Periodica Polytechnica Transportation Engineering, 52(1), pp. 18–23, 2024

Environmental Impact of Freight Transport – Freight Footprint as a New Freight Transport Indicator

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Received: 15 August 2023, Accepted: 31 October 2023, Published online: 11 December 2023

Abstract

One of the most pressing questions today is how to prevent or slow down climate change. As a service sector, transport significantly contributes to this and increases greenhouse gas emissions. Furthermore, creating long-term sustainable social, economic and environmental processes by eliminating current systemic failures can also be a significant challenge for individual nations. One thing is sure: the status quo is not sustainable. Taking all these aspects into account, this paper seeks to answer the question of the extent to which the performance of freight transport in each EU Member State contributes to the change in the ecological footprint and how national characteristics influence this. The research introduces a newly established indicator, the freight transport footprint, which is based on a family of footprint formulas and specifically seeks to answer the extent to which freight transport burdens our environment.

Keywords

ecological footprint, carbon footprint, goods transport, freight footprint

1 Introduction

Of the many aspects of freight transport and transport itself, one of the most important is its impact on the environment and the pollution it causes in a given area. Transport externalities are by-products of transport activities that can have unintended consequences, usually contributing negatively to our quality of life. In addition to the environment and noise pollution, it is essential to mention the adverse effects resulting from the design of the infrastructure, which can be grouped into two types of pictures. One is the spatial separation/ breaking up of communities. Highways or railways can be disruptive to communities if not properly planned. They can break community ties and affect social networks. Another impact is the potential loss of landscape, visual effects, and cultural heritage (Nash, 2015). Nowadays, creating sustainable, economically viable areas has become crucial not only from a regional but also from a settlement planning perspective (Farkas et al., 2023). Efforts to reduce energy use in freight transport tend to be centered around "model-based" approaches, namely improving the energy efficiency of energy-intensive modes such as trucks and shifting more freight to energy-efficient modes such as rail. Examining sectoral aspects can also be an important aspect, such as the application of sustainable solutions in the case of air transport, among other things from a technological point of view (Bagdi et al., 2023).

Over the past two decades, an ever-expanding list of new risk measures and footprint-style indicators has been introduced to the scientific community to raise public awareness of humanity's environmental impact (Marczis et al., 2023). Based on a literature review of related fields, ecological, energy, carbon and water footprints are selected indicators to define the footprint family (Fang et al., 2014). The groups in the proposed footprint families can be seen as complementary, as each focuses on different environmental issues. Fig. 1 summarises the environmental footprint families and their possible overlaps.

The carbon footprint has been hugely popular recently and has sparked widespread debate in the scientific community. It is the direct or indirect CO_2 equivalent of an activity or the total amount of greenhouse gas emissions over the life cycle of a process or product. The usefulness of the carbon footprint, unlike the energy footprint, is justified in two ways: it takes into account non-CO_2 emissions (e.g. CH_4, N_2O), which have a much higher global warming potential than CO_2, and it facilitates the allocation of global warming

Cite this article as: Boldizsár, A. (2024) "Environmental Impact of Freight Transport – Freight Footprint as a New Freight Transport Indicator", Periodica Polytechnica Transportation Engineering, 52(1), pp. 18–23. https://doi.org/10.3311/PPtr.23215

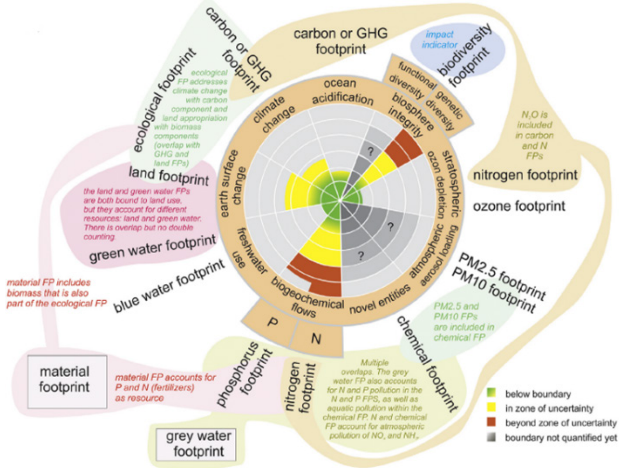

Fig. 1 Summary of environmental footprints (Vanham et al., 2019)

responsibility among consumers (Wright et al., 2011). In the following, the relevance of the carbon footprint from the perspective of freight transport is examined.

2 Examination of the ecological and carbon footprint of international freight transport

The definition of globalization is difficult to determine as we discuss a complex process. The worldwide unification of advanced civilizations practically shapes globalization. In addition, beyond growth, it is essential to examine the economy and the environment from the point of view of sustainability (Hajnal, 2023). Several experts view globalization as a new phenomenon and only speak of a phenomenon that started in the last half of the 20th century, but some date it to the discovery of the American continent (Pongrácz, 2019). The history of the whole of humanity, at least since the beginning of the discovery of America, includes the process of the coming together of different economic formations, societies, and cultures. We can distinguish several areas of globalization, for example, cultural, linguistic, economic or financial, and the processes belonging to each area are always characterized by unification and integration (Kőszegi et al., 2022). As a result of globalization, the world's closed markets have become increasingly open in terms of demand and supply. All this could not be served without establishing a proper logistics system, which requires proper international supply chains and transport networks and quality logistics services such as speed, punctuality, availability and reliability. As a result of globalization, customers' needs have also become more uniform, so the same type of product can be sold anywhere in the world. In addition, it is also essential to mention the raison d'être of the global-local paradox, according to which, thanks to global operations, companies and organizations operate beyond their local borders. At the same time, in the operation of global companies, the importance of localization factors, which enable them to function correctly, increases simultaneously with globalization processes (Forman, 2023). The proper functioning of global supply chains also requires a well-developed international distribution network.

It should not be forgotten that there are many criticisms of globalization. Globalization-critical movements consistently reject actions based on acquiring material goods and ethnic and religious conflicts caused by the power elite. The anti-globalization movements do not deny globalization or the free flow of production, cultures, and contact with modern techniques, but the form in which it is realized: where enrichment and profit are more important than people. According to many opinions, globalization processes have slowed down to the present day and, in many cases, have even stopped (Artner, 2016).

A 2015 study by the International Transport Forum (ITF) explores the evolution of the ecological footprint of changes in international trade trends, especially in freight transport, in relative detail, estimating their magnitude up to 2050 (International Transport Forum, 2015). The study predicts a surprising increase in CO_2 emissions from global freight transport to quadruple from current levels over the next 30 years. This is explained by the fact that the growth in international trade is characterised by globalization and the geographical fragmentation associated with international production processes. Supply chains have become longer and more complex as logistics networks link more and more economic centres across oceans and continents. Increasing attention is being paid to the issue of transport corridors that can provide trade links across continents, with a significant impact on the regions involved (Bernek, 2023). Changing consumer preferences and new manufacturing requirements are also influencing international trade and thus shaping freight transport patterns (Oláh et al., 2023). This has led to an increasing frequency and size of smaller shipments, often travelling in containers that are only half-filled or not even complete, and therefore an increased demand for fast and energy-intensive transport, such as air transport. As the propulsion of freight vehicles is heavily dependent on fossil fuels, and current technologies are still relatively far from entirely switching to cleaner energy sources, this is one of the most challenging sectors to decarbonise. International trade contributes to CO_2 emissions mainly through the transport of goods. The ITF estimates that international trade-related freight transport accounts for around 30% of total transport-related carbon emissions from fuel combustion and over 7% of global emissions. In the base year 2010, global emissions from trade-related freight transport were estimated at 2,108 million tonnes and could rise to 8,131 million tonnes in the baseline scenario, while CO_2 emissions could triple (International Transport Forum, 2015).

In fact, road transport is the main carbon emitter in international trade-related transport, as it has the highest emissions intensity per tonne-kilometre compared to other modes of transport and is responsible for more than half of all trade-related freight transport emissions. Road freight will account for a share of total international trade-related emissions, growing from 53% in 2010 to 56% in 2050. Over the same period, air transport is projected by the ITF to grow by 2 percentage points from 7% to 9%. The carbon share of maritime freight, on the other hand, is estimated to fall from 37% to 32% over the same period, while rail freight will remain stable at around 3%. There are three main factors contributing to the increased CO_2 emissions and the changing share of emissions. Firstly, in addition to the increase in trade volumes, the increase in average transport distance means that goods have to be moved over greater distances between the main trading partners, resulting in more fuel being burned. The largest absolute increase in carbon emissions is recorded in Asia, while the strongest relative increase is in Africa (+689%). Secondly, freight transport between Asian and African countries will increase significantly, which could lead to increasing trade volumes being driven by more carbon-intensive road transport, as alternative transport infrastructure in these regions is currently less developed than elsewhere. Thirdly, air freight will gain a competitive advantage in terms of transporting high-value goods, and as countries export increasingly sophisticated products, this will increase the ratio of emissions from air freight to emissions from aviation (International Transport Forum, 2015).

From a logistical point of view, the COVID-19 epidemic affected individual countries and regions in different ways. However, at the same time, it is indisputable that it had a powerful impact, and significant disruptions were noticeable in international shipments. Since the epidemic started in China, the supply chains and transport routes connected to the country were blocked entirely, especially sea transport, as the ports were closed almost immediately (e.g. Shanghai) (Zhou et al., 2022). In 2020, there was also a slight decline in freight volumes (Gonzalez et al., 2022); however, by 2021, the previous volume of freight volumes had fully recovered, which I later proved, so this period was considered in this analysis. The epidemic and the closures related to it made their impact felt mainly in the field of urban logistics, where on the one hand, the number of physical contacts was reduced and greatly influenced the shopping habits of the population. E-commerce purchases increased enormously, due to which distribution faced new, unexpected challenges, although it is indisputable that logistics companies recorded growth (Castillo et al., 2022).

In addition to the COVID-19 epidemic, the Russian-Ukrainian conflict that broke out in February 2022 must also be mentioned, the effects of which can also be seen in logistics and goods transport. The previously used and well-proven delivery routes ceased to exist, and raw materials from these countries, or even semi-finished products, were suddenly transformed into unobtainable products, which caused or continues to cause, severe disruptions in the supply chains (Lin et al., 2023). It is important to note that, on the one hand, due to the sensitivity of the topic (there is little or even unreliable data available regarding the verification of correctness), and on the other hand, due to the short time that has passed, the scientific research in this area is not yet identifiable.

3 Transport footprint calculation

The concept and definition of the ecological footprint were first coined by Wackernage and Rees (1996 cited in Csutora, 2011:p.6), who developed the methodology for the calculation, but there are now many more versions. The calculation aims to define a framework that shows "the share of human use in ecosystem goods and services, using the amount of productive land (land and sea) needed to produce these goods and services as an indicator" (Csutora, 2011:p.6).

The EU's ecological footprint is even higher than the world average, as a WWF article published on European Overexploitation Day reported that 2.8 hectares of land are needed for the Community to survive. The ecological footprint of the EU Member States increased from 1.6 billion global hectares in 1961 to 2.3 billion in 2016, and although the EU accounts for only 7% of the world's population, it contributes about 20 % of global biocapacity (WWF, Global Footprint Network, 2019):

1. arable land: land used for the production of arable crops,
2. pasture: land used for grazing livestock,
3. fishing areas: marine areas used for fishing,

4. forest areas: areas covered with forest,
5. built-up areas: built-up areas covered by infrastructure used for industrial, transport or residential purposes,
6. carbon sinks: the amount of forest area theoretically needed to absorb the carbon dioxide emitted.

This is the basis of the formula for calculating the ecological footprint (Szigeti and Borzán, 2012):

$$\mathrm{EF}_P = \frac{P}{Y_N} \times \mathrm{YF} \times EQF \tag{1}$$

where:

- EF_P: ecological footprint of production in global hectares or planet equivalent [0...1],
- P: the quantity of the primary product. For CO_2, refers to total carbon dioxide emitted [tonnes CO_2],
- Y_N: average yield [tonnes CO_2], the indicator measures the average yield of CO_2 emission,
- YF: yield factor (national yield/world average yield) [-],
- EQF: equivalence factor, expressing the fertility of different land types in relation to each other (global hectares/world hectare) [-].

From the theoretical foundations, it can be seen that carbon emissions are the most critical determinant of the ecological footprint of freight transport, so we will now look at the EU Member States from this perspective. In addition to the ecological footprint, another helpful indicator is the carbon or carbon footprint, as mentioned earlier (Barna and Gelei, 2014). According to Eurostat, the carbon footprint is the carbon dioxide generated by the final use of the goods produced (KSH, 2018). The calculation of the carbon footprint has been the subject of several national and international researchers and articles, but research has not covered the EU Member States from the perspective of freight transport, looking at the individual transport sectors and their impact on the carbon footprint.

In most studies, the carbon footprint, or carbon dioxide emissions, is based on distances travelled, thus making km traveled directly proportional to emissions. However, it is essential to note that carbon footprints are not only used for transport purposes. They can also be used as a tool for businesses to measure, for example, sustainability performance (Vanham et al., 2019).

Data analysis shows that Germany has the highest performance and volume, followed by the UK and France. It is interesting to note that the ecological footprint of the individual Member States shows a very different picture from the top three countries. In order to put the data on the same footing, we have created a so-called "freight transport footprint" based on the ecological footprint presented earlier and, in this case, looking at the EU Member States. The new formula was developed as follows:

$$\mathrm{FF}_{\mathrm{EU}} = \frac{V_f}{Y_N} \times \mathrm{YF}_{\mathrm{EU}} \times EQF \tag{2}$$

where:

- $\mathrm{FF}_{\mathrm{EU}}$: freight footprint (global hectares),
- V_f: freight transport performance per country (tonnes),
- Y_N: average EU freight transport performance (tonnes),
- $\mathrm{YF}_{\mathrm{EU}}$: yield factor (national yield/EU total return),
- EQF: equivalence factor, expressing the fertility of different land types in relation to each other (global hectares/world hectare). For carbon, this value is 1.26.

The transport footprint measures the amount of carbon dioxide a country (or even a smaller region) contributes to collective emissions relative to the amount of carbon dioxide transported per unit of transported volume. Hence, as with the other footprints, a country is in an ideal state if this value is below 1. Inserted into the formula, Figs. 2 and 3 show how the freight footprint of EU Member States evolved in 2018 and 2021.

Figs. 4 and 5 show the evolution of the EU Member States' freight transport footprint in terms of population over the same years.

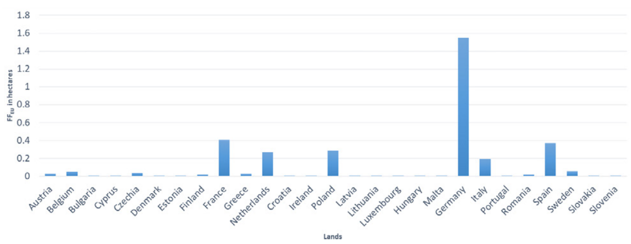

Fig. 2 Global freight footprint in hectares in 2018

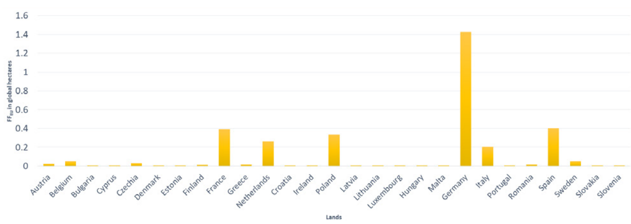

Fig. 3 Global freight transport footprint in hectares in 2021

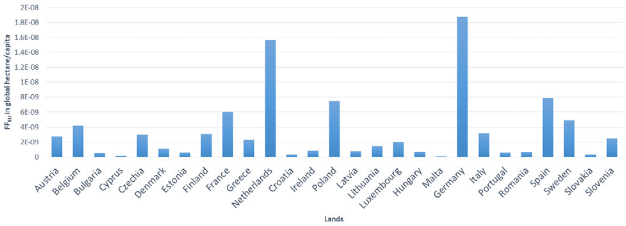

Fig. 4 The freight footprint in global hectare/capita in 2018

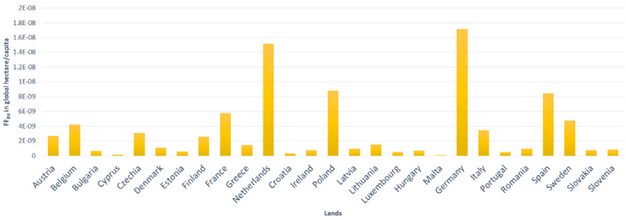

Fig. 5 The freight footprint in global hectare/capita in 2021

It can be seen that while Germany's ecological footprint is ranked 14th among EU Member States, it is well above the other countries in terms of volume in freight transport. Furthermore, if we also consider the indicator in terms of population, the Netherlands moves up to second place in the ranking after Germany and Poland to third, although there was no indication of this before, based on the volume of goods transported. This suggests that these countries have the most significant individual freight transport footprints of all EU Member States regarding their contribution to collective carbon dioxide emissions from their freight transport needs. For both the freight transport footprint and the freight transport footprint per hectare, it can be observed that there is no overall significant change between the two years under consideration due to the impact of the COVID-19 epidemic. When looking at the Member States separately, there is a visible increase in Poland and Spain, among others, while Greece, Luxembourg and Slovenia show a decrease, similar to the evolution of the volumes of goods transported.

4 Summary

This research sought to answer the question of what factors drive the participants in freight transport systems and what conclusions can be drawn from the new indicator that can specifically address the challenges related to freight transport. Transport and environmental pressures are popular topics in research, but little attention has been paid to the relationship between freight transport and the ecological footprint, which can be used to conclude, for example, the freight transport situation in a country. Overall, the current literature and research, as well as the results of statistical calculations, point in almost the same direction, i.e. until fossil fuel vehicles are replaced or substituted in freight transport, carbon emissions will increase, increasing the ecological footprint of national economies. At present, the only way to reduce the ecological footprint of the freight transport sector while increasing performance is to shift volumes from road to other transport sectors in line with EU ambitions or to phase out fossil fuels.

As a result, a new indicator, the Freight Footprint, was created to provide a transparent picture of the freight transport situation in Europe and its impact on the environment. In most studies, the carbon footprint, or carbon dioxide emissions, is based on the distances travelled, thus making the km travelled directly proportional to the emissions. The present research sought to answer what happens if the ecological footprint formula is adapted to freight transport and how the footprint calculation is calculated between EU Member States. It can be seen that Germany has the highest total volume of goods transported among the EU Member States, with the highest volume of goods transported by road. The calculation shows that EU countries' role in freight transport performance, indicators and carbon dioxide emissions varies, but that Germany is still the leader.

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