVs because of the currently low efficiency of producing and storing hydrogen while the costs of hydrogen fuel cells are still relatively high [11]. So, hydrogen is likely to be used in the short term primarily for those transports for which battery power is not well suited, such as long-haul heavy-duty road freight vehicles, long-distance buses, trains on non-electrified routes, ferry boats, and medium-distance ships. Another possibility is the use of Electric Road Systems (ERS), i.e., powering vehicles using electric motors with electricity that is provided to them either by using overhead lines and pantographs as they drive along the road, or by conductor rails buried in the road. According to some reports, Sweden is building the world's first permanent ERS for EVs to charge while driving [14].

Besides the measures for producing and using clean fuels, other measures and policies are being proposed for decarbonization of both passenger as well as freight transport. They include improving conventional powertrains to reduce carbon emissions as well as to use alternative "drop-in" fuels, such as natural gas, or advanced biofuels. Also, improving vehicle body design to reduce weight and air drag as well as rolling resistance. Improving conventional powertrains is already a priority for vehicle manufacturers because, despite the growing market penetration of electrified vehicles, internal combustion vehicles are still expected to dominate the vehicle fleet in the short-to-medium term. CO_2 emissions of only 100 gr/km have already been achieved, and there is potential for a further improvement of about 25% in terms of life-cycle carbon emissions. Improving vehicle body design to reduce weight and air drag is also pursued rigorously and this includes the following three cases [18]:

a. Using light materials to reduce vehicle weight. This can typically reduce the energy consumed by up to about 10%.
b. Improving aerodynamic performance. This can reduce the energy used by up to 10% depending on the type of vehicle.
c. Improving rolling resistance. Using new designs of energy-efficient tires can reduce energy consumption and therefore emissions.

All the above measures and policies focus mainly on the "supply" of transport services and together with an appropriate push to all stakeholders for policy acceptability and implementation (see for example [19]), can have a marked impact. A major sector of the suggested decarbonization policies also includes proposals for managing the "demand" for transport services. The global environmental impacts of cutting the "demand" for transport services have been clearly seen during the first years of the COVID-19 crisis when daily CO_2 emissions were temporarily decreased locally (in urban or peri-urban areas) by more than 50–70% depending on the locality. At the global level a reduction in transport-related emissions, due to the COVID epidemic, of −17% was estimated in 2020 of which almost half was due to reductions in surface transport [20]. Perhaps one positive outcome of the painful COVID-19 crisis was that it provided a "window into the future" through which millions of citizens have experienced improved air quality in cities that could permanently be provided through the impact of the decarbonization measures that are aimed at drastic reductions (mainly) in road transport. Policymakers must utilize this "window into the future" experience to implement a similarly healthy environment on a sustainable basis due to a properly managed (and reduced) demand for freight (and passenger) transport services.

For the freight transport sector, the policies and measures that have been suggested for managing the "demand", are shown in the next section.

2.2. Measures Specific for Freight Transport

With the demand for freight transport services in the EU expected to increase by approximately 30% by 2050 compared to today [5], the task of reducing CO_2 emissions from freight transport, to—practically—zero by 2050 seems a daunting task. Measures and policies for reducing the "demand" for freight transport trips play a very important role. Options for reducing the demand for freight vehicle-kms include the following [13]:

1. Restructure the supply chains to bring suppliers closer to consumption.
2. Increase the use of digital technologies (e.g., internet of things, cloud technologies, etc.) for supply chain management.
3. Prioritize goods with increased "material efficiency", i.e., give priority to using products with materials and components that can eventually be re-used (circular economy), or using online information in place of material books, newspapers, CDs, and DVDs, miniaturized or lightweight products, and 3D printing to eliminate supply chains.

4. Promote the use of long-life and repairable products and encourage consumers to buy “experiences” instead of material goods.
5. Others, e.g., reduce the growth in demand for transported goods by charging suppliers for disposal, etc.

Other measures refer to the decarbonization of the “supply” of freight transport. So far, the following options have been considered [11]:

a. Shifting freight from road to rail, inland waterways, or short sea shipping [21,22].
b. Using electric vehicles to deliver freight, especially in urban areas [23–25].
c. Improving vehicle load factors (i.e., higher load factors to reduce the number of freight vehicles on the road) [26–28].
d. Improving vehicle routings to reduce the distances traveled, especially during delivery tours in urban areas [29–31].
e. Improving driver performance, e.g., eco-driving [32–34].
f. Platooning of trucks when traveling on motorways [35–37].
g. Using autonomous vans and drones [38–40].

The difficulty of delivering the CO_2 and other GHG emissions reduction from freight transport that would be necessary to limit global warming to +2 °C by 2100, has been addressed by McKinnon [13]. As it was explained there, a 6-fold reduction in freight transport emissions would need to be delivered by 2050 to meet the targets of Europe on the move package. A plausible scenario for achieving such a 6-fold reduction would require the following sub-sector targets to be achieved, as a minimum, by 2050:

- 30% modal shift from road to rail,
- 20% increase in routing efficiency,
- 30% higher load factors,
- 50% greater energy efficiency of the vehicles used, and
- 50% less carbon content in the energy vectors.

2.3. Classification of Measures

To be able to refer, in the following, to the various measures and policies suggested for decarbonizing freight transport in a concise and practical way, we can classify them into four main categories as follows:

I. Managing the “demand” for freight transport services with a view to reducing freight trip-making.
II. Shifting freight transport to less carbon-intensive modes.
III. Improving the energy efficiency of existing (internal combustion engine) freight vehicles.
IV. Transitioning to less or no-carbon-intensive fuels or electricity.

Each of these categories can be subdivided into several sub-categories by consolidating the individual measures and policies into similar types of measures within each broad category. This is done in the next section as shown in Table 1. It is assumed that if all these measures and policies are materialized and successfully implemented, the “net-zero” objective (i.e., cutting the freight transport related GHG emissions to as close to zero as possible), by 2050, can be achieved.

3. An Overview of the Role of IT in the Four Categories

In all categories of measures and policies, as they were delineated above (although to a differing degree), IT applications play a key role in implementation, operation, monitoring, and evaluation. “Smart transport” means cleaner transport both in terms of reduced fuel consumption as well as in terms of reduced mileage and increased reliability and security. The role of IT in implementing decarbonization policies is one of “facilitator”, i.e., facilitating implementation through facilitating access to energy supply points, handling and disseminating information and data, implementing monitoring, charging and incentivizing policies, facilitating the integration of the various decarbonized transport services, and many other relevant and complementary tasks. It is quite indicative of the importance attached to the role and contribution of IT in freight transport decarbonization policies, the fact that the European Single Transport Area promoted by the EC [9], is expected to be materialized through increased interoperability, digitalization, automation, and multimodality. These are the four elements denoted as critical for a competitive and resource-efficient European transport system in the future. Two of them directly, but in practice all four of them, are heavily dependent on IT applications and services. In the following, we look in more detail at the role that IT can play in each of the four categories of measures and policies for the decarbonization of the freight transport sector in Europe.

As regards managing the "demand" for freight transport services, IT plays a primary role through two main channels:

a. Facilitating the e-commerce functions and the related freight delivery and distribution activities with a minimum of road freight traffic, and
b. Collecting, handling, and disseminating information and data that are gradually changing the way people behave, act, and live.

"Demand" management policies have so far found very limited application. As a result, they also had limited impacts on overall GHG emissions, of the order of 4–5% when implemented individually or higher if several are implemented simultaneously [11]. In the longer term, IT applications are expected to play a primary role in demand management measures and policy implementation as digital technologies penetrate larger sections of the population.

The shifting of freight transport to less carbon-intensive modes category of measures and policies is very much influenced by the degree to which the owners of the freight (the goods being transported) can be incentivized to shift from road to rail or maritime transport. This depends on the cost of each alternative route but also on the ease of access to all relevant information and data that will allow a proper modal evaluation to be made [11]. A more recent development is the use of "green crowd-shipping" services (i.e., the use of nonprofessional operators in transporting goods by public transportation) [41]. So far, considerable IT applications have been put forward to enable this type of functionality. Digital technologies have been found to contribute significantly to a reduction of freight vehicle-kms on the roads by making it easier to use multimodal options (mainly combined transport links using rail as the main mode for inland transports, and inland waterways or short sea shipping for longer-distance transports). All these IT applications are usually combined with other investments in mode interchange infrastructures and improvement of existing network capacities. Many examples of web-based IT platforms and software packages that offer multimodal service planning for the door-to-door transport of freight can be mentioned. A characteristic example of such a platform is the five-pillar-based platform of Rail Freight Forward (a coalition of 23 European rail freight companies) intended to support the strategy for shifting 30% of European freight from road to rail by 2030. IT plays a key role in operations, data collection, and monitoring as well as in safety and security issues in all of the five pillars of this platform, i.e., [42]:

1. The Digital Platform (DP), a consolidated data system that allows all countries and rail companies to develop more competitive rail freight products for customers and achieve seamless international transport. Many European rail freight companies have agreed to cooperate to further develop and utilize one such platform for the whole of Europe.
2. The European Rail Traffic Management System (ERTMS) which is the well-known European rail traffic management system that provides consistent digital infrastructure for traffic management and control in the railway networks.
3. The Digital Capacity Management (DCM) system, which enables internationally standardized capacity planning for instant and fully digitalized freight booking.
4. The Autonomous Train Operation (ATO) system which provides for automatic steering and pacing for fully automated control in railway lines, terminals, and shipyards. This will enable the supervision of a substantial amount of train traffic by one train operator. In this way, more trains can operate simultaneously.
5. The Digital Automatic Coupling (DAC) system which makes train assembly at terminals fully automated replacing all current manually operated coupling with a stronger standardized digital solution.

In improving the energy efficiency of existing freight vehicles' category, there are quite significant emission reductions already achieved, especially by the Euro 5 and upward categories of freight vehicles (currently up to Euro 7 level). As already mentioned in the previous section, the main options here are: (1) improving conventional powertrains to increase their energy efficiency including hybridization, (2) improving vehicle body design to reduce weight and air drag as well as rolling resistance, and (3) modifying conventional powertrains to use alternative "drop-in" fuels, such as natural gas, or advanced biofuels. To these, one could add the option of encouraging users to choose smaller vehicles and engine sizes. This, fourth, option might include incentives such as exemptions from road tolls or reduced charges for small and low-emission vehicles, and so on. It is here that IT applications can play a key role. For the other three options, the role of IT is rather limited, and it mainly consists of assisting during the planning and construction phase of the relevant technical improvements.

In the fourth (final) category of measures and policies for achieving net-zero freight transport services in the future, i.e., transitioning to less or no-carbon fuels or electricity, IT applications have a vital role to play. This category of measures is expected to achieve the most substantial reductions in GHG emissions both in the short and in the long term. Electrification of road transport in the EU has already begun and is already offering some reductions in GHG emissions even with the current power generation mix. When fully "green" electricity production is achieved (a "sine qua non" condition for true decarbonization by using electric mobility), this category of measures will bear the main burden of bringing freight transport to net-zero condition. IT applications will play a vital role in this transition, mainly through:

a. Facilitating the finding of recharging points along the road networks.
b. Regulating the electric network power distribution and allocation on the charging stations grid when this grid is fully developed.
c. Increasing the reliability of electric batteries and other internal electric vehicle systems through facilitating proper monitoring and vehicle maintenance functions.

It must also be pointed out here, that full electrification of the freight vehicle fleet is not foreseen in the foreseeable future because for the long-distance freight transport routes, in both road and maritime transport, recharging batteries is not a feasible possibility and so other energy carriers such as hydrogen and fuel cells are foreseen to be used in these cases [43].

IT applications in all four of the above categories abound already in current practice. Examples:

Demand management:

- *Uber freight* (https://www.uberfreight.com). A technology platform connecting truck owners/managers with cargo needed to be shipped. It assists in the management of freight transport demand by distributing and tendering loads faster and tracking them from origin to destination.
- *Convoy* (https://convoy.com). A platform that simplifies processes between shippers and carriers in handling available loads. It automatically matches shippers and carriers, reducing empty miles and carbon emissions.
- *Transfix* (https://transfix.io). An intelligent freight mobile app, connecting in real time shippers and carriers by use of AI technology. It allows carriers to search, book, and manage loads and optimize supply chains.
- *Loadsmart* (https://loadsmart.com). A logistics web-based platform and app, facilitating shippers and carriers to book, ship, and track freight, and optimizing the distribution of demand for freight services.
- *Fretlink* (https://www.fretlink.io). A platform offering software as a service (SaaS) functionality to connect shippers and carriers and consolidate shipments exploiting empty return trips.

Truck navigation and real-time vehicle routing:

- *OptimoRoute* (https://optimoroute.com). Routing and scheduling, real-time information, and estimated time of arrival. Also, tracking and tracing.
- *SmartTruckRoute* (https://www.smarttruckroute.com). A route navigation app that creates truck-specific routes considering several restrictions (bridge heights, clearances, load limits, etc.).
- *PTV Navigator* (https://www.ptvlogistics.com/en/products/ptv-navigator). A driver app, used as a dynamic routing analysis tool based on real-time traffic conditions.
- *Trucker Path* (https://truckerpath.com). Mapping and truck navigation app enabling truck drivers with a navigation and freight matching tool. It provides drivers with real-time information about routes, parking, fuel expenses, weight stations, etc.

- *Route4Me* (https://route4me.com). A mobile phone app providing routing operations and carbon-neutral last-mile optimization.
- *Sygic Truck* (https://www.sygic.com). A GPS navigator app, calculating routes according to specific parameters taking into account several truck features (low bridges, narrow streets, load settings). It can also create routes avoiding restricted emission zones.
- *Wakeo* (https://wakeo.co/platform/overview). A platform that provides access to real-time information, estimated times of arrival for shipments, and reduced delays as well as monitoring and control of freight emissions.
- *Quartix* (https://www.quartix.com). A fleet tracking app that allows users to track vehicles in real-time, providing detailed data for their movements, speed, and fuel consumption information.
- *Masternaut* (https://www.masternaut.com). A tracking platform providing real-time access information regarding vehicle's location, driving behavior, optimized vehicle utilizations, and fuel costs by use of fleet intelligence analytics.
- *Dynafleet* (https://www.volvotrucks.com). This is Volvo's truck platform that offers information about the fleet and fuel consumption as well as regularly updated data on the performance of the truck and the driver. The platform is also a fleet management tool for electric trucks to monitor their performance and efficiency.
- *Einride* (https://www.einride.tech). An "intelligent" freight mobility platform which has been designed to enable smart routing and planning of freight operations and provide data on resulting emissions.
- *HERE* Navigation (https://www.here.com/products/navigation-on-demand). A platform for location data and navigation services specially adapted to electric mobility especially freight deliveries by electric delivery vehicles.

Fleet management:

- *Oracle Transportation Management* (https://www.oracle.com/scm/logistics/transportation-management/fleet-management-product-tour). An integrated cloud platform supporting companies to manage fleet operations, assign, consolidate, and optimize shipments, and provide real-time information.
- *FleetMatics* (https://www.verizonconnect.com/solutions/apps). A mobile app that allows real-time fleet operations designed to provide notifications about vehicle maintenance costs.
- *FleetWave* (https://www.chevinfleet.com/products/fleetwave). A fleet management app providing real-time information about drivers, and vehicles, gaining visibility of fuel costs, and tracking maintenance and repair services.
- *Wialon* (https://gurtam.com/en/wialon). A fleet management platform that assists users in monitoring vehicles, goods, transport delivery, fuel consumption, engine hours, etc.
- *Tesla Fleet* (https://www.tesla.com/semi). An app (developed by Tesla Motors) that provides a suite of tools to efficiently manage and monitor a fleet of Tesla electric vehicles.

Energy charging and energy management for electric vehicles:

- Hundreds of apps exist for locating nearby charging stations for electric vehicles, reserving slots, and making secure payments. Examples: *ChargePoint* (www.chargepoint.com), *GridPoint* Energy (https://www.gridpoint.com), *Mercedes Me* (for all Mercedes Benz electric vehicles) (https://www.me.mercedes-benz.com), *EVgo* (https://www.evgo.com), and so on.
- Many apps for predicting the range of electric vehicles, e.g., *Bosch Range Assistant* (https://www.bosch-mobility-solutions.com)
- Electric mobility platforms to seamlessly plan multi-modal trips that may involve electric vehicles, public transport, or shared mobility options, e.g., *Geotab* (https://www.geotab.com).

The above overview shows that the number and nature of IT applications in helping to decarbonize certain sectors of transport is—literally—in the thousands. Most of these IT applications have been and are being developed to help apply decarbonization policies successfully. These are all the products of research work followed by development and application activities that produce the innovations that help apply the policies. The work presented in this paper differs substantially from all this work (aimed at formulating and developing commercially successful IT applications) in that it takes a more strategic viewpoint and follows a more global approach in assessing the value of the IT sector as a whole for the successful application of decarbonizing policies for freight transport.

4. Can the Role of IT be "Quantified"?

4.1. Choosing the Appropriate Methodology

A novel method of quantifying the impact of IT within a given sector or group of activities, has been formulated and tested by the current authors in the case of assessing the level of importance and contribution of IT to the formulation of the output of the Intelligent Transport Systems (ITS) sector [44]. This methodology utilized data found in national and EU statistical records and expressed the impact and level of contribution that can be attributed to IT products and services as a percentage of the total value produced from products and services within the ITS sector. It was found that, for the European data used, the impact of IT applications was in the order of 8–10% of the total value produced by ITS products and services and that the elasticity of the sector's output value to the IT-related capital was 0.160. This means that for a 10% increase in IT capital, there is a 1.6% increase in the sector's output.

The basic idea behind this quantification methodology was to define the appropriate sets of panel data to calculate the coefficients of a formula like the one below:

$$Y_{it} = \alpha K_{it}^{\beta 1} L_{it}^{\beta 2}\ I_{it}^{\beta 3} e^{[v_{it} - u_{it}]} \tag{1}$$

where:

Y_{it}: the "observed" output of the sector in terms of value or other relevant measure,

K_{it}: the non-IT capital used in the sector (e.g., investments in infrastructures and equipment other than IT-related),

I_{it}: the capital related to IT infrastructures (hardware, software, databases, data transfer, etc.),

L_{it}: a measure of the labor force serving the sector (e.g., number of people or salary expenses),

$\beta_1,\ \beta_2,\ \beta_3$: coefficients to be defined by regression, and

$v_{it} - u_{it}$: the standard error of the function of which v_{it} is the deviation of the prediction from the observation due to random error (distributed according to a normal distribution), and u_{it} the error term representing "inefficiency".

By using Formula (1) once with and once without the term IT-capital, the percentage difference in the values of Y that resulted from these two runs would be a measure of the impact and contribution of IT in this sector's output. Such quantitative methodology is not possible to be used in the case examined here, for two main reasons. First, the four categories of actions for net-zero freight transport emissions cannot be clearly defined in terms of content, scale, or geographic area of application and therefore it is very difficult to find the appropriate data to run regression analyses, and second, even if such formula could be defined it would be in terms of the measures under one specific sub-category of measures and not the total applications.

Under the circumstances, a more feasible methodology to use in order to estimate the impact and contribution of IT in the materialization of each of the four categories of measures and policies mentioned in the previous section was the so-called MAMCA. Within this particular MAMCA application, two Multi-Criteria Decision Analyses (MCDA) were employed, using two groups of experts one representing the IT industry and the other the transport decarbonization stakeholders, as well as a Delphi method of convergence in order to bring the experts' opinions to converge. The MAMCA approach has become over the years a popular evaluation-quantification method with numerous recorded applications addressing complex problems [45–47]. The MCDA in the field of transport has also been used extensively, especially in terms of its multi-attribute theory variants Analytical Hierarchy Process—AHP [48], Multi-Attribute Utility Theory—MAUT [49] and Multi-Attribute Value Theory—MAVT [50,51]. In parallel to these, some well-known outranking methods to evaluate and rank alternative levels of IT involvement are also used and assigned a degree of preference based on how well they are valued by the two independent expert groups acting as decision-making mechanisms. Two well-known outranking methods were used, the Preference Ranking Organization Method for Enrichment of Evaluations—PROMETHEE I and II [52] and ELECTRE (ELimination Et Choix Traduisant la REalite) [53]. The ease of applicability, the logic, and the structured nature of the results were the main reasons for deciding on this methodology.

The PROMETHEE I model uses an analytical hierarchy process for ranking, using weights for the evaluation criteria. It has freely available software and presents several other advantages which are presented in detail in [47]. A major assumption is that the structural elements of the system being evaluated (i.e., the various subcategories of measures to be employed) are independent of each other. This is true to a sufficiently large degree but not entirely as in our case, the structural elements of the system being evaluated are the sub-categories of the four categories of decarbonization measures and policies mentioned in Section 3 above, which are defined during the system mapping in Section 4.2 below. Their interdependencies (where they exist) are relatively weak and indirect, something that cannot be defined and quantified properly. It is therefore assumed that they do not significantly affect the validity of our applied process. The item to be evaluated-quantified through the above process, is the level of importance and value of IT applications for the successful implementation-operation of the four categories of measures and policies, examined separately. We refer to all the IT applications to be used in each of the four categories of measures and policies, with the general term "IT use".

4.2. Formulation of the Model

The formulation of the MAMCA model for the case of the four categories of measures, followed three steps as shown in Figure 1. Step 1, involved the system mapping, i.e., analyzing each category into sub-categories of measures and actions. This is necessary in order to develop a common view and understanding of the nature and content of the four categories for the experts in the two expert groups as well as in order to decide on the weights for the evaluation criteria and the subsequent quantification, Step 2 involved the setting of the evaluation criteria and deciding on their weights. Step 3 involved the formulation of the evaluation matrix, i.e., the assignment of (Likert type) values and formulating/presenting the results. For the application of the methodology, two groups of experts were formed:

1. The IT experts group. This consisted of six experts in the field of IT as well as other areas of applications in the transport sector (mainly consultants and transport researchers). In particular, in this group, there were two experts from the IT sector, two from the freight transport sector, and two from the environmental/climate change sector. The current authors were part of this group.
2. The stakeholders group. These were a group of seven persons that mainly came from companies active in implementing systems and services in one or more of the sub-categories of each category in Table 1 (mainly employees of companies active in freight transport operations or IT systems installation. One of these seven people was from the transport Administration sector (Ministry of Transport).

The selections/decisions of each of the participants in these expert groups were harmonized and converged through the use of a Delphi process—a well-known technique for eliciting & combining experts' judgments that have been used for many decades now [54]. Each group of experts was working independently of the other.

Table 1 shows the "system mapping" of the four decarbonization categories, i.e., Step 1 in our MAMCA model as shown in Figure 1. In this Table, the four categories of measures and policies are analyzed into further sub-categories following consultation with the stakeholders and experts groups and literature review.

The next step of the process (Step 2 in Figure 1) was to define the evaluation criteria and their weights by use of a Delphi procedure and use of the PROMETHEE software (the Visual Promethee 1.4). The selection of the evaluation criteria involved two phases. In the first, the stakeholders and the experts groups, acting independently, were asked to suggest a preliminary list of evaluation criteria and assign them priorities (weights). In the second phase, the suggestions in each group were converged to one final list of evaluation criteria and their weights by use of a Delphi process. The weight values for each evaluation criterion were set at between 1 (very low), 2 (low), 3 (medium low), 4 (somewhat low), 5 (neutral), 6 (somewhat high), 7 (medium high), 8 (high), 9 (very high), and 10 (extremely high). The convergence limit was set at 75%; a consensus was considered to have been built at the 75% threshold of agreement. Suggested in the literature convergence limits for the Delphi method range from 80% [55] to 70% [47].

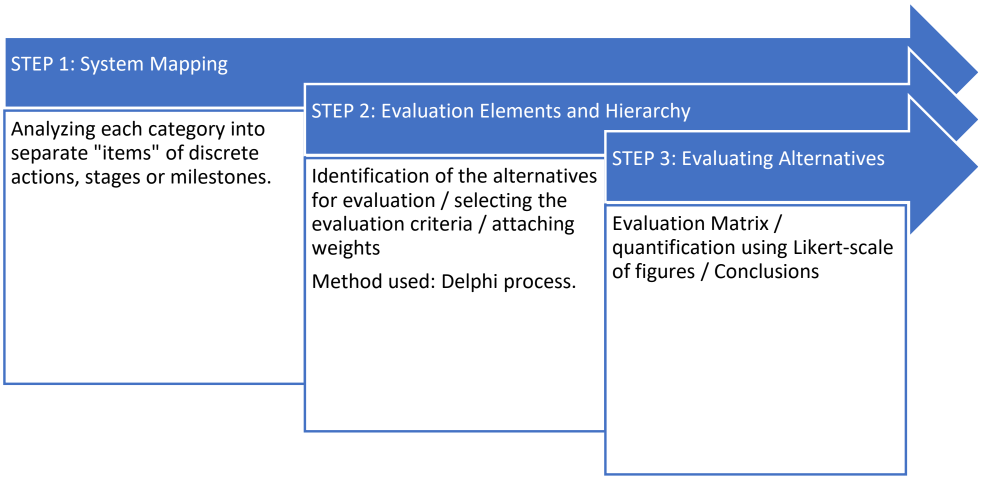

Figure 1. The steps used in the evaluation—quantification process.

Table 1. System Mapping for Freight Transport Decarbonization Options

Categories of Measures and Policies	**(I) Managing the "demand"**	**(II) Shifting to Less Carbon Intensive Modes**	**(III) Improving the Energy Efficiency of Current Vehicles**	**(IV) Use of "clean" Energy Carriers**
Description	Measures affecting the demand for freight transport services and policies to incentivize fewer trip-making.	Measures to incentivize freight transport to use less carbon-intensive modes.	Improving the energy and emissions efficiency of existing freight vehicles	Transitioning to fuels with a no-carbon footprint ("green" electricity and hydrogen)
Main Sub-categories	I.1 Reduce the demand for vehicle-km on the roads by restructuring the supply chains. I.2 Increase the use of digital technologies for supply chain mgmt. (smart tags, internet of things, big data, asset tracking, delivery scheduling, etc.). I.3 Prioritize goods with increased "material efficiency". I.4 Reduce the growth in demand for transported goods. (For some examples of measures in the above sub-categories see the note at the end of this Table. For a detailed description and justification of each of the above sub-categories see [13].	II.1 Develop efficient and user-friendly multimodal freight transport platforms for facilitating info and data dissemination for all modes. II.2 Develop/ Facilitate last-mile operations for effective door-to-door service. II.3 Insert externalities in the calculation of tolls and other levies for the use of road transport vehicles.	III.1 Improve vehicle body design for minimum aerodynamic and rolling resistance. III.2 Improve conventional Powertrains to reduce carbon emissions. III.3 Reduce the carbon content of existing fuels by mixing them with biofuels, methane, or others. (See also [11])	IV.1 Use of battery electric vehicles. IV.2 Use of fuel cells using hydrogen. IV.3 Use of Hydrogen as direct fuel. IV.4 Use of Electric Road Systems.

Note: Examples of specific measures and policies in the "Managing demand" sub-categories: *Change the location of the production of goods and the procurement of materials (suppliers) to bring them closer to consumption; Create more inventories and place them closer to the production/consumption sites; Change consignments with "electrons" (e.g., prefer e-books instead of printed books). Prioritize products with less physical material (miniaturization, light-weighting), and use of 3D printing. Promote the use of goods with long lives, which can be readily repaired or renovated.*

The consensus convergence rules for both the selection of the evaluation criteria and their weights were the following:

a. When 75% of the answers of the participants in one group agreed on a particular weight rating within 3 iterations the rating was adopted.
b. If a consensus of 75% was not reached after 3 iterations on the value of including a particular evaluation criterion, this criterion was rejected.
c. If a 75% consensus was reached but for a weight rating below 2, then the criterion was also rejected.

Step 3 of the process involved the formulation of the evaluation matrix, i.e., the assignment of (Likert type) values to denote the importance of "IT use" in each of the four categories and their subcategories shown in Table 1. There were five levels of values used, i.e., 1: not important, 2: somewhat important, 3: important, 4: very important, and 5: critically important.

4.3. Application Results

The list of the evaluation criteria that were finally selected according to the above process is shown in Table 2. This Table gives a summary of the results of the two Delphi processes for the selection of the evaluation criteria and their weights.

Table 2. Final evaluation criteria and their weights (results of Delphi process) for assessing the "IT use" element in freight transport decarbonization policies and measures.

Name of Criterion (Support in…)	**Description**	**Delphi Results (Criterion)**	**Weight * (1–10)**		**Delphi Results (Weight)**
			Experts	Stakeholders	
The planning stage	Support in formulating the policies and/or the group of measures to be implemented.	Rejected (Iteration 3)			
During measure application	Support during the real-world application of the selected policies and/or measures and their proper tuning.	Rejected (Iteration 2)			
Info dissemination-promotion	Support in the promotion of the measure or policy with a view to getting user acceptance.	Selected (Iteration 2)	5	7	Selected (Iteration 3)
Other information dissemination	Dissemination of all relevant information to the freight vehicle and the supply chain actors for more efficient and environmentally friendly operation.	Selected (Iteration 2)	7	8	Selected (Iteration 2)
Operation	Supporting other functions of the day-to-day operation of the specific measure or policy (e.g., smart finding of charging stations for electric vehicles, or linking to port or highway authorities, etc.).	Selected (Iteration 1)	9	9	Selected (Iteration 1)
Monitoring and user compliance	Support in the monitoring and user compliance of all users during the operation (control by the appropriate agencies). E.g., weigh-in motion or speed limits observance.	Selected (Iteration 1)	6	8	Selected (Iteration 3)
Data collection	Support in the collection of data relevant to the operation, implementation, compliance, etc. of the specific measure or policy.	Selected (Iteration 1)	8	8	Selected (Iteration 2)
Data analysis & dissemination	Support in handling (big) data, analyzing them, and providing real-time information to the users.	Selected (Iteration 1)	8	9	Selected (Iteration 2)

* The use of the AHP for the criteria weight formulation did not yield the expected results leading to high inconsistencies. The final weights shown here were based on "direct" weight allocation by each group.

Table 3 gives an overview of the "IT use" rankings for each of the measures and policies subcategories of Table 1 for each of the two groups of experts and stakeholders. The scores in the column "Final Assessment" of Table 3 are the weighted averages of the scores given by each group in each evaluation criterion in the corresponding sub-sector. The weighted average is calculated using the weights for each criterion shown in Table 2. In Table 3, we also give the overall score for each (overall) category calculated in the same way as for the sub-categories. Finally, in the last column of Table 3, the four categories of decarbonization measures and policies are ranked according to their average weighted scores.

Table 3. "IT use" assessment and ranking for categories of measures/policies and their sub-categories.

Category and Sub-category (***Table 1***)	***Final Assessment (score) for "IT use" **** *(Scale 1–5 ***)*		***Ranking of Sub-categories within Their Category as Regards Importance of "IT use"***		***Ranking of Categories (as a whole) as Regards "IT use"***	
	Experts group	*Stakeholders group*	*Experts group*	*Stakeholders group*	*Experts group*	*Stakeholders group*
I.1 *Reduce the demand for vehicle-km on the roads by restructuring the supply chains*	2.8	3.2	3	3		
I.2 *Increase the use of digital technologies* for supply chain mgmt.	8.9	9.0	1	1		
I.3 *Prioritize goods with increased "material efficiency".*	2.5	3.7	4	2		
I.4 *Reduce the growth in demand for transported goods.*	3.7	2.1	2	4		
Overall score for category I (Managing demand)	3.4	3.8			2	2
II.1 *Develop efficient and user-friendly multimodal freight transport platforms*	4.2	4.1	2	2		
II.2 *Develop/Facilitate last-mile operations*	2.5	2.9	3	3		
II.3 *Insert externalities in road transport*	4.5	4.6	1	1		
Overall score for Category II (Shifting to less carbon-intensive modes).	4.0	4.3			1	1
III.1 *Improve vehicle body design*	1.2	0.8	3	3		
III.2 *Improve conventional Powertrains*	1.5	1.3	2	2		
III.3 *Reduce the carbon content of existing fuels*	1.8	2.1	1	1		
Overall score for Category III (Improving the energy efficiency of current vehicles)	1.7	1.9			4	4
IV.1 *Use of battery electric vehicles.*	3.9	3.8	1	1		
IV.2 *Use of fuel cells using hydrogen.*	3.4	3.8	2	1		
IV.3 *Use of Hydrogen as direct fuel.*	2.3	1.8	3	3		
IV.4 *Use of Electric Road Systems.*	2.3	1.9	3	2		
Overall score for Category IV (Use of "clean" energy carriers)	3.0	2.9			3	3

** For each category or sub-category, the result shown is the weighted average of the scores for each of the six accepted evaluation criteria of Table 2. The scores for each criterion emerged from the Delphi process of the answers in each group (experts and stakeholders) handled with the Visual Promethee 1.4 software.*
*** 1: not important, 2: somewhat important, 3: important, 4: very important, and 5: critically important.*

5. Discussion and Conclusions

The role, type, and strength of the contribution of IT to the implementation and successful operation of freight transport decarbonization measures and policies have traditionally been thought of as—generally—important but never quantified or evaluated in detail. This paper has attempted to evaluate the type and magnitude of IT's contribution to the successful implementation of decarbonization policies in the freight transport sector towards the attainment of the "net-zero" EU target for 2050. Based on bibliographic evidence and previous studies, the various measures and policies that can be considered effective in achieving this "net-zero" vision in the freight transport sector were classified into four broad categories, i.e., measures that: manage (and reduce) the demand for freight transport services (and consequently reducing the need for freight trip making); change the modal split of freight transport services and shift freight to modes that are less or no carbon-intensive; improve the energy efficiency of existing internal combustion engines, and; introduce the use of less or no-carbon intensive fuels (e.g., electricity or hydrogen).

For each of the above four broad categories of measures, a further distinction to more vertical and narrowly specified subcategories gave the results in Table 1 (system mapping for freight transport decarbonization options). The formulation of categories and subcategories of measures and policies is a necessary conceptual step in trying to delineate the role of IT, in each one of them, for their implementation and successful outcome. It may be argued that this classification and categorization of measures and policies may not be fully objective, inclusive, or comprehensive enough and also, that priorities and means of implementation may change from location to location (country or region). This, however, does not affect or change the legitimacy of the approach followed here because irrespective of the specific nature and content of the measures to be applied in each case, it will always be possible to associate them with the broad categories or sub-categories used here—at least the great majority of them.

Based on the four broad categories of measures and policies for decarbonization in the (freight) transport sector, a first qualitative examination of the extent and contribution of IT applications and services to each of them was made. Also, several examples of existing well-known IT apps and platforms that are used commercially in the freight transport market were given as examples of IT's role and contribution. It was found that as regards managing the "demand" for freight transport services, IT plays a primary role in facilitating the e-commerce functions and the related freight delivery and distribution activities that reduce road freight traffic on the roads. However, as regards the other important function of demand management, i.e., collecting, handling, and disseminating information and data that can gradually change the way people behave, act, and live, there are not many applications to be found or progress made. As regards the second of the four broad categories of measures, i.e., that of shifting freight transport to less carbon-intensive modes, so far, an extensive array of IT applications have been put forward to enable this type of functionality—thus indicating IT's significant role and value—but other incentives and policies that were put forward towards the same goal have failed so far to produce the desired outcome as regards the level of modal shift towards rail or water.

As regards the third broad category, i.e., that of improving the energy efficiency of existing freight vehicles, the role and importance of IT applications there were found to be limited, as this category mainly consists of mechanical engineering elements for the planning and construction of the relevant technical improvements to vehicles. In the fourth and final category of measures, i.e., that of transitioning to less or no-carbon fuels or electricity, IT applications were found to have an extended and quite important role to play. In electric mobility, IT applications play a vital role in facilitating the finding of recharging points along the various road networks; regulating the electric network power distribution and allocation on the charging stations grid, and; increasing the reliability of electric batteries and other internal electric vehicle systems through facilitating proper monitoring and vehicle maintenance functions. Through all the various IT applications related to electric mobility, the electric vehicles constructed now are increasingly resembling "computers on wheels".

Having conducted a broad overview of IT applicability and applications in each of the four broad categories of decarbonization measures, a more quantitative delineation of IT's role and contribution was sought. It was found that a traditional quantification process through the use of a mathematical model cannot be performed in this case and therefore a different approach was sought in the form of a multicriteria analysis. The method used was the MAMCA in which, two panels of experts were used to define evaluation criteria, assign to them weights, and assess the significance and rank the role and importance of IT applications in each of the broad categories of measures and policies defined earlier as well as their subcategories. The end results of this exercise are summarized in Table 3.

The highest impact, applicability, and contribution of IT seems to be in the measures and policies aimed at shifting freight to less or no-carbon-intensive modes. Here, at a scale of 1 (not important contribution) to 5 (critically important), the IT contribution scored 4.0 and 4.3 (by the group of experts and stakeholders respectively). Similarly, the applicability and contribution of IT seem very high in the category "Demand management", i.e., on measures and policies aimed at changing the characteristics of the demand for freight transport services to make them more environmentally friendly and carbon neutral. The scores in Table 3 for the overall category I (Demand management), are 3.4 and 3.8 for the experts and stakeholders groups correspondingly and these scores are close to 4 so the contribution of IT to demand management measures is considered very important (level 4 on a scale from 1 to 5).

Of all four of the broad categories, the least dependable to IT was found to be category III (Improving the energy efficiency of current vehicles). This was to be expected as this category involves measures of a mechanical engineering nature such as using light materials to reduce vehicle weight; improving the aerodynamic performance of the vehicles (air drag); improving rolling resistance, and similar. The average overall scores for this category by the two panels were 1.7 (experts) and 1.9 (stakeholders). This low score refers mainly to the direct role and impact of

IT in the planning, implementation, and execution of the tasks at hand and not to its indirect role, i.e., in the accomplishment of the design and manufacturing processes.

In category IV (Use of clean energy carriers) the contribution of IT was found to be "important" with scores of 3 and 2.9 correspondingly (experts and stakeholders). This result was somewhat below our expectations because of the role of IT in facilitating the finding of recharging points along the road networks and regulating the electric network's power distribution and allocation at the charging stations. When looking, however, at the scores for the detailed subcategories of this category we find that the scores given to sub-category IV.1 (Use of battery electric vehicles) and IV.2 (Use of hydrogen fuel cells), were much higher, i.e., 3.9/3.8 and 3.4/3.8 correspondingly. These are close to 4 (very important). So, the IT applications in these subcategories are indeed thought of as of a fundamental nature.

The overall conclusion is that of the four categories of measures and policies the one where the role and contribution of "IT use" are considered as "very important" and thus indispensable for its successful implementation and operation, is the "Shifting to less or no-carbon intensive modes". This category has drawn the highest scores, i.e., 4.0 and 4.3 (experts and stakeholders correspondingly). The second most relevant category is that of "Demand management" with overall scores of 3.4 and 3.8. Politically, these are the two most difficult policies to implement, and the EU and European governments have so far fallen behind in their successful implementation. So, the policy implications of our findings are that more funding should be allocated to the use of IT solutions and apps that facilitate the shifting of cargo to less or no-carbon-intensive modes mainly from road to rail. The same policy implication goes for the application of demand management measures. Here, the role that IT can play is perceived as marginally less important than in the previous case and this is perhaps because of the difficulties associated with changing people's habits.

The above results, though not quantitative, in the strict sense of the word, are indicative of the level of significance that is attributed to IT applications for the successful implementation of the various decarbonization strategies. They can also be practically useful, in formulating the new EU strategies which will have to be formed as the experience so far, shows that the EU decarbonization targets set for 2030 (i.e., the 55% reduction of emissions) and 2050 (net-zero target) will be difficult to obtain. There are serious impediments that have slowed down progress so far. Two of the most pronounced such impediments are the COVID-19 pandemic and the war in Ukraine. This situation makes the role of IT even more important and valuable because, to achieve "zero carbon emissions" by 2050 in the freight transport sector, a combination of new measures and policies will be necessary to be taken simultaneously. In achieving this, the various applications of IT will have a very challenging role to play.

Success will utterly depend on a broad array of key actions like the building of the necessary infrastructures for low, or no-carbon energy vectors including renewable electric power and hydrogen, or developing massive capacities of charging infrastructures in the cities and along highways for the battery electric vehicles. IT will always be a "tool" and "facilitator" whose crucial role will be to enable the policymakers and legislators to find the "silver bullet" in the form of the optimum combination of measures and policies to apply for decarbonizing a certain sector.

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Data Availability

The data is available upon reasonable requests from the corresponding author.

Author Contributions

Conceptualization: A.G.; Data curation: T.M.; Formal analysis: A.G., & T.M.; Investigation: A.G., & T.M.; Methodology: A.G., & T.M.; Project administration: T.M.; Resources: A.G., & T.M.; Software: A.G., & T.M.; Supervision: A.G.; Validation: T.M.; Visualization: A.G., & T.M.; Writing – original draft: A.G.; Writing – review & editing: A.G., & T.M.

Conflicts of Interest

The authors have no conflict of interest to declare.

References

1. European Parliament. (2021). *Regulation (EU) 2021/1119 of the European Parliament and of the Council of 30 June 2021 establishing the framework for achieving climate neutrality and amending Regulations (EC) No 401/2009 and (EU) 2018/1999 ('European Climate Law')*.
2. European Environment Agency (EEA). (2023). *Transport and Mobility*. https://www.eea.europa.eu/en/topics/in-depth/transport-and-mobility (accessed 6 September 2023).
3. IEA. (2023). *Transport: Improving the sustainability of passenger and freight transport*. https://www.iea.org/topics/transport (accessed 6 September 2023).
4. McKinnon, A. (9 March 2018). *Decarbonization Targets and Measures to Achieve Them Current State of Knowledge*. ALICE. (2018). Towards 2050 Zero Emissions Logistics Workshops: Logistics Emissions Reduction Paths Towards Zero Emissions Logistics, Strombeek-Bever, Belgium.
5. European Commission (EC). (2016). *EU reference Scenario 2016: Energy, transport and GHG emissions trends to 2050*.
6. European Parliament. (2023). *CO_2 emissions from cars: facts and figures (infographics)*. https://www.europarl.europa.eu/news/en/headlines/society/20190313STO31218/co2-emissions-from-cars-facts-and-figures-infographics (accessed 4 December 2023).
7. EUROCONTROL. (2022). *EUROCONTRO Forecast Update 2022-2024: Recovery from COVID-19 and Russian invasion of Ukraine*. https://www.eurocontrol.int/publication/eurocontrol-forecast-update-2022-2024 (accessed 6 September 2023).
8. Eurostat Statistics Explained. (2023). *Freight transport statistics - modal split*. https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Freight_transport_statistics_-_modal_split (accessed 6 September 2023).
9. European Commission (EC). (2011). *White Paper: Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system*.
10. European Council. (2018). *Renewable energy: Council confirms deal reached with the European Parliament*. https://www.consilium.europa.eu/en/press/press-releases/2018/06/27/renewable-energy-council-confirms-deal-reached-with-the-european-parliament (accessed 6 September 2023).
11. EASAC. (2019). *Decarbonization of transport: options and challenges*. https://easac.eu/projects/details/decarbonisation-of-transport (accessed 6 September 2023).
12. European Environment Agency (EEA). (2022). *Greenhouse gas emissions from Transport in Europe*. https://www.eea.europa.eu/ims/greenhouse-gas-emissions-from-transport (accessed 5 September 2023).
13. McKinnon, A. (2018). *Decarbonizing logistics: Distributing Goods in a Low Carbon World*. Kogan Page.
14. Min, R. (2023). *Sweden is building the world's first permanent electrified road for EVs to charge while driving*. Euronews. https://www.euronews.com/next/2023/05/09/sweden-is-building-the-worlds-first-permanent-electrified-road-for-evs-to-charge-while-dri (accessed 6 September 2023).
15. Marcucci, E., Gatta, V., & Le Pira, M. (Eds.). (2023). *Handbook on city logistics and urban freight*. Edward Elgar.
16. Eurostat Statistics Explained. (2018). *Renewable energy statistics*. https://ec.europa.eu/eurostat/statistics-explained/index.php/Renewable_energy_statistics#7.25_of_renewable_energy_used_in_transport_activities_in_2016 (accessed 5 September 2023).
17. European Investment Bank (EIB). (2023). *EIB investment report 2022/2023: Resilience and Renewal in Europe*. https://www.eib.org/en/publications/20220211-investment-report-2022.htm (accessed 6 September 2023).
18. Raubal, M., Jonietz, D., Ciari, F., Boulouchos, K., Küng, L., Georges, G., et al. (2017). *Towards an Energy Efficient and Climate Compatible Future Swiss Transportation System* (Working Paper). Swiss Competence Center for Energy Research—SCEER.
19. Marcucci, E., Gatta, V., & Maltese, I. (2023). Policy Acceptability and Implementation in Urban Logistics. In *The Routledge Handbook of Urban Logistics* (1st ed., pp. 267–281). Routledge.
20. Le Quéré, C., Jackson, R. B., Jones, M. W., Smith, A., Abernethy, S., Andrew, R. M., et al. (2020). Temporary reduction in daily global CO2 emissions during the COVID-19 forced confinement. *Nature Climate Change*, *10*, 647–653. https://doi.org/10.1038/s41558-020-0797-x
21. Jonkeren, O., Francke, J., & Visser, J. (2019). A shift-share based tool for assessing the contribution of a modal shift to the decarbonisation of inland freight transport. *European Transport Research Review*, *11*, 8. https://doi.org/10.1186/s12544-019-0344-x
22. Zhang, J., Zhang, S., Wang, Y., Bao, S., Yang, D., Xu, H., et al. (2021). Air quality improvement via modal shift: Assessment of rail-water-port integrated system planning in Shenzhen, China. *Science of the Total Environment*, *791*, 148158. https://doi.org/10.1016/j.scitotenv.2021.148158
23. de Mello Bandeira, R. A., Goes, G. V., Gonçalves, D. N. S., Márcio de Almeida, D. A., & de Oliveira, C. M. (2019). Electric vehicles in the last mile of urban freight transportation: A sustainability assessment of postal deliveries in Rio de Janeiro-Brazil. *Transportation Research Part D: Transport and Environment*, *67*, 491–502. https://doi.org/10.1016/j.trd.2018.12.017
24. Bosona, T. (2020). Urban freight last mile logistics—Challenges and opportunities to improve sustainability: A literature review. *Sustainability*, *12*(21), 8769. https://doi.org/10.3390/su12218769
25. Zhang, R., & Hanaoka, T. (2021). Deployment of electric vehicles in China to meet the carbon neutral target by 2060: Provincial disparities in energy systems, CO2 emissions, and cost effectiveness. *Resources, Conservation and Recycling*, *170*, 105622. https://doi.org/10.1016/j.resconrec.2021.105622
26. Carlan, V., Sys, C., & Vanelslander, T. (2019). Innovation in Road Freight Transport: Quantifying the Environmental Performance of Operational Cost-Reducing Practices. *Sustainability*, *11*, 2212. https://doi.org/10.3390/su11082212
27. Gialos, A., Zeimpekis, V., Madas, M., & Papageorgiou, K. (2022). Calculation and Assessment of CO2 Emissions in Road Freight Transportation: A Greek Case Study. *Sustainability*, *14*, 10724. https://doi.org/10.3390/su141710724
28. Ghisolfi, V., Tavasszy, L. A., Correia, G. H. d. A., Chaves, G. d. L. D., & Ribeiro, G. M. (2022). Freight Transport Decarbonization: A Systematic Literature Review of System Dynamics Models. *Sustainability*, *14*, 3625. https://doi.org/10.3390/su14063625
29. Kechagias, E. P., Gayialis, S. P., Konstantakopoulos, G. D., & Papadopoulos, G. A. (2020). An application of an urban freight transportation system for reduced environmental emissions. *Systems*, *8*(4), 49. https://doi.org/10.3390/systems8040049

30. Li, Y., Lim, M. K., Tan, Y., Lee, Y., & Tseng, M. L. (2020). Sharing economy to improve routing for urban logistics distribution using electric vehicles. *Resources, Conservation and Recycling*, *153*, 104585. https://doi.org/10.1016/j.resconrec.2019.104585
31. Dündar, H., Ömürgönülşen, M., & Soysal, M. (2021). A review on sustainable urban vehicle routing. *Journal of Cleaner Production*, *285*, 125444. https://doi.org/10.1016/j.jclepro.2020.125444
32. Jazairy, A., Pohjosenperä, T., Sassali, J., Juga, J., & von Haartman, R. (2023). Driving the talk: examining professional truck drivers' motivations to engage in eco-driving. *International Journal of Physical Distribution & Logistics Management*, *53*(11), 98–124. https://doi.org/10.1108/IJPDLM-07-2022-0236
33. Fafoutellis, P., Mantouka, E. G., & Vlahogianni, E. I. (2020). Eco-driving and its impacts on fuel efficiency: An overview of technologies and data-driven methods. *Sustainability*, *13*(1), 226. https://doi.org/10.3390/su13010226
34. Ng, E. C., Huang, Y., Hong, G., Zhou, J. L., & Surawski, N. C. (2021). Reducing vehicle fuel consumption and exhaust emissions from the application of a green-safety device under real driving. *Science of the Total Environment*, *793*, 148602. https://doi.org/10.1016/j.scitotenv.2021.148602
35. Bibeka, A., Songchitruksa, P., & Zhang, Y. (2021). Assessing environmental impacts of ad-hoc truck platooning on multilane freeways. *Journal of Intelligent Transportation Systems*, *25*(3), 281–292. https://doi.org/10.1080/15472450.2019.1608441
36. Validi, A., & Olaverri-Monreal, C. (2021). Simulation-based impact of connected vehicles in platooning mode on travel time, emissions and fuel consumption. In *2021 IEEE Intelligent Vehicles Symposium (IV)* (pp. 1150–1155). IEEE. https://doi.org/10.1109/IV48863.2021.9575899
37. Paddeu, D., & Denby, J. (2022). Decarbonizing Road freight: Is truck automation and platooning an opportunity? *Clean Technologies and Environmental Policy*, *24*, 1021–1035. https://doi.org/10.1007/s10098-020-02020-9
38. Yowtak, K., Imiola, J., Andrews, M., Cardillo, K., & Skerlos, S. (2020). Comparative life cycle assessment of unmanned aerial vehicles, internal combustion engine vehicles and battery electric vehicles for grocery delivery. *Procedia CIRP*, *90*, 244–250. https://doi.org/10.1016/j.procir.2020.02.003
39. Massar, M., Reza, I., Rahman, S. M., Abdullah, S. M. H., Jamal, A., & Al-Ismail, F. S. (2021). Impacts of autonomous vehicles on greenhouse gas emissions—positive or negative? *International Journal of Environmental Research and Public Health*, *18*(11), 5567. https://doi.org/10.3390/ijerph18115567
40. Ercan, T., Onat, N. C., Keya, N., Tatari, O., Eluru, N., & Kucukvar, M. (2022). Autonomous electric vehicles can reduce carbon emissions and air pollution in cities. *Transportation Research Part D: Transport and Environment*, *112*, 103472. https://doi.org/10.1016/j.trd.2022.103472
41. De Oliveira Leite Nascimento, C., Gatta, V., & Marcucci, E. (2023). Green Crowdshipping: Critical factors from a business perspective. *Research in Transportation Business and Management*, *51*, 101062. https://doi.org/10.1016/j.rtbm.2023.101062
42. Rail Freight Forward. (2020). *White Paper: 30 by 2030 Rail Freight strategy to boost modal shift*. https://www.railfreightforward.eu/sites/default/files/usercontent/white_paper-30by2030-150dpi6.pdf (accessed 5 September 2023).
43. Feldmann, J., Byrum, Z., & Cyrs, T. (2023). *Clean hydrogen: Outlook for freight transport in the United States* (Working Paper). World Resources Institute. https://doi.org/10.46830/wriwp.21.00155
44. Giannopoulos, A. G., & Moschovou, T. P. (2023). Estimating the Value of Information Technology in the Productivity of the Transport Sector. *Future Transportation*, *3*(2), 601–614. https://doi.org/10.3390/futuretransp3020035
45. Macharis, C., de Witte, A., & Ampe, J. (2009). The multi-actor, multi-criteria analysis methodology (MAMCA) for the evaluation of transport projects: Theory and practice. *Journal of Advanced Transportation*, *43*(2), 183–202. https://doi.org/10.1002/atr.5670430206
46. L'Hostis, A., Muller, B., Meyer, G., Bruckner, A., Foldesi, E., Dablanc, L., et al. (2016). *MOBILITY4EU - D2.1 - Societal needs and requirements for future transportation and mobility as well as opportunities and challenges of current solutions.* Mobility4EU. https://hal.science/hal-01486783v2 (accessed 6 September 2023).
47. Gagatsi, E., Giannopoulos, G. A., Aifantopoulou, G. A., & Charalampous, G. (2017). Stakeholders-based multi-criteria policy analysis in maritime transport: from theory to practice. *Transportation Research Procedia*, *22*, 655–664. https://doi.org/10.1016/j.trpro.2017.03.062
48. Wong, J. K. W., & Li, H. (2008). Application of the analytic hierarchy process (AHP) in multi-criteria analysis of the selection of intelligent building systems. *Building and Environment*, *43*(1), 108–125. https://doi.org/10.1016/j.buildenv.2006.11.019
49. Cohon, L. J., & Morgan, M. G. (2017). Multi-Attribute Utility Theory and Multi-Criteria Decision Making. In *Theory and Practice in Policy Analysis* (pp. 155–184). Cambridge University Press. https://doi.org/10.1017/9781316882665.007
50. Belton, V. (1999). Multi-Criteria Problem Structuring and Analysis in a Value Theory Framework. In T. Gal, T. J. Stewart, & T. Hanne (Eds.), *Multicriteria Decision Making. Springer International Series in Operations Research & Management Science* (pp. 335–366). Springer. https://doi.org/10.1007/978-1-4615-5025-9_12
51. Shakirov, V. (2019). Decision-Making Based on Multi-Attribute Value Theory Under Preference Uncertainty. In *Proceedings of the 7th Scientific Conference on Information Technologies for Intelligent Decision-Making Support (ITIDS 2019)* (pp. 177–183). Atlantis Press. https://doi.org/10.2991/itids-19.2019.32
52. Goswami, S. S. (2020). Outranking Methods: Promethee I and Promethee II. *Foundations of Management*, *12*(1): 93–110. https://doi.org/10.2478/fman-2020-0008
53. Madanchian, M., & Taherdoost, H. (2023). A Comprehensive Overview of the ELECTRE Method in Multi Criteria Decision-Making. *Journal of Management Science & Engineering Research*, *6*(2), 5–16. https://doi.org/10.30564/jmser.v6i2.5637
54. Hsu, C., & Sandford, B. A. (2007). The Delphi Technique: Making Sense of Consensus. *Practical Assessment, Research, and Evaluation*, *12*, 10. https://doi.org/10.7275/pdz9-th90
55. Ulschak, F. L. (1983). *Human Resource Development: The Theory and Practice of Need Assessment.* Prentice Hall.