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Abstract

Sustainability is a crucial dimension of our life at the beginning of the third millennium. Our society transforms and changes even faster and more continuously than earlier. Our work aims to define a new concept: the cognitive sustainability domain. Several fields of science were explored to recognise how the interdisciplinary approach of cognitive sustainability is valid. The former joint use of cognitivity and sustainability was reviewed in the literature. Results showed that digital development lets us extend our experiential cognition in most fields of our lives. Limits of the available resources and the development of cognitive functionalities are the enablers of connecting and addressing sustainability. The main dimensions and parameters of cognitive sustainability were identified, and several key research areas were defined. The structured handling of cognitive tools within sustainability results in a broader interpretation framework for analysing, understanding and developing processes in sustainability.

Keywords

Cognitive Sustainability, Mobility, Architecture, Economics, Interdisciplinarity

1. Introduction

Sustainability is a day-to-day issue of 21st-century life in technical and technological processes such as mobility (Zöldy, 2021), which use resources directly, even irreversibly, and in economics and the humanities. In addition to the growth-driven mindset of recent decades, there is an increasing drive to maintain the current state and its qualitative dimensions. The cognitive perception spreading in our world opens new dimensions in understanding sustainability.

The term 'sustainable' started to become famous after Lester R. Brown (1981) first published the terminology of sustainability from a social aspect (sustainable society) and the work of the Brundtland Commission (1987), although examples of practical implementation remained few and far between, as shown by the events at the United Nations as the UN Conference on Environment and Development (Rio Earth Summit) in Rio de Janeiro (1992), World Summit on Sustainable Development in Johannesburg (2002) and the UN Conference on Sustainable Development (Rio+20) in 2012. This can be explained by the slow transition from philosophy to practice, conflicts of interest and the difficulties in interpreting the integrative nature of sustainability. Most of the international sustainability-related conferences provided a unique opportunity to reveal and rethink political commitments considering the three dimensions of sustainable development acknowledged today. The UN SDGs

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(Agenda 2030) are in scope both from policy and scientific perspectives. The concept of sustainable development is strongly tied to environmental protection. Environmental impacts and research results have drawn attention to the importance of environmental protection and the need for international cooperation in this area.

Parallel to the emergence of sustainability, different interpretations have also been developed. One-dimensional models mainly focused on ecological limits and environmental considerations. Two-dimensional models were the next step, adding socio-economic aspects to the focus and differentiating between welfare and well-being. The three-dimensional model is the most recent and the most popular one, according to which the three dimensions are the biosphere, the economy and the society, which are interdependent and have complex interactions. Further dimensions have also emerged in literature, such as the institutional dimension, which is related to establishing the background necessary for measuring and monitoring progress towards sustainability (data acquisition and analysis). Cultural aspects have also been emphasised as a direct result of putting man at the centre of sustainability. The multi-dimensional model of sustainability includes technological, time and space dimensions in addition to the original three. In summary, the magnificence and complexity of the concept of sustainability come from the fact that it can be applied to all levels and dimensions. The field of cognition-related knowledge can deliver a broader and more holistic perspective in the further development of sustainability science.

Our goal was a deep understanding of cognitive sustainability across disciplines in this research. Sustainability can be interpreted in almost all fields of science, but in many cases, with entirely different content. However, increasing cognition allows for better understanding and is the key to better understanding, thereby increasing sustainability. In the scientific literature, several studies have drawn attention to different approaches to defining sustainability depending on the characteristics of the possible sustainable development pathways (Munasinghe, 1993; Luke, 2005; Liu, 2009; Hussen, 2013; Ramsey, 2015; Sauvé, 2016; Whyte-Lamberton, 2020; Ruggerio, 2021). The structure of sustainability in terms of cognition and motivation has previously been examined by van Dam and van Trijp (van Dam, 2011) from consumers' perspectives. Users of sustainable products have been empirically compared with the Brundtland definition (WCED 1987) and the Triple-P-Baseline definition (Hammod, 2006) of sustainability. Their results show that research into consumers' cognitive understanding of sustainable development aligns with consumer motivations and thus helps them buy sustainable products.

In his summary, Bruni (2010) links the implications of the expansion of digital culture for sustainability, in particular the economic crisis of 2007/2008. The work puts the impact of the expansion of digital culture on the relationship between sustainability and information technology in context. This path outlines the eco-ethical dimensions of development and the expansion of comprehensive digital-interactive-immersive representation technologies. Three aspects are examined: Batesone's sustainability (Bateson, 1972), recent developments in the technosphere and Yuri Lotman's concept of the semiosphere (Lotman, J. (2005/1984). As a result of his work, some eco-ethical dimensions are outlined.

The merger of cognitive capabilities for humans and the developing artificial cognition of machines open space to measure, understand and predict sustainability more deeply. The current models are not well equipped to deal with the challenges we face, so a new approach is needed, which also concerns the cognitive sphere. A new way of thinking is necessary, for example, in engineering, economics, urban development and finance. This new attitude is the approach of „cognitive sustainability", which is based on interdisciplinarity, as several areas of life are interconnected in their links to the issue of sustainability.

Climate change is one of the most critical economic and social challenges of the 21st century, and its environmental unsustainability is confirmed by a number of documents (Stern et al., 1996; Stern, 2006; WWF, 2011; IPCC, 2019; IPCC, 2021). The climate challenge is too big for anyone disciple to solve alone. All spheres must work together in a coordinated and aligned manner. Their work must be complementary, as their functions and toolkits are different. It is necessary to exchange knowledge and share best practices in an emerging and uncharted territory of work for many.

This paper aims to provide a possible framework in which human and machine capabilities are part of a holistic, sustainable system.

2. Definition

Cognitive Sustainability (CogSust) investigates the links between sustainability and cognitive sciences research areas. Sustainability can be interpreted as an environmental discipline issue to a first-order approach. Alternatively, as an engineering challenge in a broader range of interpretations, but can be interpreted in many more disciplines.

The key aim of CogSust is to provide a holistic view of how sustainability in a broader sense can be understood, described (modelled) and optimised for human value creation by the application of the tools of cognitive sciences. It results in a deeper merger of artificial and biological cognitive systems with engineering applications.

The sustainability requirement is intended to mean that the objectives cannot be chosen freely in one dimension or sector but must respect certain constraints due to complex systemic contexts (Fleischer, 2014).

Three essential characteristics of cognitive sustainability should be defined: the substance, the equity and the implication of sustainability. Figure 1 introduces the frame of reference considering the main characteristics of the CogSust concept.

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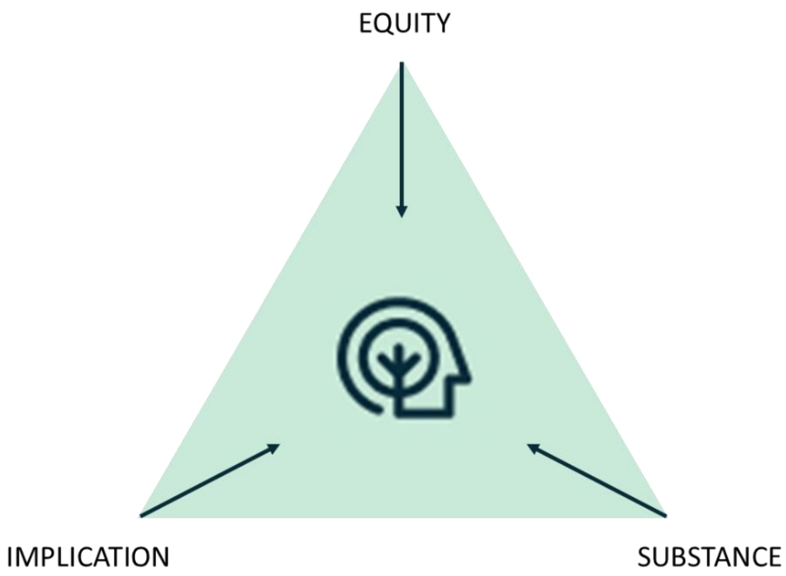

Figure 1. The main characteristics of the cognitive sustainability concept

Substance of Sustainability

Physical sustainability – sustainability can be interpreted at the level of substances.

Non-physical sustainability – sustainability can not be interpreted at the level of substances (i.e. social sustainability or emotional sustainability)

Equity of sustainability

Inter-cognitive sustainability – the actor/decision-maker and its affected zone are different cognitivity levels.

Intra-cognitive sustainability – the actor and the area are at the same cognitivity level.

Implication of sustainability

Extended sustainability – when the decision-maker makes his decision not only by himself but also by managing the set of aspects and dimensions affected by the action.

Island-like sustainability – when the decision-maker puts the sustainability of only the narrowest circle in the focus of his decision.

3. Discussion - Historical view

The cognitive sustainability research area will be examined from a historical and cognitive informatics perspective in the discussion section.

During the industrialisation in the second half of the nineteenth century and the twentieth century, humanity realised by the turn of the 1960s and 1970s that the processes going on for a long time could no longer continue. The unprecedented results, including the pace of urbanisation and the improvement of industrial and agricultural productivity, are based on the use of resources that adversely affect spatially and or temporally distant societies due to their finiteness. An emblematic event in this process was the 1972 Stockholm Conference, or the same year's report of the Club of Rome (Meadows et al., 1972).

The 1980s drew attention to the fact that not only do we consume environmental goods, but we also pollute our environment with emissions. Deforestation caused by acid rain or increased ultraviolet radiation associated with the depletion of the ozone layer was also perceptible environmental damage due to pollutant emissions. Around the turn of the millennium, the issue of climate change put the issue of sustainability at the centre: the environment is now perceived as a sensitive, functioning system with a finite absorption capacity. Human activity can overload the environment in such quantities that it can change the established processes of nature, and consequently, the environment we have adapted to over the centuries is also modified.

Cognitive methodologies have been incorporated into science in parallel with an increasingly broader interpretation and deeper understanding of sustainability. In addition to advances in engineering, the increase in data in other fields, such as finance or sociology, has allowed for a more detailed understanding of sustainability through data and analysis (Fleischer, 2014).

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Most authors vigorously defend the ecological dimension of sustainability because it discusses non-human nature and promotes the idea that the more nature changes, the less environmentally sustainable it is. The less human intervention in nature, the more sustainable it will be. For example, environmental data collection has evolved exponentially with the proliferation of meteorological sensors and the expansion of their detection, allowing for a deeper understanding, modelling, and prediction of the environmental impacts of actions (Börcsök et al., 2020).

The cultural dimension focuses on modernisation models and integrated rural production systems, emphasising changing the core of cultural continuity and incorporating the normative concept of ecological development into a range of individual solutions that reflect the specific characteristics of each ecosystem, culture, and site.

The economic dimension revolves around treating the planet's resources and efficiently using natural resources in a competitive environment. With the globalisation of the financial world the almost total online tracking of market processes, a considerable amount of data is available to understand the processes better and create more effective interventions. The strengthening of sustainability in the economy is linked to the development of behavioural economics.

One of the cornerstones of sustainability is the social dimension. The protection of the environment and the conservation of natural resources only make sense and are relevant if products are made from renewable raw materials that different societies can use. Our social processes, primarily through the tremendous digital development of recent decades, are better and more widely documented and analysed than ever before in history. Increasing analytical capacity expands the assessment of past social events and sometimes raises the need for reassessment (Szenthe, 2021).

The spatial dimension encompasses space organisation, follows the occupation criteria and is intertwined with a permanent natural network that seeks to restore quality of life, biodiversity, and human-size in every fragment of the system and every neighbourhood. The proliferation of sensors and the combination of traditional architectural principles prioritise sustainable architecture to minimise environmental impacts.

Sustainability focuses on several strategies and policy documents on the global, regional, and local levels. In the political dimension, sustainability is built by social actors active in their socio-economic and cultural environment, whom the government gives several opportunities to control the resources needed for policy decisions.

Finally, the psychological dimension involves a sense of well-being that transcends the social aspect, as it includes emotions as a quality that is part of the individual’s subconscious.

It can be considered that the different dimensions and levels of sustainability may be related to cognitivity. The aim of CogSust is primarily a holistic approach to sustainability, connecting its areas with the tools used by info-communication. It connects certain elements of the system, such as ecology, economy, sociology, or politics, and offers a common space for optimisation with the help of IT tools, which they consider to be part of a cognitive system.

4. Examples

In this chapter, some examples are provided which clearly show the combination of cognitive levels, sustainability modes, and sustainability types.

4.1. Sustainable vehicle energy and emission management

The sustainability question of mobility increases in several fields in the value chain: design, production, use and waste management. The emission of vehicles goes hand-in-hand with their energy management. In the early decades of the vehicle industry, the diesel oil and gasoline used were the by-products of public lightning petroleum refining. The oil crisis in the 1970s and the lead use supported increasing octane demand in the eighties led to energy and fuel quality consciousness. Hybridisation in the first decades of the third millennium opened management opportunities. Today, alternative fuels (Valeika et al., 2021) plug-in-hybrid technology enables the most significant optimisation space for managing the vehicle's energy demand and environmental load (Zsombok 2019). On-board energy management importance is confirmed, especially for self-driving vehicles (Cao and Zöldy. 2019). On-board sensors collect data about the vehicle (mass, C_v, tire pressure, available fuel/energy etc.) and mobility (speed, fuel consumption, etc.). The data acquisition of sensors is not limited to the vehicle itself; the traffic information and geography of the chosen route and weather information are also gathered. It must be extended with refuelling/recharging information such as time-to-wait, expected charge/refuel time, price etc. Combining these provides a complex decision matrix (Zöldy et al. 2018), where sustainability has to be one of the main deciding factors.

The cognitive approach, supported by the large amount of data coming from the vehicle and its surroundings, helps make vehicle-level mobility decisions based on sustainability criteria.

4.2. Sustainable traffic and emission management

Nowadays, the environmental aspect of mobility can be improved by energy and fuel management and applying so-called soft tools, like traffic management or marketing, to change travel behaviour and attitude towards new modes of transport. *Sustainable mobility* is a complex term here. As mentioned above, the emission of vehicles goes hand-in-hand with their energy management. However, what would happen if there were no emissions? Should we stop transporting, or can we change to less

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environmentally polluting modes of transport? The answer, according to modern economists, is pricing. However, who determines the prices? Are all used resources counted when forming a price? Does one make a conscious decision, perceiving all circumstances? Data acquisition in this field is minimal. We have a massive amount of rapidly changing information around us. Moreover, although information has significant monetary value, it is changing rapidly. In contrast, sustainability should be the main deciding factor.

4.3. Sustainable, intelligent urban development and cognitivity

Nowadays, urbanisation processes go hand in hand with the dynamic development of information and communication technology (ICT). However, the growth of cities – due to environmental degradation and pollution, intensive energy use, ineffective urban planning, traffic congestion, increasing social vulnerability and decreasing living conditions, and so on – can threaten the sustainability of cities (Bibri 2019). Meanwhile, ICT has become pivotal in decreasing the recent and possible impacts and risks of urbanisation to meet the requirements of sustainability innovatively. Digital transformation can paint a picture of utopian cities where futuristic solutions make people live better than ever. In terms of sustainability, the potential of digitalisation is still untapped, and the consequences are not precisely predictable. The different subsystems of a city can play a pivotal role in the multi-dimensional resilience of the city due to technical, socio-economic, nature-based and cognitive solutions. Nowadays, the role of local people as intelligent agents of a city has become more crucial in the practical implementation of innovative, sustainable city goals enhancing the main aim of the Sustainable Development Goal 11 (SDG 11). The potential risks of ICT solutions to sustainability can also be grasped from the stakeholders' perspective related to social sustainability in terms of equity, fairness, participation, inclusion, privacy, security, polarisation, social vulnerability etc. (Bibri 2019).

From a management perspective, according to sustainability and cognitive aspects, the stakeholder-oriented approach may provide an overview and highlight the interrelations between the examined terms in different urban subsystems (Szalmáné Csete 2021). As intelligent agents of the urban environment, local citizens or residents also need to have special cognitive skills. Effective urban policies should deliver feasible solutions that can foster the practical implementation of sustainable urban development in the era of climate change and digitalisation, which may be crucial, especially in the 21st century. The question is whether digitalisation is a solution that can support the transition towards the practical implementation of sustainability (Szalmáné, 2021). There is a lack of cognitive aspects in urban policy development and planning, which can hide future cities' hidden potential.

4.4. Cognitivity in sustainable management

Sustainable management can be applied in all the fields of our life to foster the necessary steps towards a practical implementation towards sustainable transition. Sustainable management methods, tools, and solutions can be related to a wide range of business operations, entrepreneurship, innovation, education, environment, healthcare, agriculture, transport, tourism, industry, society, etc., and in our activities.

Sustainable management processes depend on the decisions of different stakeholders on diverse levels in distinct fields of activity. These processes can be based on top-down or bottom-up approaches, can be ex-ante or ex-post, community-based or individual-oriented, supply or demand side-related, etc. There is one common aspect of the sustainable management issues independent from the space and time range, the stakeholder perspective, or the area of the planned intervention, and that is the significant role of decision. The future of sustainable management issues should consider not only the capability to successfully preserve or further develop the quality of life in general, but it should be a result of a series of conscious decisions taking into account all the positive synergies of cognitive developments.

4.5. Sustainable cognitivity in economics

Economics is the science of efficiency: the core question is how resources could be allocated efficiently and effectively. According to mainstream economics, thinking is rather technical because it is value-neutral – but can that be the case when we face a macro-critical challenge (IMF 2021), such as climate change? The shocks induced are already impacting the social sphere, economic activity, financial stability, and inflation. The scale of the impact is already significant and growing further. While environmental risks are non-linear, complex, and subject to radical uncertainty and 'green swan' event (Bolton et al. 2020)s, the extent to which they materialise partly depends on the action we take today. For that reason, it is more and more urgent to integrate the future in our thinking and economic models. In the field of sustainability, economics, by definition, must consider the technological possibilities (Söderholm 2020). However, knowledge can come only from engineering or architecture, respectively – this is one example of the interdisciplinarity mentioned above. How can an environmentally sustainable project be financially sustainable? Where does funding fit in with the environmental sustainability of the financed activity? Can an economist, in his or her own right, make appropriate economic decisions or is it necessary to have a broader approach to economic problems if we are talking about sustainability? We badly need „long-term sustainable economics" (Virág, 2019), but what are its most essential features and pillars?

4.6. Cognitivity in sustainable architecture

Sustainability in architecture is a series of interconnected ideas that can be interpreted on several levels or layers. The benefits of technology, sociology, and regionality must be addressed in parallel, all so that the minimum lifespan of buildings is fifty years.

Advances in technology and building management systems in conjunction with alternative energy sources cannot deliver satisfactory results. Installing an infinite number of intelligent systems and sensors is an advantage, but in many cases, it can be avoided if engineering design properly balances regional environmental impacts and building materials with the potential of technology. According to the theoretical architect Lebbeus Woods (Manaugh 2007), fundamental revolutionary changes in the architecture of the future cannot take place until humanity changes its current sociological model. Of course, this change must have regional diversity to be sustainable.

The future architecture must reduce the carbon footprint of construction and operation while creating flexibility that is expected to accommodate the functional needs arising from changing social and sociological influences over the lifetime of the building.

5. Conclusions

Sustainability is one of the most exciting challenges of the 21st century. The compulsion of continuous growth in recent decades has guided our thinking and actions, but it is now clear that this leads to the destruction of the planet and humanity. Cognitive sustainability is the result of a belief that fundamental change is required. We need to move beyond the usual framework, and the disciplines must work together to find a solution. The new framework, which also sets out what needs to be done at the level of ordinary people, needs to be created scientifically. A deeper understanding of the world, supported by a better understanding of sensors, the growing amount of data, and artificial and natural thinking, is an essential help in designing the new system.

This recognition is the basis for this article to describe the cognitive sustainability framework. Its most important characteristics are presented and defined: the substance, the equity and the type of sustainability. Cognitive mobility, sustainability, urban planning and architecture, and economics are considered examples.

The presented topics illustrate the interdisciplinary existence of the cognitive sustainability approach. It is necessary and enriching to research sustainability issues beyond the disciplines and by thinking together. These are brought together in a system by cognitive sustainability.

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Investigation of the concentration of particles generated by public transport gas (CNG) buses

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Abstract

The sustainable development of public transport is inseparable from its key elements, transport. In recent years, reflections on green public transport have been steadily intensifying and setting new guidelines for its development focused on the environment. Gas-powered, more environmentally friendly diesel buses are used for this purpose. Part of such a transport fleet in Vilnius consists of such buses. Pollution from mobile sources is predominant in cities, so particulate matter from different gas buses (powered by CNG) was identified in this study. In this study, particle concentration measurements were performed, in which the dependence of the particle concentration on the mileage of the buses was determined.

Keywords

Sustainability of public transport, gas buses, particulate pollution

1. Introduction

Since industrial revolution urbanization process started to spread all over the world. Nowadays, it has almost reached the point when disadvantages exceed benefits. Overflow of citizens in cities is the main problem which causes higher level of air, particle, noise and light pollution (Dyr et al., 2019). All these and other reasons may do harm to environment and human health(C. Wang et al., 2015), (Tong et al., 2000), (Smieszek et al., 2019).

Exhaust gasses from motor vehicles are the primary origin of air pollutant emissions (Chernyshev et al., 2019)(Chernyshev et al., 2018). Various harmful substance proportions in emitted gasses varies depending on vehicle type, it's age and fuel type which is being used. However, the scale of air pollution mostly depends on number of vehicles that are in traffic. Public transport serves the purpose of optimizing traffic. In majority of busses heavy-duty engines are used (Yu & Li, 2014)(Chao Wang et al., 2018). Although, other emission standards apply with higher emission factors and pollution levels (Shan et al., 2019), air pollution decreases when public transport is being involved in daily citizen trips (Chao Wang et al., 2018).

To determine how air pollution changes and how emissions depend on used fuel type and on technical condition of vehicle several research was made. Multiple studies show that vehicles produce less greenhouse gasses and toxic materials when is fueled with natural gas than vehicles fueled with diesel. In China, if diesel driven buses are switched to gas-hybrid electric buses, the emissions will be reduced by approx. 75 % (Chao Wang et al., 2020). Due to budget limitations and natural gas

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supply infrastructure, this goal can be achieved in steps and the percentage of hybrid electric buses should reach 50 % in 2030(Zhang et al., 2014). Another study was conducted in British Columbia, Canada (Pourahmadiyan et al., 2021). It showed that compressed natural gas (CNG) vehicles contributes to global warming 60 % less than diesel driven ones. According to dynamic simulation results liquified natural gas (LNG) driven buses emits 5.9 % less greenhouse gases than diesel in driving phase. Less optimistic study conducted in Imphal City, India showed that CO and C_xH_y emissions are at higher level when using light-duty diesel engines and that in heavy-duty diesel engine vehicles these factors are in alarmingly high levels (Singh et al., 2022). Other study emphasizes that not all buses' emissions are meeting the standard norms and that best results were revealed when testing CNG vehicles, that tend to have lower CO_2 emissions in India(Cooper et al., 2014). Same study discusses the best fuel type for public buses in Brazil: lowest emissions were conducted by buses fueled by biodiesel and CNG. One more study conducted in Madrid, Spain compared CNG and diesel fueled buses' emissions (Gómez et al., 2021). With respect to distance and average emitted material quantity results showed that heavy-duty Euro VI-C buses emissions are comparable and practically the same.

It is becoming very important to identify the amount of particulate matter emitted by CNG-powered buses, as the level of PM concentration is highly dependent on the final products of combustion of complex hydrocarbons (diesel). When it comes to CNG fuels, their main component is methane, so PM levels are low. In the present work, studies of the concentration of aerosol particles were performed in order to identify the concentration of particles in the operation of different gas buses operating in the field of transportation of urban residents. Such an objective is to ensure the concept of sustainability in the field of public transport, where, according to the EU White Paper on Transport, the key aspects are focused on the sustainable development of public transport. This is achieved by improving ambient air quality by reducing pollution from mobile sources.

2. Methodology

The particles concentration in the exhaust gas was determined using a P-Trak Ultrafine Particle Caunter 8525 particulate meter (Figure 1). The technical specifications of this device are given in Table1.

Figure 1. Particulate Meter P-Trak Ultrafine Particle Caunter 8525 (1 - On / Off button; 2 - Isopropyl alcohol cartridge; 3 - Data connector; 4 - Power connector; 5 - Headphone connector; 6 - Telescopic probe hose)

Table 1. Particle meter technical specification

Concentration range	**0 – 500 000 part./cm^3**
Aerodynamic particle diameter range	0,02-1 μm
Temperature range	-40 – 70 °C
Intake air flow: **-flow of one sample** **-total sample flow**	100 cm^3/min 700 cm^3/min
Type of alcohol used in the appliance	100% isoprophil

This device is designed to measure particles with an aerodynamic diameter of 0.02 - 1μm. As shown in Fig. 1, it consists of a housing with a pump already installed, data processing equipment, a cassette containing isopropyl alcohol and a telescopic probe to be connected. (TSI Incorporated 2019). Table 1 also states that the P-Trak Ultrajine Particle Counter 8525 has a measuring range of up to 500,000 particles per cubic centimeter and an ambient temperature of -40 ° C to 70 ° C.

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In order to isolate the measuring medium from the ambient air, in which particles are also detected, and to ensure the most accurate possible values of the particles, the telescopic probe of the meter was inserted into the exhaust pipe extension (hose) and fixed in the same position as shown in Figure 2:

Figure 2. Particulate concentration measurement

Measurements were performed 5 times for each vehicle. One measurement took about 20-25 seconds. During this time, the instantaneous particle concentration recorded by the device and displayed on its screen usually became constant. For the analysis of the obtained results, the averages of the particle concentration values were used, which were calculated by the device after each measurement and stored in the internal memory of the device.

6 units were taken for research. Vehicles of class M3 of the same make and type. All of these buses met EURO 6 emission standards. Their data are presented in Table 2.

Table 2. Class M3 test vehicles

Designation	Make	Mileage, km	Engine type	Engine power kW	Year of manufacture	Emission standard
A.	Solaris Urbino 12 CNG	778967	Cummins L9NE6E320	235	2018	EURO 6
B.	Solaris Urbino 12 CNG	999236	Cummins L9NE6E320	235	2018	EURO 6
C.	Solaris Urbino 12 CNG	821635	Cummins L9NE6E320	235	2018	EURO 6
D.	Solaris Urbino 12 CNG	1145212	Cummins L9NE6E320	235	2018	EURO 6
E.	Solaris Urbino 12 CNG	843257	Cummins L9NE6E320	235	2018	EURO 6
F.	Solaris Urbino 12 CNG	986578	Cummins L9NE6E320	235	2018	EURO 6

3. Results

The obtained research results showed (Fig. 3) that a certain grouping of particle concentration according to the number of buses was observed. The concentrations of A, C and E particles in the study buses were very similar and did not differ by more than 10%. The quantile field of the results of these buses was small and reached up to 10 parts. / cm^3. This result is very reliable, as the dispersion of the particle concentration was up to 2% of the value of the results. It can be argued that the concentration of particles generated by these buses is minimal and particulate pollution is minimal. In the case of buses B and F, it was observed that although the average of the results was very similar to the aforementioned buses A, C and E, the field of quantiles of the results was significantly wider and accounted for up to 12% of the value of the results. Such differences can be explained by the more intensive operation of buses, during which the concentration of particles generated due to the natural wear of bus units' increases.

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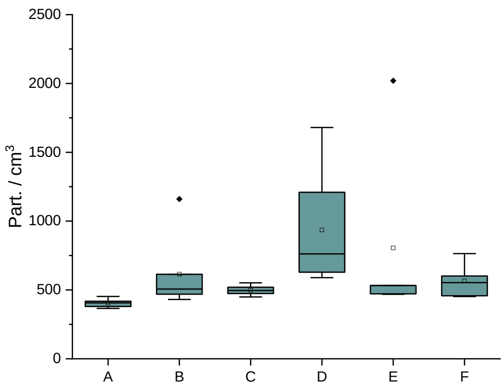
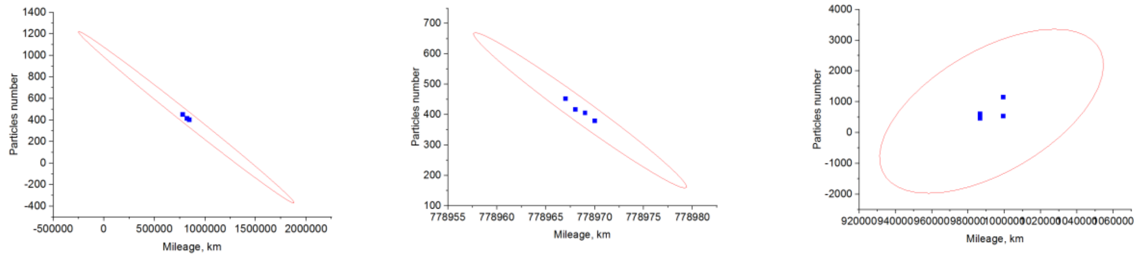


Figure 3. Particulate concentration measurement results

This trend is clearly illustrated by the D bus. Its operating frequency is the highest among all buses tested (Table 2), as shown by the value of particle concentration. It is distinguished not only by the value of its results (it is almost twice as high as the bus studied earlier), but also by the very large (up to 96%) dispersion of the particle concentration from the value of the results. This already indicates uneven engine performance and can be identified as an imminent need for engine repair. If we examine the scattering of the random measured values, it is noticeable to the previously stated dependence that Bus D had an instantaneous particle concentration up to 1720 part. / cm^3.

It is observed that such dispersion of the amount of particles was caused by the technical condition of the buses and could be used as an indicator to signal the required periodic technical inspection of gas buses. We see that the double difference in particle size is decisive for bus mileage. Assuming that buses in Vilnius are operated in a hilly area, when bus loads change significantly, it is necessary to take this account when assessing their particulate emissions under real road conditions. They can grow significantly and have a direct impact on the health of the urban population.

Based on these research results, three distinct groups of buses can be identified: A, C, and E; B and F; and D. These groups differ in mileage and concentration of the generated particles (Figure 4):



A, C and E buses　　B and F buses　　D bus

Figure 4. Atskirų autobusu grupių koreliacinė priklausomybė nuo dalelių koncentracijos ir autobusų kilometražo

According to the correlation, it is observed that the greater the dispersion of the particle concentration results, the weaker the correlation. This tendency is clearly observed in FIG. 4. The mileage of bus D is the highest of all the buses studied, so the highest scattering of the particle concentration results was obtained, and at the same time the weakest correlation. The opposite trend is observed in the scattering of the results of bus groups A, C and E, where the highest correlation was observed.

4. Conclussions

Concentration studies of particles generated by gas buses have shown that:

1. The concentration limits of the particles were sufficiently low and ranged from 400 to 1250 parts. / cm^3, excluding bus D ratings, was 400-600 parts. / cm^3, which is twice less than the results of bus D.
2. The high mileage of a bus increases the dispersion of particle concentration results and at the same time signals the need to diagnose such a bus in order to avoid imminent failure.

The proposed method makes it possible to identify the technical condition of buses depending on the amount of particles generated. The application of this method can be used not only within one company, but also in other companies engaged in passenger transport. It is observed that the lower amount of particles generated by gas buses allows to ensure the concept of a green city, which has a corresponding impact on the health and well-being of the urban population.

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Design aspects for in-vehicle IPM motors for sustainable mobility

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Abstract

In battery electric vehicles, synchronous interior permanent magnet (IPM) motors are gaining more and more ground due to their high power density and highly efficient operation. In order to reach a desired total torque, low torque ripple and high efficiency, and a lot of pre-planning is required. The modern age engineering industry can rely much on complex simulation software, such as MotorAnalysis-PM. In this paper, an initial IPM motor design with delta magnet arrangement was created for vehicle application. The aim was to find correlations between rotor layout arrangement and crucial motor operational attributes, such as: torque components, torque ripple, cogging torque and efficiency. Time stepping magnetostatics Finite Element (FE) and time stepping transient FE simulations were used. Each arrangement change had its own simulation file, thus the effect of each change could be separately examined. Arrangements where the distance between magnets is smaller resulted in greater torque and efficiency. The use of enlarged magnets had the same results. Size should be increased and distance should be decreased with care to avoid a growth in torque ripple. Examinations proved that such simulation software greatly expands the design choices for sustainable mobility.

Keywords

Permanent magnet synchronous machines, magnetostatics, efficiency map, IPM motor design, simulations, sustainable mobility

1. Introduction

Electric vehicles can help to reach sustainable mobility by their lower energy consumption and local emission. The new era of electric drivetrains reappeared in the last decade, therefore, drivetrain developers, and researchers should learn the new design aspects quickly these years. The main reasons for the reappearance of electric vehicles are the emission regulation changes and the interest of novel, cleaner and more silent vehicles (Vepachedu, 2017). Today the future of road vehicle drivetrains is uncertain. According to the trends, in the passenger vehicle segment, the battery electric drive seems to be the future.

However, the motivation to design and produce battery electric vehicles has enormously grown. The increasing autonomy of the vehicles offers synergies with the electric drive (Török et al., 2018). More than seven million such vehicles are in the streets today (Zöldy et al., 2018). The emission standards are becoming stricter and stricter because of the increasing environmental contamination and greenhouse gas (GHG) emission, to which transportation significantly contributes (Mészáros et al., 2021, Albatayneh et al., 2020). In consequence, the intention of reducing the emission of environment polluting substances is increasing. Electric vehicles will have an important role in reaching environmental aims (Sanguesa et al., 2021). Most of the research projects in this topic pointed out that Well-to-Wheel (WTW) valuing, which is a part of Life Cycle Analysis (LCA), must be carried out to get closer to understanding the real environmental impact of the electric vehicle industry on our surroundings (Zöldy et al., 2018, Sanguesa et al., 2021, Un-Noor et al., 2017).

The increasing popularity of electric vehicles could be considered from other aspects. Power electronics are important subsystems of a fully electric powertrain. They consist of a controller/inverter and semiconductors (Lundmark et al., 2013). The appearance of MOS (metal-oxide-silicon) semiconductors and MOSFET (metal–oxide–semiconductor field-effect transistor) transistors meant a considerable step forward in the development of electric vehicles. Power electronics can operate on a much higher switching frequency with lower power loss, and the modern microcontrollers can manage every element of the operation control (Lundmark et al., 2013). Research is still in progress to improve them further (Young-Kyun et al., 2015).

The architecture of an electric vehicle powertrain can be created in many ways. Batteries are usually mounted underneath the vehicle between the two axles, adequately protected (Nyerges and Zöldy, 2020). The emplacement of the electric motor

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(or motors) offers more executable solutions. Firstly, electric motors can be placed in the wheel hub to drive the wheel directly (Mihály et al., 2014). This solution results in fewer losses and better controllability, as the driving torque of each wheel can be controlled separately (Karki et al., 2020). In most constructions, however, the motor is mounted on one of the axles, or a separate motor drives each axle. In the simplest layout, there is a single-speed reduction gear between the differential and the electric motor.

Energy consumption is significant for electric vehicles (Nyerges, 2021), and there are efforts to design multi-speed gearboxes for electric powertrains with the aim of energy saving (Md. Ahssan et al., 2018).

The vehicle industry sets new standards for electric motors. The rapid spread of hybrid vehicles will help researchers understand the electric driveline better, and pinpoint its application area (Zöldy and Zsombók, 2018). New considerations, such as space-saving, power density, great efficiency in a wide range, fast reaction time, and well-realizable price get greater focus. Manufacturers use more expensive magnetic materials and liquid cooling, with which power and torque per volume can be decreased. From the mechanical engineering side, the invention of integrated systems has appeared as a solution (Hemsen et al., 2019).

As parameters of electric vehicle motors have become more crucial than ever before, production requires much pre-engineering. Simulation software can be used for these processes, predicting the operational parameters of a designed and parameterized electric motor. Researchers choose one or more specific parameters to change, and analyze how these changes affect certain characteristics (Hwang et al., 2018a, 2018b, Lim et al., 2015, Ma et al., 2018, Fang and Hong, 2009, Yang et al., 2016, Artexte et al., 2018). These studies offer solutions on how the examined part of a motor should be designed for targeted operation. Examining torque ripple, cogging torque, total torque, efficiency are common topics. Torque ripple and cogging torque lead to undesired noise, vibration and increase alternating load, thus the expected lifetime is decreased. When greater efficiency is achieved, a battery made of fewer cells could be applied to achieve the same range. Although mainly electrical engineers carry out this kind of research, the point of view of vehicle engineering has also become relevant. In conventional drivetrain system design, vehicle engineers have devised plenty of experiments, while nowadays the aim is to conduct these experiments in battery electric vehicles.

In this paper, an initial interior permanent magnet (IPM) motor to be applied in a compact vehicle was created. Parameters of the rotor were chosen to be altered; then, simulation files were generated for each change. The examined parameters were: the length and width of magnets, the distance between magnets of a pole and of adjacent poles, the geometry of flux barriers and the material of permanent magnets (PMs). These attributes greatly influence the magnetic circuit of an IPM motor, thus the motor operation, too. Firstly, magnetostatic results belonging to each change were explored, and then the created efficiency map of each model was analyzed. The goal was to draw conclusions about how altering the chosen parameters affects motor operation. The applied software delivered numerical results, which were compared with each other. As a result of the comparison and evaluation, suggestions were formulated, which could be used in a design process of an IPM motor. Usage of better design ideas results in an end product which has longer lifetime and which operates with better efficiency. Both of these attributes support sustainability.

2. Simulation tools

By today, designing and simulation technologies have reached high levels. As they are cheap and time-effective to use, they have become basic devices in development departments. Software is available for magneto-statics, statics, fluid mechanics and finite element analysis. Such software programs are mostly used to define operational characteristics (like nominal torque) and portray magnetostatics flux lines.

This study used the MotorAnalysis-PM software (Nyitrai and Orosz, 2021), which is applicable for creating and analyzing electromagnetic designs. It is based on C++ and Matlab programming languages, and provides the possibility of creating both rotor and stator designs in its Geometry Editor with specific parameters. Diverse analysis methods are available, each has different accuracy and requires different computing capacity. These are:

a. magnetostatic finite-element analysis;
b. dynamic FE analysis;
c. steady state *d-q* analysis;
d. dynamic *d-q* analysis.

As only a. and c. are used in this paper, only these two methods are described shortly. Magnetostatic finite-element analysis is used to create an analysis at a specific operating point. It can calculate the most important motor parameters, such

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as torque, power, efficiency, power factor, voltage, current, back electromotive force and power losses. These simulations assume an ideal sinusoidal or trapezoidal waveform.

Steady state *d-q* analysis relies on the ordinary *d-q* reference frame model; hence, it must be created before c. could deliver exact results. Efficiency maps, steady-state performance characteristics and other performance maps could be calculated with it. When flux linkages are computed, cross-saturation effects are observed, too (Nyitrai and Orosz, 2021):

(1) $$\psi_d = \psi_{md} + L_d I_d + L_{dq} I_q$$

(2) $$\psi_d = \psi_{md} + L_d I_d + L_{dq} I_q$$

Voltages resolved into *d* and *q* components are the following (Nyitrai and Orosz, 2021):

(3) $$V_d = R_s I_d - \omega\psi_d - \omega L_{sew} I_q$$

(4) $$V_d = R_s I_q - \omega\psi_d - \omega L_{sew} I_d$$

Electromagnetic is calculated as (Nyitrai and Orosz, 2021):

(5) $$T = \frac{3}{2} p\left(\psi_d I_q - \psi_q I_d\right)$$

In these equations, variables mean the followings:

Table 1. Definition of the parameters of the equations

Parameter sign	Definition
R_s	stator resistance
L_{sew}	stator end winding inductance
L_d	*d* direction inductance
L_q	*q* direction current
I_d	*d* direction current
I_q	*q* direction current
Ψ_d	*d* direction flux linkage
Ψ_q	*q* direction flux linkage

3. Initial IPM motor

The goal was to create a motor design and setup which offers a wide range of possibilities for parametric sensitivity analysis. Specific attributes were to approach medial values, which are easy to be decreased or raised. The initial IPM motor was designed to be applied as a power source of a compact vehicle. The initial total torque was aimed to be about 290–310 Nm. There were 3 pole pairs and 3 phases. A previous, not comprehensive sizing was done based on reference (Kuptsov et al., 2018).

3.1. Initial stator design

The stator slot number was chosen with regard to the value of *q*, which is the slot number per slot and per phase. Applying the *q* = 2 design results in excellent third and fifth-order voltage harmonics. As a consequence, *Qs* was set to 36 to ensure this property. The geometry of the stator slot was chosen with respect to its area. Too small stator slots can result in too high current density, which is undesirable, because it can lead to too high temperatures in the winding. The width of the stator tooth (distance between two adjacent slots) is not supposed to be too small to avoid too high magnetic flux densities. Stator slot geometry was designed with the Geometry Editor. The given parameters are listed in Table 2:

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Table 2 Values of specific stator geometry parameters defined in Geometry Editor

Parameter name (unit)	Symbol	Value
Slot number (mm)	Q_s	36
Stator outer diameter (mm)	D_{1s}	308
Stator inner diameter (mm)	D_{2s}	212
Rotor outer diameter (mm)	D_{1r}	210
Slot depth (mm)	S_{ds}	23
Tooth width (mm)	W_s	6
Slot opening depth (mm)	O_{ds}	3
Slot opening width (mm)	O_{ws}	3
Tooth tip angle (°)	T_{as}	10
Bottom corner radius (mm)	R_{cs}	3
Top corner radius (mm)	R_{cs_ag}	3
Area of a stator slot (mm^2)	A	281.55

3.2. Initial rotor design

The first objective was to choose a magnetic arrangement. More possibilities are at the hands of a designer. Delta and V arrangements are quite common. Delta arrangement can produce high magnetic torque and low torque ripple (Fang and Hong, 2009). Furthermore, it has several parameters to change, so this arrangement was chosen. It is composed of three magnets per pole: one's symmetry axis coincides with the *d*-axis, and the other two are symmetrical to each other about the *d*-axis. As the symmetric magnets create a "V" shape, they will be called V magnets; the upper magnet will be referred to as "D" magnet. Magnetic flux barriers are put at each end of each magnet.

Table 3 Values of specific rotor geometry parameters

Parameter name (unit)	Symbol	Value
Thickness of V magnet (mm)	V_T	5
Length of V magnet (mm)	V_L	34
Distance between *d*-axis and a V magnet (mm)	$D_{d,V}$	6
Distance between V and D magnet (mm)	$D_{V,D}$	15
Angle between V magnet and *d*-axis (°)	α	21
Thickness of D magnet (mm)	D_T	4
Length of D magnet (mm)	D_L	16
Distance between D magnet and D_{2s} (mm)	$D_{D,D2s}$	9.8
Magnets volume per pole (mm^3)	$V_{magnets}$	62712

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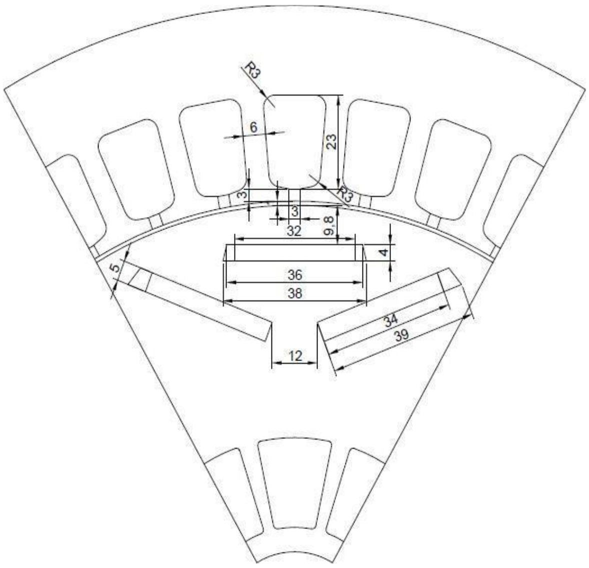

Figure 1 Geometry of the initial motor

Any exaggeration in sizing was avoided. Magnets were not close to the outer diameter of the rotor, which equals a bigger flux bridge. The size of the bridge influences the stresses in the rotor. A smaller flux bridge results in higher stress in the bridge itself (Pyrhönen et al., 2014). Important rotor parameter values are listed in Table 3.

Main flux barriers were designed to avoid magnetic saturation in the rotor interior. The geometry of flux barriers can be described with numerical parameters only with difficulty, so they are going to be presented with the whole motor geometry in Figure 1.

3.3. Selection of materials

For both stator and rotor laminates M–15 G29 non-oriented silicon steel material was chosen. For magnets, N42 rare earth neodymium material was used. Neodymium magnets have lower Curie temperature than ferrite materials, but they have higher residual flux density and coercivity, so higher torque density can be reached. For winding, copper was chosen instead of aluminium due to its lower electric resistivity (Brenner, 2009).

3.4. Winding Selection

The important parameters of winding are described in Table 4. For winding connection, a star connection was chosen, which results in higher torque. The goal was to model a square winding, which typically has a slot fill factor of approximately 0.65. Higher slot factor results in higher power efficiency. The increased conductor area decreases phase resistance and conductor losses. From another point of view, decreasing slot area decreases the flux density near the slots and the iron losses. The number of conductors, strands and wire diameter were chosen in accordance with this value.

Table 4 Values of specific winding parameters defined in Winding Editor

Number	Parameter name (unit)	Symbol	Value
1.	Number of winding layers (-)	-	1
2.	Number of parallel paths (-)	*Npp*	1
3.	Number of conductors per slot (W)	*W*	12
4.	Number of strands in conductor (-)	-	3
5.	Wire Size method (-)	-	AWG
6.	Wire size (AWG)	-	10 AWG
7.	End winding axial overhang (mm)	-	38
8.	Coil span in slot pitches (-)	-	23
9.	Slot fill factor (-)	k_{Cu}	0.667

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4. Analyzed parameters

In this section, the aims of the parameter sensitivity analysis will be presented. As it was mentioned previously, the analysis has focused on the rotor's geometry.

4.1. Magnet sizing and placement

The thickness and length properties of D and V magnets were changed. Besides the size of the magnets, the distances relative to magnets of one pole and magnets of adjacent poles were changed, too. V magnets were in focus first, then D magnets were analyzed. Table 5 and Table 6 contain the examined values.

Table 5 Alterations related to V magnets

Number	Parameter name (unit)	Symbol	Value
1	Thickness of V magnet (mm)	V_T	4
2	Length of V magnet (mm)	V_L	37
3	Distance between *d*-axis and V magnet (mm)	$D_{d,V}$	4.1
4	Distance between V and D magnet (mm)	$D_{V,D}$	11
5	Distance between V and D magnet (mm)	$D_{V D}$	13
6	Distance between V and D magnet (mm)	$D_{V,D}$	18
7	Angle between V magnet and hor. axis (°)	α	23
8	Angle between V magnet and hor. axis (°)	α	18

Table 6 Alterations related to D magnets

Number	Parameter name (unit)	Symbol	Value
1	Thickness of D magnet (mm)	D_T	3
2	Thickness of D magnet (mm)	D_T	5
3	Length of D magnet (mm)	D_L	14
4	Length of D magnet (mm)	D_L	18
5	Distance between D magnet and D_{2s}	$D_{D, D_{2s}}$	9
6	Distance between D magnet and D_{2s}	$D_{D, D_{2s}}$	11
7	Distance between D magnet and D_{2s}	$D_{D, D_{2s}}$	12

4.2. Flux barriers

Flux barriers significantly affect the electromagnetic performance of the motor. They can contribute to torque improvements and affect torque ripple (Sayed et al., 2019). Various barrier designs were created by changing their size and shape. Different barrier geometries are presented in Figure 2:

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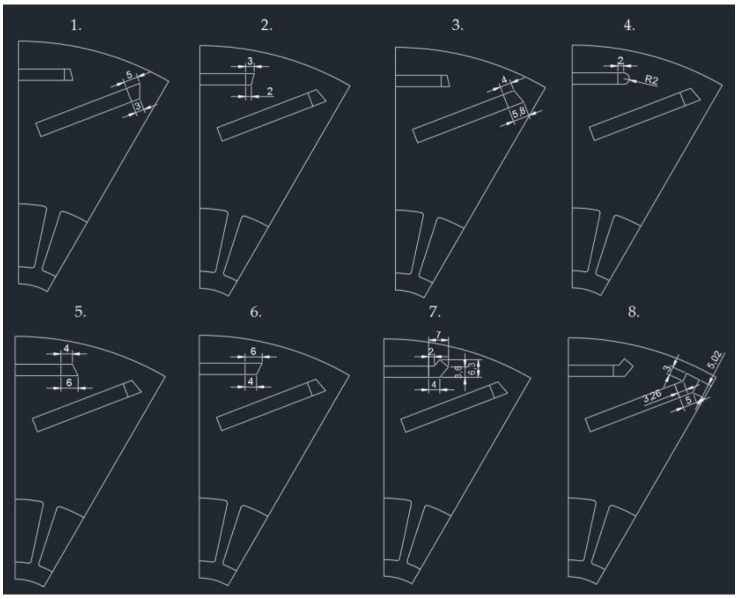

Figure 2 Analyzed flux barrier geometries. Markings are above the drawings

4.3. Permanent magnet material

For permanent magnets, other neodymium magnets were chosen with higher quality. The N48 and N52 materials have even higher remanence flux density *(B_r)* and coercivity *(H_c)* than the N42 material. A PM material with worse quality, N38 was also investigated.

Table 7 Main properties of used permanent magnet materials

Property (unit)	Symbol	N38	N42	N45H	N52
Remanence flux density (T)	B_r	1.26	1.315	1.35	1.45
Coercivity (A/m)	H_c	923000	943000	1011000	979000

5. Results

A simulation model was created for every alteration. Magnetostatic simulations were run first. Then *d-q* models were created within the software, and efficiency maps were created later.

5.1. Magnetostatics

Values of many important characteristics are given in this simulation, but only the examined results are presented: magnetic torque, reluctance torque, torque ripple, and efficiency. Magnetic flux density figures were investigated. For efficiency, it has to be noted that results of these magnetostatics simulations are valid only for this operation point where the load current and the advance angle are constant. It will be pointed out that the magnetostatics efficiency results give an adequate foresight concerning efficiency maps. The electric advance angle was set to 45°.

5.1.1. Initial motor

Table 8 Magnetostatic results of Initial design (Initial Model)

Analyzed characteristic	Value
Magnetic torque (Nm)	306.98
Reluctance torque (Nm)	-0.37
Cogging torque (Nm)	0.9
Torque ripple (%)	27.97
Efficiency (%)	90.65

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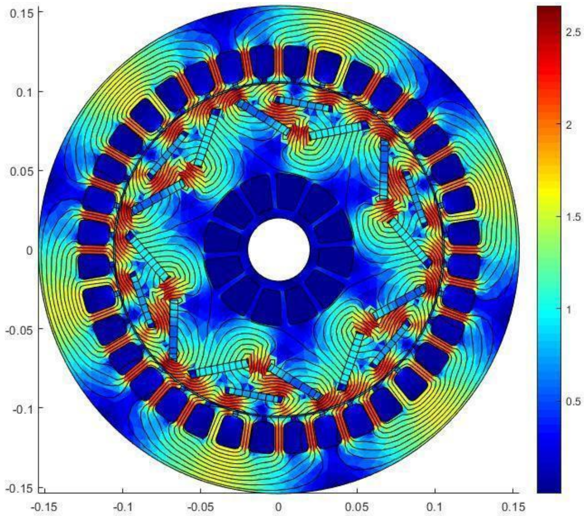

Figure 3 Flux density and flux lines related to initial motor

5.1.2. V magnets

These changes resulted in significant diversity in both torque components and torque ripple. Altering the size of the magnet significantly affects these values. This phenomenon is comprehensible, as it alters the magnet volume, which is responsible for the created rotating magnetic field. Reducing the thickness reduced magnetic torque and resulted in negative reluctance torque. Negative reluctance torque is caused by normal saliency, so L_d is higher than L_q. Lengthening with 3 mm (which meant +7.7% magnet volume) resulted in +18.4% magnetic torque and a small amount of positive reluctance torque. With this change, the distance between V magnets of adjacent poles was altered, too. Bigger magnets resulted in higher efficiency.

Table 9 Magnetostatic results related to V magnets (V magnet – Model 1-8)

Analyzed characteristic	1	2	3	4	5	6	7	8
Magnetic torque (Nm)	294.21	345.54	320.73	345	318.74	294.3	313.44	272.97
Reluctance torque (Nm)	-10.18	17.99	9.67	26.24	15.96	-15.28	7.85	-23.87
Cogging torque (Nm)	0.76	2.3	1.68	4.9	2.24	0.24	1.58	0.43
Torque ripple (%)	30.29	20.94	21.64	23.33	20.91	43.33	17.49	46.71
Efficiency (%)	89.97	91.98	91.25	92.13	91.36	89.81	91.03	88.67

Increasing the distance between D and V magnets vitiated torque components and efficiency. Increasing this distance by 2 mm and 4 mm resulted in lower torque ripple (-4.64%, -7.06%, respectively), but an increment of 8 mm (100% in this case) increased the torque ripple from 27.97% to 43.33%. When the relation between $D_{V,D}$ is presented in a diagram, it can be seen that this relation is not linear.

The rotation of V magnets brought important results. It reduced the angle between the D and V magnet by only 3°, which generated +4.4% magnetic torque and positive reluctance torque, and reduced torque ripple by 10%. Increasing this angle only by 2° generated -0.146% magnetic torque and a little less reluctance torque. Torque ripple was increased by 18.78%, resulting in the highest torque ripple of all iterations. By this latter model, flux density was above 2.3 T between the outer rotor diameter and the V magnets on a decently great area. Too high flux density can be responsible for high torque ripple.

A tendency could be noticed: higher magnetic torque results in higher cogging torque. This tendency is not linear, which could be seen when Models 1, 2 and 4 were compared. The difference between the magnetic torque of Models 1 and 2 is 51.33 Nm and between Models 1 and 4, 50.79 Nm. Cogging torque differences were the following: between Models 1 and 2, it was 1.54 Nm, and between Models 1 and 4 it was more significant, 4.14 Nm.

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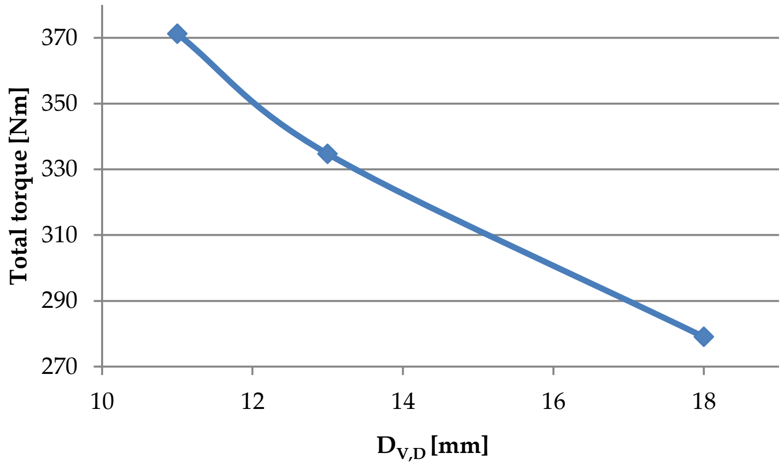

Figure 4 The relation between the value of $D_{V, D}$ and the total torque

5.1.3. D magnets

Altering the size of the D magnet did not cause significant changes in the magnetic torque and reluctance torque values compared to the V magnets. Reducing the thickness by 1 mm (which here meant -4% magnet volume) decreased the magnetic torque only by 2.3 Nm and decreased the reluctance torque by 4.47 Nm. Altering the length caused significant changes: reducing it by 2 mm (which here meant -2% magnet volume) decreased magnetic torque by 7.41 Nm and reluctance torque by 11.81 Nm. Thus, the length of this magnet influences the magnetic circuit. This is caused by the number of the torque producing fluxes close to D_{2S}, which are higher with wider magnets. Just as previously, thicker and longer magnets achieved higher efficiency. Both thinner and thicker magnets increased the torque ripple slightly. Reducing the length by 2 mm reduced torque ripple by 6.28%.

Table 10 Magnetostatic results related to D magnets (D magnet – Models 1 – 7)

Analyzed characteristic	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Magnetic torque (Nm)	304.3	307.21	299.54	314.14	311.57	302.77	302.38
Reluctance torque (Nm)	-4.84	4.2	-12.18	14.5	2.22	-1.59	-2.06
Cogging torque (Nm)	0.95	1.03	1.04	0.94	0.68	1.13	1.11
Torque ripple (%)	29.63	28.24	21.69	29.79	28.49	26.73	23.36
Efficiency (%)	90.44	90.78	90.08	91.21	90.8322	90.5	90.48

Altering the distance between D magnets and D_{2r} changes both magnetic and reluctance torque values slightly and affects torque ripple. Decreasing this distance by 0.8 mm generated +4.59 Nm magnetic and +2.59 Nm reluctance torque. Increasing this distance by 1.2 mm generated -4.2 Nm magnetic and -1.23 Nm reluctance torque. Torque ripple was decreased by 1.23%. Decreasing the distance further by1 mm caused nearly no changes in torque values, but decreased torque ripple further by 3.38%. A closer magnet to D_{2S} results in higher torque ripples in the air gap and results in a higher overall torque ripple. The relation between $D_{D,D2S}$ and torque ripple also provest that the relationship between specific parameters and motor operation is nonlinear.

Changing of D magnets did not result in such significant changes concerning cogging torque, as the changing of V magnets. The lowest cogging torque value of these models was 0.68 Nm, and the highest was 1.13 Nm. Extending the size of D magnets, and increasing D_{2S} increases cogging torque. As models 6 and 7 show, when D_{2S} is increased over a value, a reduction in cogging torque arises.

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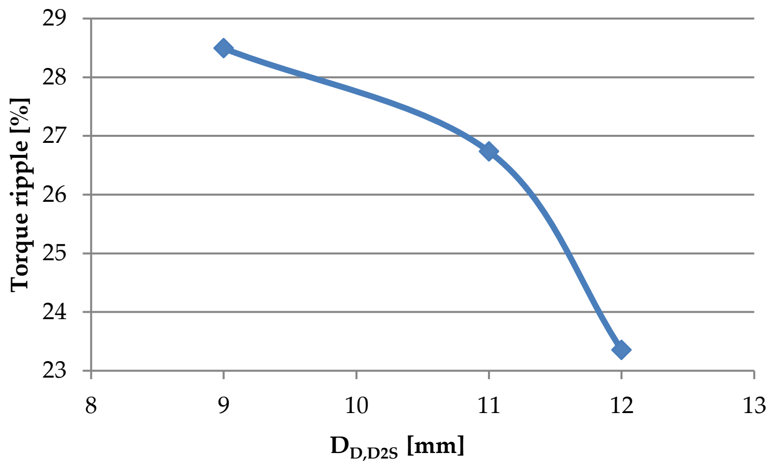

Figure 5 The relation between the value of *D*D, D2S and the torque ripple

5.1.4. Flux barriers

Flux barrier – Model 4 resulted in significantly high torque ripple, due to demagnetization. According to the results of this model, the value of maximum flux density was 20 T, which is not supposed to be reached. Therefore, the results of this simulation had to be discarded.

Table 11 Magnetostatic results related to Flux barriers (Flux barrier – Models 1-8)

Analysed characteristic	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Magnetic torque (Nm)	311.31	308.14	308.15	298.51	307.18	309.34	310.58	317.93
Reluctance torque (Nm)	1.79	2.65	3.78	29.33	9.08	16.94	28.47	47.69
Cogging torque (Nm)	0.65	0.84	0.78	0.61	0.96	0.95	1.13	0.95
Torque ripple (%)	27.08	27.33	27.83	189.63	27.71	24.01	29.47	46.15
Efficiency (%)	90.81	90.76	90.48	90.24	90.91	91.17	91.47	92.03

Although altering flux barriers seemingly made differences in magnetic torque, changing the geometry of flux barriers had an obviously more significant impact on reluctance torque. All simulation models brought more reluctance torque; the increase is more significant by simulation models from 5 to 8. A tendency can be seen from these iterations: with larger flux barriers, greater reluctance torque can be achieved. These changes increased the difference between L_q and L_d inductances. The value of reluctance torque depends on this difference.

In Flux barrier – Model 7 and Flux barrier – Model 8, flux barriers were put seemingly quite close to D_{2r} with upwards extending geometries. The increase in reluctance torque is spectacular. Model 7 resulted in +28.84 Nm, while Model 8 resulted in 48.05 Nm reluctance torque. Meanwhile, these geometries also increased torque ripple, Model 7 by only 1.49%, but Model 8 by 18.17%. Both models increased efficiency, Model 8 resulted in the highest efficiency (92.08%) out of the flux barrier related models.

Model 6 resulted in a great compromise of these characteristics, as it increased both magnetic (+2.36 Nm) and reluctance torque (+17.31 Nm) with decreasing torque ripple (-3.96 %) and increasing efficiency (+0.52%).

Concerning cogging torque, the same could be written as in the previous subsection: the changes of cogging torque are not so significant as in the case of V magnets. Comparing the results of Model 1 with Model 3, and Model 5 with Model 6, the following could be noticed: altering the V magnet flux barriers causes more significant changes than altering the D magnet flux barriers.

5.1.5. PM materials

A tendency is obviously observable from these results. Choosing better quality PM materials results in better operational characteristics. Material N45H in comparison with material N42, has greater coercivity by 68 000 A/m and greater residual

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flux density by 0.085 T, and the usage resulted in +10.79 Nm magnetic and +4.23 Nm reluctance torque. This material generated a -3.49% and slightly increased efficiency by +0.4%.

With N38 materials, the model resulted in a magnetic torque decrease by12.15 Nm and reluctance torque increase by 1.36 Nm. This material in comparison with material N42, has lower coercivity by 20 000 A/m and lower residual flux density by 0.055 T.

Usage of the premium N52 material resulted in the best characteristics. Comparing it to Model 6, it increased the magnetic torque further by 17.76 Nm, but surprisingly reduced reluctance torque by 5.56 Nm. Efficiency became better by 0.29%.

Usage of permanent magnet material with higher energy content increases the cogging torque. Comparing the cogging torque of the N38 and the N52 model, the growth is 0.62 Nm, which means a 84% rise. Higher magnetic torque can be explained by the fact that these better materials have a hysteresis loop to a greater extent. Analysis suggests that the B_r value of a PM material contributes more to the motor's operation.

Table 12 Magnetostatic results related to PM materials

Analyzed characteristic	N38	N45H	N52
Magnetic torque (Nm)	293.47	317.76	335.52
Reluctance torque (Nm)	0.99	3.86	-1.7
Cogging torque (Nm)	0.74	1.03	1.36
Torque ripple (%)	30.32	24.38	21.68
Efficiency (%)	90.3	91.05	91.34

5.2. Efficiency map

Efficiency maps define the efficiency value belonging to each operating point defined by motor revolution and motor torque. These figures provide information about the extent of the MTPA (Maximum Torque Per Ampére) and flux-weakening regions. The value of the nominal torque, the maximal rotational speed and the phenomenon of anomalism could be read from the maps, too. Efficiency maps can be described with the highest efficiency value and its extent.

5.2.1. Initial motor

The maximum rotational speed (n_{max}) was 9670 rpm, and the highest efficiency value was 97%.

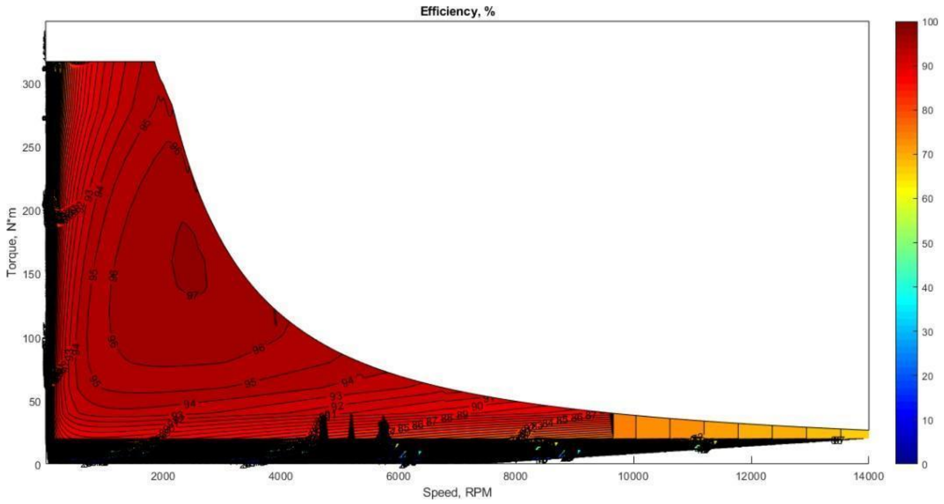

Figure 6 Graphic of efficiency map of the initial motor

5.2.2. V magnets

These results suggest that bigger (longer or thicker) V magnets increase not just the maximum torque, but also the maximum rotational speed (n_{max}). For example, using magnets thinner by 1 mm decreased n_{max} from 9670 $\frac{1}{min}$ to 8703 $\frac{1}{min}$, and increasing length by 3 mm increased n_{max} to 13090 $\frac{1}{min}$. Longer magnets increased the 97% efficiency zone area, while with thinner magnets, this zone disappeared.

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Greater distance between the V and D magnets decreases n_{max}. The difference is quite spectacular between $D_{V,D}$ = 11 mm and $D_{V,D}$ = 18 mm. With the preceding distance, n_{max} was 7862 $\frac{1}{min}$, while in the latter case it was 13100 $\frac{1}{min}$. Not just the n_{max}, but values of the efficiency map decreased as well.

Increased α angle resulted in higher n_{max} and bigger zone of 97% efficiency. Reducing this angle generated an interesting result: at the MTPA region, a considerable torque addition can be seen, called torque spike. It supposedly happens because the advance angle belonging to the nominal torque is slightly lower than 45°. This change significantly reduced n_{max}, its value is 6601 $\frac{1}{min}$.

5.2.3. D magnets

Differences are not as significant as in the previous section, but only one magnet per pole was altered this time. The experience concerning usage of greater magnets could be observed here, too: enlarging the thickness and width of D magnets increased n_{max} and efficiency. Increasing DL from 14 mm to 18 mm increased n_{max} from 8730 rpm to 10870 rpm. The width of D magnets has a more significant influence on motor operation. DL = 18 mm resulted in the greatest 97% efficiency zone and the smoothest bordering line. On the efficiency maps of the other magnet size-related simulations, at the beginning of the flux-weakening region, a little break in the continuity of the bordering line can be seen.

Increasing $D_{D, D2S}$ reduced n_{max} and only slightly changed the efficiency and the extent of the efficiency zones but resulted in a smoother bordering line that followed a parabolic curve in the whole flux-weakening region. Changing $D_{D,D2S}$ from 9 mm to 11 mm reduced n_{max} from 10060 rpm to 9222 rpm, but when $D_{D,D2S}$ was reduced to 12 mm, the value of n_{max} was reduced to rpm 9054. This proves that the changes concerning magnetic arrangement may not be in linear connection with the results.

5.2.4. Flux barriers

Although increasing the size of flux barriers and designing them closer to the outer rotor diameter increased torque ripple, their usage significantly increased n_{max} and resulted in higher efficiency. The n_{max} value of Model 7 was 11340 rpm, and n_{max} of Model 8 was 13630 rpm. The extent of the 97% efficiency zone of Model 10 was significantly increased.

Between the initial design and Flux barrier – Model 2, and between Flux barrier – Model 5 and Flux barrier – Model 6, the difference in the shape of the flux barriers next to the D magnets was changed: the size of the opposite sides was reversed. The size of the barriers has a greater extent in rotor Model 5 and 6. Differences are easily provable. This change made more considerable differences when greater barriers were used. Designing the longer side nearer to the outer diameter of the rotor resulted in a higher n_{max} and a greater extent of 97% efficiency. With smaller barriers, the difference concerning n_{max} was 210 rpm (from 9670 rpm to 9880 rpm), with greater ones, this difference was 370 rpm (from 10130 rpm to 10500 rpm). The extent of 97% was slightly increased, too.

In Model 4, the shape of the flux barriers next to the D magnets was changed: they were rounded off. This small change resulted in a great difference in the efficiency maps. Two different constant torque lines appeared in the MTPA region. The value of L_q did not change linearly in this section. Efficiency and n_{max} values showed only slight differences.

5.2.5. PM materials

Efficiency map results also proved that applying better quality PM materials results in better operational attributes. With N38 material, the 96% zone meant the highest efficiency value. N45H materials generated a 97% efficiency zone; N52 materials increased the extent of it. At the same time, n_{max} was also increased well observably. From N38 through N45H to N52, n_{max} values were 8871 rpm, 10510 rpm, and 11740 rpm, respectively.

6. Discussion

Carrying out prevenient simulations before bringing the product into production has become essential in the fields related to engineering. In order to attain knowledge about how each motor attribute affects motor operation, parametric sensitivity analysis can be carried out. This study analyzed rotor geometry attributes and PM materials. The effects of magnetic arrangement, the size of magnets and the size and shape of flux barriers were explored. One of the goals was to define the sensitive parts of rotor geometry concerning the motor operation and the efficiency map, and deduce consequences, which are forward-looking in an IPM motor rotor design process. During this study, my experience was that even small changes could result in significant changes. This was especially valid for the flux barriers.

Varying the length of V and D magnets has a greater impact on the characteristics of the motor, regarding total torque and torque ripple. A smaller distance between D and V magnets results in higher efficiency, higher total torque and smaller torque ripple, but choosing it to be too small increases torque ripple. The rotation of V magnets greatly affected motor characteristics. When two adjacent V magnets were put too close to each other, flux density around the adjacent edges was too high, and torque ripple was significantly increased. Changing the distance between a D magnet and the outer rotor diameter did not significantly affect the torque components and efficiency, but too small a distance resulted in increased torque ripple.

The shape of flux barriers also has to be designed with care. A small geometrical change (using round ends in this example) caused demagnetization. Flux barriers rather change the reluctance torque component than the magnetic one. With a more complex design in which the barriers are quite close to the outer rotor diameter, reluctance torque was significantly increased, but so was the torque ripple. Designing the upper side of a barrier longer than the lower one resulted in better characteristics.

A correlation between magnetostatic results and efficiency maps was observed. Geometry with high efficiency in the examined static point presumably created an efficiency map with greatly extended high efficiency zones (96% or even 97% zones) and high nominal rotational speed.

Usage of better permanent magnet materials improves the motor characteristics in every aspect: higher total torque, higher efficiency, lower torque ripple and higher maximum rotational speed could be achieved with them.

An important experience has to be noted: all parameters, which comprise the magnetic arrangements, should be examined together. Furthermore, a magnetic arrangement should be examined concerning its relation to the adjacent poles. It has also been noted that the relation between the parameters and motor characteristics is not linear, which can make the evaluation of the results more challenging.

This study shows that with an adequate number of iterations, a proper design can be approached, which operates with higher efficiency. That results in a longer reachable range, enabling electric vehicles to travel greater distances with one charge without enlarging the battery size. With this advancement, electric vehicles could be a worthy substitute of internal combustion engine vehicles for longer drives, leading to more sustainable transport.

7. Conclusion

In this article, some parameters of an IPM motor were altered and a model in MotorAnalysis-PM software was created for each alteration. Selected results of magnetostatic simulations and efficiency maps were evaluated. The experiences of these results can be summarized as follows.

1. Placing the magnets of one pole closer to each other greatly increases total torque, efficiency and n_{max}. If, however, the magnets are put too close to each other, torque ripple increases.
2. Rotating V magnets closer to D magnets is advantageous, as it reduces torque ripple, while it increases both torque components and efficiency.
3. Usage of bigger magnets results in higher total torque, higher efficiency, higher n_{max} and less torque ripple.
4. The length of D magnets more greatly influences the torque producing magnetic fluxes than their thickness.
5. In the process of flux barrier design, a compromise must be made between efficiency and torque ripple. With flux barriers which are brought closer to the outer diameter of the rotor, higher efficiency and higher n_{max} can be reached, but torque ripple increases as well.
6. Usage of better quality permanent magnet material results in higher total torque, higher efficiency and less torque ripple, but it slightly increases cogging torque.
7. Changing the geometry alters the place of the highest efficiency area. Consequently, with simulation tools and with proper knowledge of the influence of different parameters, the efficiency map of the electric motor can be adjusted to the application of the electric vehicle, by aiming this zone to be in those operational points in which the vehicle is planned to be used most of the time.

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Cognitive rationality and sustainable decision based on Maslow`s theorem: A case study in Slovakia

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Abstract

Nowadays, the social pressure on the producers of passenger cars in the scope of their pro-environmental innovativeness is accelerating. However, the market does not accept the shift from traditional fuel technologies, and thus, a significant consumption schism has been created. One of the possible reasons for such a situation is a structured analysis of the principles of needs. Motivations of consumers in this aspect, where the phenomenon of car brand is also significant. However, stating the general functional mechanisms and patterns is not enough in this respect, but the structure of consumer characteristics relevant for these mechanisms and patterns would be useful to explore. Thus, this article analyses the possible marketing tools from the marketing management side. The hypothesis is that the individual passenger car influences more levels of the Maslow pyramid. Therefore, changes are harder to be reached. Some preliminary car usage data has been collected in Slovakia by surveying to investigate the socio-economic dependence of car usage. These data have been evaluated via descriptive statistics. The results serve as a platform for further research. It has been found that socio-economic characteristics could significantly influence Maslow's theorem. Thus, contemporary knowledge about the influence of psychographic characteristics should be revised in favor of this new knowledge.

Keywords

Maslow's theorem, consumer characteristics, consumer behaviour, green marketing, car usage

1. Introduction

Cognitive rationalization refer to the process in which pertinent cognitions are modified or inferred in relation to a problematic behavior. In this paper cognitive rationality is focusing on sustainable decision on personal level. The cognitive development of mobility is one of the most acute tasks nowadays. From an environmental point of view, the situation should be the top priority not only for national governments and companies operating in the relevant sectors but also for individuals (Zoldy, Baranyi, 2021). According to the American psychologist Abraham Maslow (1908-1970), human actions are motivated to meet their needs. Therefore, he created the pyramids (or hierarchy) of needs, based on what caused happiness for people. Maslow presented his concept of the hierarchy of needs in his 1943 article, *The Theory of Human Motivation*. This hierarchy (Maslow, 1943) assumes that people are first motivated to meet basic needs before moving on to more complex and advanced needs (Figure 1). The central belief of his theory was that people have a desire for self-fulfilment. That is, they want to be what they can be. However, before the ultimate goal of self-fulfilment is achieved, people must meet their most basic needs, such as food, security, love, and self-esteem.

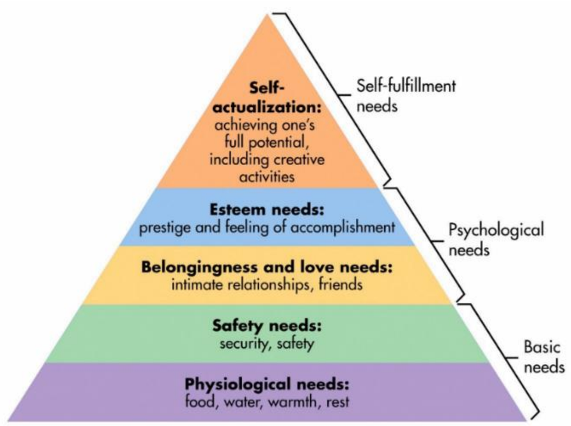

Figure 1 Maslow's Hierarchy of Needs

(Source: Abraham Maslow (1943): Theory of Human Motivation)

The modern marketing concept includes social responsibility, which extends to environmental protection. That also includes personal social responsibility, not only the well-known and researched corporate social responsibility. Social responsibility

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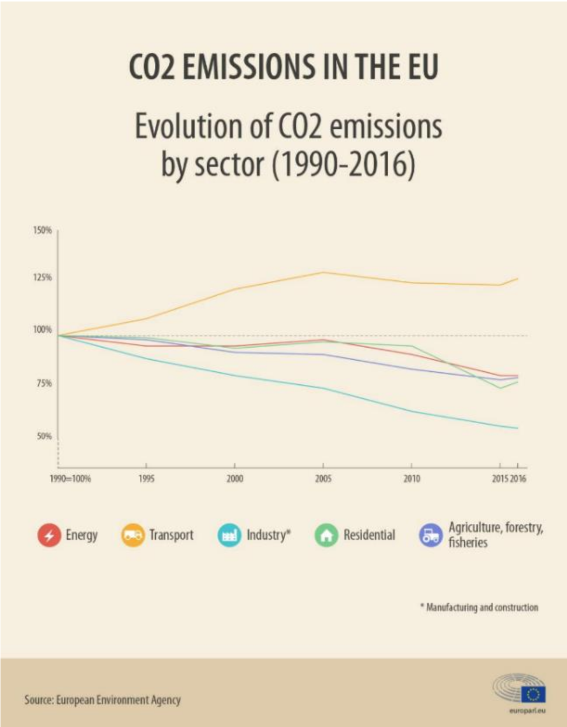
pays increased attention to the implications of marketing decisions, action programs, social and ethical considerations into marketing practices. These include the prevention of pollution, the production of nature- and human-friendly products or services and also the protection of consumer interests. The approach, often defined as eco-marketing, is closely related to the issue of sustainable development. In addition to the interpretation of environmental responsibility in a national or a global dimension, the marketing literature nowadays emphasises corporate sustainability strategies and (environmentally) conscious consumer behaviour and segments. A conscious consumer is aware of and exercises their consumer rights. An essential feature of an ethical consumer is that he or she considers ethical, social, and environmental aspects in his or her decisions and the interests of other people, the future generation, and the values of the natural environment. The current form of road transport imposes significant burdens on society and the environment that are not new (Transport 2000, 1997). Key research areas are road accidents, emissions, noise pollution, traffic congestion, social isolation, and segregation (Figure 2a, 2b):



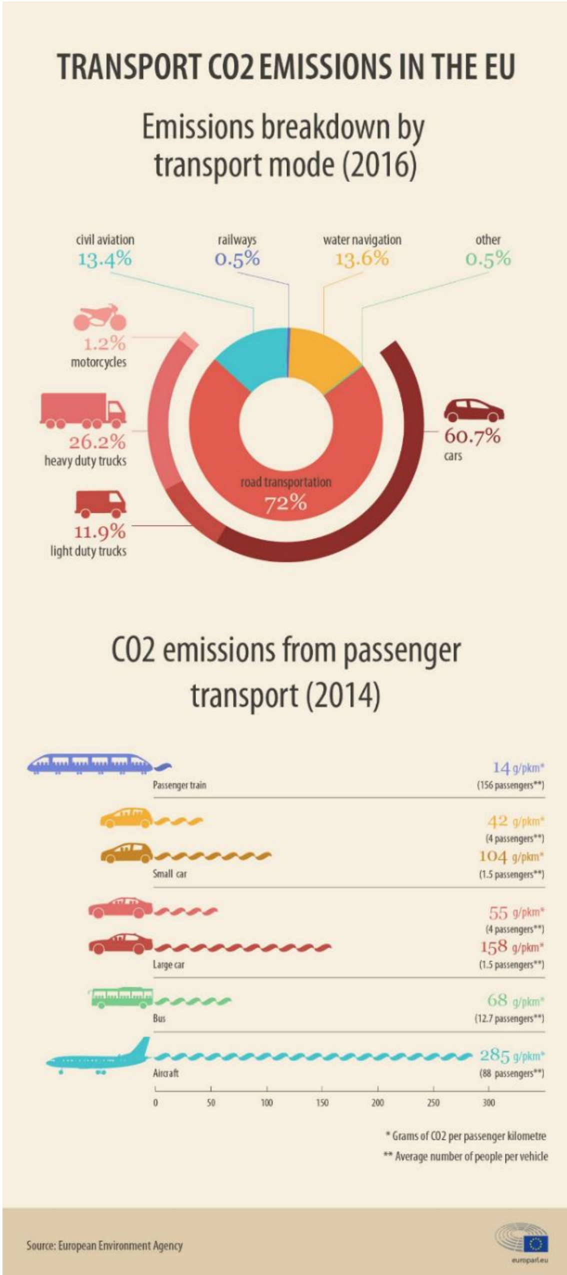


Figure 2a CO_2 emission in the EU 1990-2016 *(Source: EEA)*

Figure 2b CO_2 emission of transport sector in 2016 *(Source: EEA)*

The present article aims to investigate the reduction of the environmental load caused by individual road transport, mainly connected by car usage and car type choice, as branding. How can car choice and usage related mindset be changed?

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The article is structured as follows. After the introduction that introduces the research question, the methodology is described: the detailed tools of survey assessment are presented. The results are analysed and compared with international literature and practical experience. Finally, the conclusion is drawn.

2. Methodology

As individual car use is flexible in space and time, the attractiveness of more sustainable public transport can only be increased if all the necessary information (stops, routes, package sizes, fares) is available to the passenger, as this is the only way to compensate for public transport. Public transport is a more significant cognitive burden, as it is necessary to plan expenses, the route, the departure time. As passengers, we do not have control, which can lead to uncertainty (Zoldy et al., 2022; Stradling et al., 2000; Wardman et al., 2001), and this further increases the attractiveness of individual road transport. On the contrary, the increasing volume of traffic has an impact, which questions the predictability of the use of individual cars and the safety of routes (Török, 2015). Destroying images is not difficult if the victim has actual or theoretical vulnerability (Wring, 1997; Beresford, 1998). There are several different de-marketing processes in the literature, of which only three are relevant for the present discussion:

- Negative marketing, including negative advertising: in a competitive situation, it is a systematic attack on the reputation of a competitor in order to increase market share. E.g., negative advertising against driving.
- Demand restraint, the point is to deter consumers of a competing product or service. E.g., car users cause traffic jams and the introduction of traffic tolls that are charges for everyone.
- Indirect preservation: creating a competing product or discouraging consumers from increasing control over shared resources. E.g., to create bus lanes to make better use of infrastructure as a shared resource to maintain the public transport service.

It is essential to understand the connection between users and passenger cars in this aspect. Unfortunately, passenger cars are still symbols nowadays, and their image vulnerability is still questionable. Therefore, a questionnaire was run in Slovakia to understand the socio-economic connection of brand dependence in car brands. The reason for choosing Slovakia as a significant country has been its strong interdependence (calculated the share on GDP per capita of inhabitants) with the automotive industry. Consequently Slovakia realised socially responsible activities on the regional basis, focused mainly on the car brands operating in the area (Kia, Volkswagen, Peugeot-Citroen). Preliminary analysis showed correlation between economical activity and performance of automotive industry. The questionnaire was fillen in by 2035 inhabitants of the Slovak republic, who were older than 15. Even though 18 is the age limit for obtaining driving licence and to buy a passenger car, the research aimed to reveal the motivations and needs of the upcoming consumer generation. Data were collected in 4th quarter of 2021, using Computer-Assisted Web Interviewing (CAWI) method, which is an internet surveying technique in which the interviewee follows a script provided in a website. The structure of the questionnaire was standardised – it had a demographical part and two individual specific parts focused separately on 1) consumer habits, needs and attitudes towards car brands and individual passenger car usage in general and on 2) consumer habits, needs and attitudes individually in case of a subjectively most valuable brand of a passenger car.

3. Analysis & Discussion

2035 respondents filled in the questionnaire country-wide. 49.9 % male and 50.1 % female (Figure 3a). The age distribution is shown in Figure 3b:

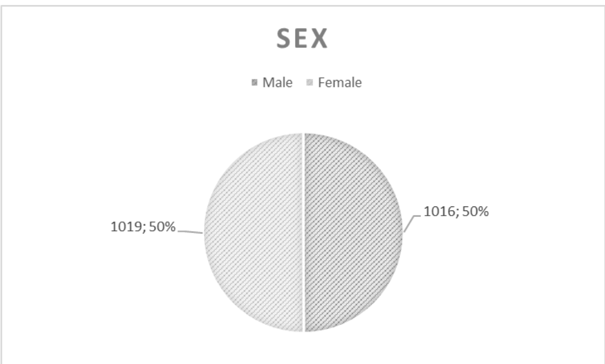

Figure 3a Sex distribution in survey
(Source: own edition)

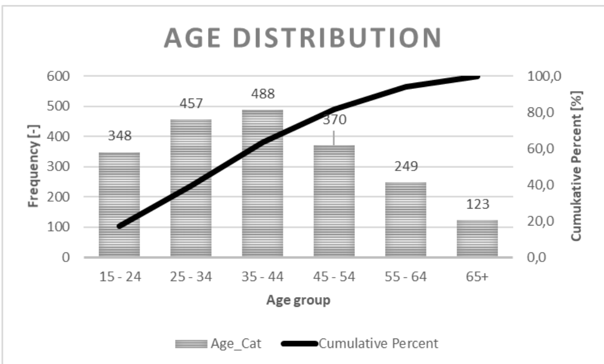

Figure 3b Age distribution in survey
(Source: own edition)

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Based on the analysis of Figure 3a, 3b, 4a, 4b, it can be said that theoretically, to achieve the environmental goals of lowering pollution caused by individual road transport, people need to be deterred from buying a car and using a car. Unfortunately, however, the purchase and use of a car have substantial public benefits, so the state or decision-makers have no interest in reducing the purchase or use. Consequently, individual car users, individual people, must be affected. The biggest problem with green marketing is that protecting our environment has no monetary benefit for consumers, companies, or society. The value of the environment can only be included in the price of economic activity if it is of value for both parties involved in the economic action (Belz, Peattie, 2012).

Maximising pleasure and minimising pain is the most basic instinct for humans and animals, and it is in line with Maslow's theorem. Unfortunately, there is no consensus in behavioural science studies on more effective influencing techniques. However, a reward can reinforce the desired behaviour (Kreps, 1997; Berridge, 2001). Unfortunately, car usage has several connections to alternate levels of Maslow's pyramid (Figure 1). Car usage can be a source of money if used as a tool (physiological level), or can be connected to the security of body, health or property (safety level), as-well-as connected to friendship or family (love level), or can increase self-confidence, respect by others (esteem level), or increase spontaneity, problem-solving (self-actualisation level). As seen in this multi-level connection, it is very problematic to modify these attitudes. The detailed analysis of the questionnaire showed that there is a significant spatial difference of passenger car preference, but choosing no car was insignificant, which strengthened the status symbol idea (Figure 4a and 4b):

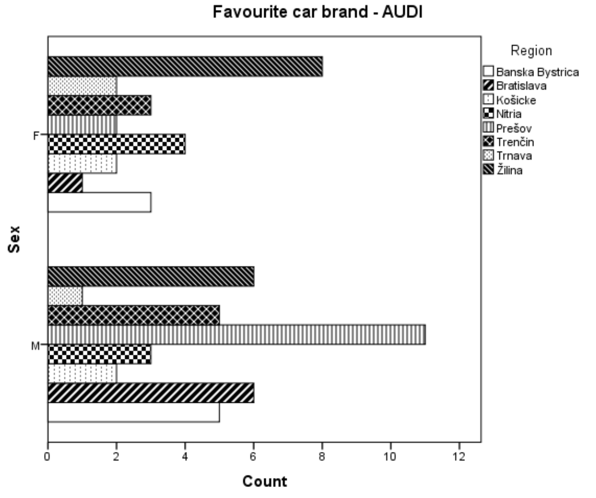

Figure 4a Example of the spatial distribution of car preference
*(Source: own edition) **

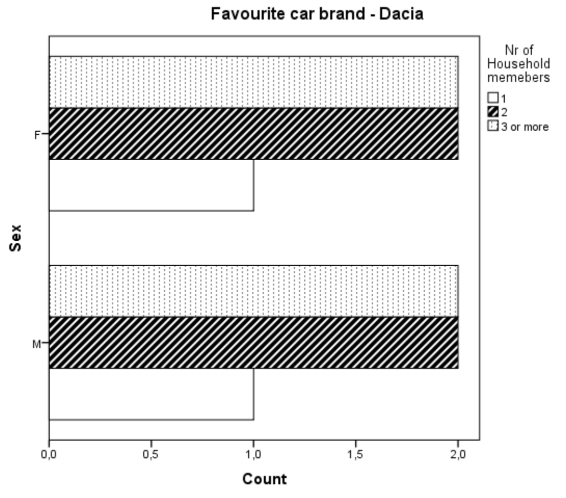

Figure 4b Example of age distribution in survey
(Source: own edition)

** Please note that no car is not significant*

** Please note that no car is not significant*

4. Conclusions

In summary, the tools of environmental marketing are scarce, and it is not easy to find a solution that only affects individual road vehicle usage. Our article shows that the car manufacture branding is deeply hidden in the mindset of Slovakian people based on the survey responses. It is difficult to curb individual road vehicle use and make cars more sustainable. Unfortunately, the spatial and temporal flexibility of individual passenger cars encourages people to make new journeys. The use of individual cars satisfies several levels of demand in Maslow's hierarchy at the same time. It is a complex system in which coercive and encouraging means can only be used together. Encouraging, restorative measures could be financed from the financial benefits of coercive solutions. However, there is still potential to develop the research of this topic and eliminate limits and barriers of general applicability of results this research has obtained. The most significant barrier in this aspect is the territorial nature of this research. According to Hofstede's socio-cultural profile evaluation of the countries, the Slovak Republic is very specific. Thus, regional specifics of the market from the psychographic point of view should be considered before applying the results from this research to different national psychographic environments.

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First steps – the nascent green bond ecosystem in Hungary

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Abstract

This study aims to provide a complex overview of the sustainability aspect of green mortgage and corporate bonds issued in the Hungarian market. The assessment is based on the green bond frameworks, the business profile of each issuer, and the publicly available data of the issuances. The study analyses the seven sectors of the green bond market (real estate, construction, mortgage banks, holding companies, manufacturing, agriculture, wholesale and retail trade). It is proven that out of the sustainable development goals (SDG), SDG 7 is the most supported one. Most issuers plan to use metrics related to pollution prevention, energy efficiency, clean transportation, and water- and wastewater management. Moreover, in four of the seven sectors involved, corporate awareness of green issues could be considered high.

Keywords
Climate finance, Corporate governance, Green bonds, Sustainable finance

1. Introduction

Green bonds have become pivotal elements in financial markets in the past couple of years. Generally, the term *green bond* is used for debt instruments issued to raise funding for projects with environmental sustainability aspects. Therefore, they can offer investors an opportunity to deal with climate and environmental risks (Clapp et al., 2016). Apart from green bonds, several other financial instruments incorporate various environmental, social, and governance (ESG) goals or are linked to sustainability-linked measures. Nonetheless, this study focuses solely on green bonds, intending to shed light on the nascent Hungarian market.

Hungarian corporate and mortgage bond markets have been developing intensively in the past four years. This dynamic evolution has been catalyzed by the active involvement of the central bank of Hungary (Magyar Nemzeti Bank, MNB). The MNB launched the Bond Funding for Growth Scheme (BGS) in 2019 due to a strategic decision to develop the capital market to increase the liquidity of the corporate bond market. The central bank program also helped the creation and development of the Hungarian sustainable debt capital market. According to the decision of the Monetary Council, the program was ended in December 2021. Concerning mortgage bonds, the central bank has launched three programs since 2018 to spur the development of the domestic market. Most recently, the MNB introduced the Green Mortgage Bond Purchase Programme in August 2021. The strategic goal is to contribute to the development of the domestic green mortgage bond market by targeted purchases and, through this, encourage green mortgage loan activities.

The development of the sustainable debt market provides opportunity for companies to avoid a high cost of debt. As Chava (2011) concluded, companies with climate change concerns have a higher cost of equity and debt than firms with lower environmental risk exposure. Consequently, issuing green bonds can demonstrate that the issuers intend to manage climate-related risks. The companies' measures against climate-change-related physical and transition risks are also crucial from monetary policy aspects, since these risks will likely affect monetary transmission channels and influence price changes, as the Network for Greening the Financial System (NGFS) March 2021 Technical document (NGFS 2021) highlights.

Environmental sustainability is one of the key challenges of the 21st century, which is relevant in all aspect of our life, including finances and financial markets. However, there is no single definition of *green bonds* in the financial industry[1]. It is not evident what sustainability means in different cases, which sectors are concerned primarily, how the specific objectives are defined and met. These aspects are important, because they determine the "essence" of the green projects and also frame the cognition of sustainability in the given context.

To date, there has been no study published that would reveal the detailed characteristics or the sectoral specialities of the Hungarian green bond market. In order to fill this gap, the objective of our research was the mapping of the Hungarian green bond ecosystem, including green corporate and mortgage bonds. This paper is structured as follows. Section 2 describes the research questions, the methodology, and the data used, Section 3 presents the results, and finally, Section 4 is the conclusion.

2. Research questions, data and methodology

This study seeks answers to the following research questions:

1. What are the general characteristics of the Hungarian green corporate and mortgage bond markets in European comparison?
2. Based on the bond frameworks and publicly available corporate data, how the nascent Hungarian green bond ecosystem can be described on a sectoral basis from the point of view of green corporate strategy and actions, followed objectives and goals, green indicators and corporate green awareness?

The green issuances of 22 issuers between August 2020 and February 2022 were analyzed. Concerning Question 1, market' size, market' structure, and the tenors used by the issuers were evaluated, based on a comparison of the Hungarian and the European publicly available aggregated data.

To answer Question 2, a sector-level classification was applied to give a comprehensive picture from an economy-wide perspective. This implies that corporate and mortgage bonds were treated as one asset class, as the aim was to identify the effects of green bonds from an economic point of view rather than a financial aspect. The primary sources of the analysis were the green bond frameworks and public data related to the issuers. Given the standardized form of most of the documents and the evolution of green market conventions, it is possible to create clusters on the available information. The present study applies graduate layers to explore all attributes of issuers' green financing activities. This approach shows similarities to Ehlers et al. (2021), who proposed core principles with gradual layering to design effective taxonomies.

(a) Corporate actions. To recognize the benefits of green bonds, Corporate actions initiated with the use of the bond proceeds were identified. The possibility of standardization varies over sectors. For example, in some cases, the real estate sector has particular conventions that define the greenness of assets or certain projects. On the other hand, other sectors have fewer standardized measures, and best practices are yet to become unified.

(b) Sustainable Development Goals. The Sustainable Development Goals defined by the United Nations (UN SDG) are 17 high-level objectives with general guidance for the actual course of action. References to these goals and targets

[1] Several organizations developed their standards. See: ICMA (2021), CBI (n.d.), CBI (2020), European Commission (n.d.). *EU taxonomy for sustainable activities*.

have also become an integral part of green bond standards; therefore, it is feasible to compare bond issuances and the level of ambitiousness.

(c) Action level indicators. Most of the green bond frameworks contain Action level indicators intended to be integral parts of the lasting impact reports. These indicators provide quantified data on the beneficial environmental impacts of green projects or investments.

(d) Corporate awareness. We evaluated the status of the green or sustainability consideration in the general governance. Corporate awareness is rated based on firm-wide sustainability strategy, action plans, dedicated departments, committees, or chief officers with green mandates.

3. Results

By February 2022, the total amount of green corporate bonds reached 536 billion HUF reserves, accounting for about 10 percent of the Hungarian market. This is well above the European average, where the share of green bonds is about 3.5 percent in the corporate bond market. The stock of Hungarian mortgage bonds exceeded 141 billion HUF or 8.7 percent of the local market. The market share of green mortgage bonds is around 1.2 percent in European countries. The difference of green shares in Hungary can be explained by the relatively matured stance of the mortgage bond market, whereas corporate bond issuances became a frequently used funding solution only in the past two years. In sum, these are the most dynamic market segments in terms of volume as well as the number of issuers.

The issuances of the 22 issuers were classified into seven sectors (Table 1).

Table 1: Sector classification

Real estate activities	Construction	Financial and insurance activities		Manufacturing	Agriculture	Wholesale and retail trade
		Mortgage Banks	Holding companies			
CPI	GTC	OTP Jelzálogbank	AutoWallis	Hell Energy	Baromfi-Coop	Stavmat
Skygreen		Takarék Jelzálogbank	LP Portfólió	Vajda-Papír		Vöröskő
Futureal		UniCredit Jelzálogbank	Crown	Deltaplast		
SunDell		Erste Jelzálogbank		Kométa		
Wingholding						
Kopaszi Gát						
Biggeorge						

(Source: own results)

In terms of the original tenor, corporate bonds have all been issued with a 10-year maturity, which is in line with the current practices in the non-green market. We find that this is below the European average of 14.4 years. 'The average initial maturity of green mortgage bonds is 9.1 years more than what we can identify for non-green issuances (7.2 years) and the European market (6.4 years). Comparing it with the peer groups, it seems that only Hungarian green mortgage bonds were issued with significantly longer maturities.

Bond issuers were assigned to economic sectors based on their activities to present a comprehensive picture of the green bond ecosystem. Issuers are grouped according to the Hungarian activity classification (TEÁOR'08) identical to the European NACE Rev.2 statistical classification standard.

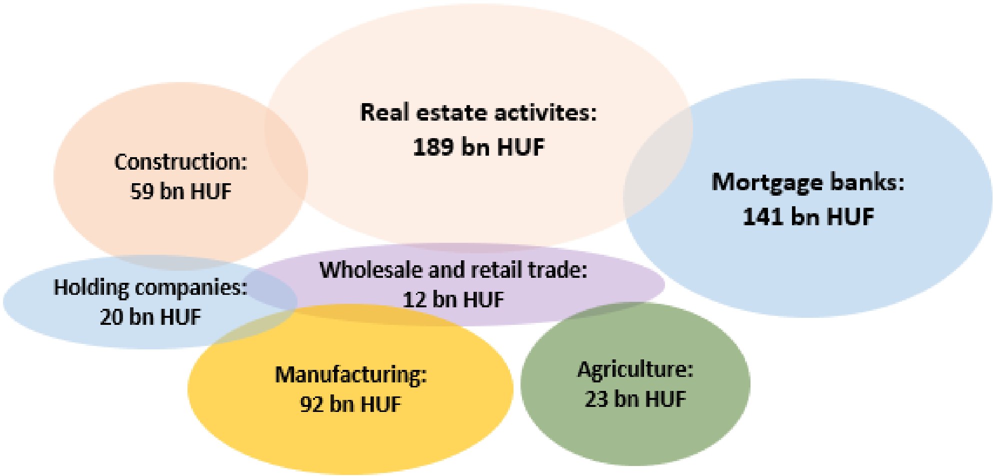

Figure 1. Sizes and connections of issuer groups

(Source: own results)

*Note: The actual sizes of the bubbles do not directly correspond to the size of the issuer groups.

Based on the nominal value of the bonds, we find that the most important sectors are real estate activities, construction, and finance *(Figure 1)*. Finance is split into two easily distinguishable subgroups: mortgage banks, and firms managing asset portfolios (holding companies). All these groups and subgroups are directly or indirectly linked to the real estate market. Another significant sector is manufacturing which, accounts for around 17 percent of the Hungarian green bond market. Agriculture is represented by one issuer, followed by two companies involved in wholesale and retail trade. Placing this into a European context *(Figure 2)*, we find that the structure of the EU green bond market is somewhat different: that market is dominated by the financial sector (38 percent), the electricity, gas, steam and air conditioning supply companies (30 percent), and the real estate developers (15 percent). Utility companies are missing from the Hungarian green bond portfolio, a sector that can play an essential role in the decarbonization efforts. According to the ECB's economy-wide climate stress test (Alogoskoufis et al. 2021), the electricity and gas sector is the second most exposed to transition risk; therefore, it could face a sharp fall in profits and higher production costs.

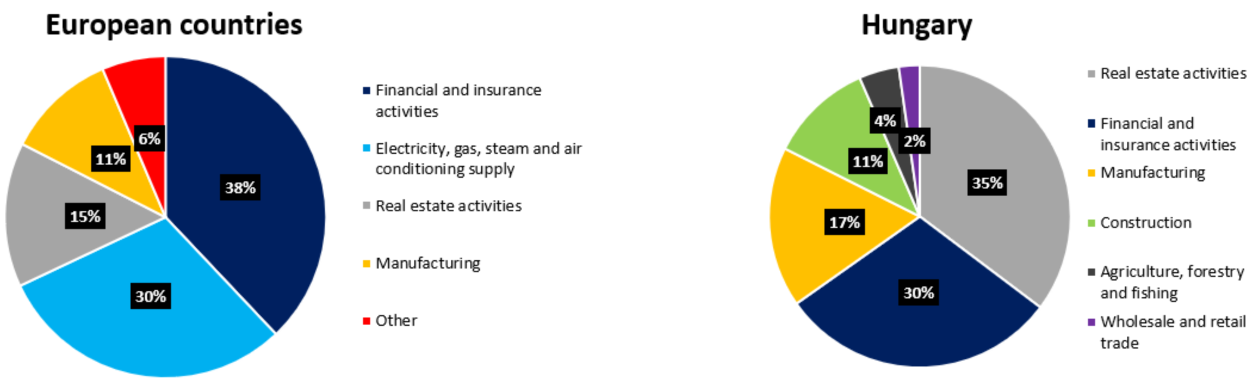

Figure 2. European and Hungarian green bond issuers by sector

(Source: Bloomberg)

*Note: Bloomberg's GICS industry classification GICS are converted to NACE codes applicable within the EU and Hungary based on our assessment.

The significance of real estate developers can be derived from the fact that buildings are responsible for around 40 percent of the EU's energy consumption and 36 percent of its GHG emissions, primarily because of construction, demolition, renovation, and usage. In addition, the European Commission estimates that about 2.5-3 percent of the building stock should be renovated and modernized every year to achieve the net-zero goals of the EU by 2050, although this rate is only around 1-1.5 percent currently. Moreover, the Climate Action Network Europe states that deep energy renovations can have environmental (energy savings, lower GHG emissions, improved air quality), economic (additional 160 thousand new green jobs), and social (7 million people can be lifted out of energy poverty) benefits (Climate Action Network Europe, 2021).

In the sectoral analysis, the four layers presented in Section 2 are applied to the defined sectors: (a) corporate actions, (b) Sustainable Development Goals incorporated in the framework, (c) action level indicators, (d) corporate awareness. The results are summarized in *Table 2*.

Table 2: Summary of assessment

	Real estate activities	Construction	Financial and insurance activities		Manufacturing	Agriculture	Wholesale and retail trade
			Mortgage banks	Holding companies			
Number of issuers	7	1	4	3	4	1	2
Issued amount	189 bn HUF	59 bn HUF	141 bn HUF	20 bn HUF	92 bn HUF	23 bn HUF	12 bn HUF
Corporate actions	- Acquisition and construction of commercial and residential real estate assets - Installation of the renewable energy sources - Renovation of existing properties - Expanding e- mobility services	- Acquisition, development and management of commercial and residential real estate assets - Installation of the renewable energy sources	- Refinancing of residential mortgage loans with high energy efficiency collaterals (Purchases of new or used homes, refurbishment and renovation of existing homes with energy saving targets)	- Acquisition of green buildings - Renovation of buildings with energy efficiency goals - Production and/or Installation of renewable energy - Development of e-mobility services	- Expansion of the production units' capacity to produce less energy- intensive goods - Increasing the share of renewable energy - Reducing waste and water use	- Capacity expansion (feed factory, mixing line, by- product facility) which also results in energy-efficiency improvement - Modern biological treatment of 25- 30% of wastewater - Automation of processes	- Acquisition and construction of green buildings (factory and warehouse) - Retrofitting of existing premises to increase energy efficiency - Automation of processes - Modernization of technologies
Top UN Sustainable Development Goals	7 AFFORDABLE AND CLEAN ENERGY; 9 INDUSTRY, INNOVATION AND INFRASTRUCTURE	11 SUSTAINABLE CITIES AND COMMUNITIES; 12 RESPONSIBLE CONSUMPTION AND PRODUCTION	7 AFFORDABLE AND CLEAN ENERGY; 9 INDUSTRY, INNOVATION AND INFRASTRUCTURE	7 AFFORDABLE AND CLEAN ENERGY; 11 SUSTAINABLE CITIES AND COMMUNITIES	6 CLEAN WATER AND SANITATION; 12 RESPONSIBLE CONSUMPTION AND PRODUCTION	6 CLEAN WATER AND SANITATION; 7 AFFORDABLE AND CLEAN ENERGY	7 AFFORDABLE AND CLEAN ENERGY; 12 RESPONSIBLE CONSUMPTION AND PRODUCTION
Impact indicators	- Site energy savings (MW/year) - CO_2 emission avoidance (tCO_2/year) - Spared water usage (m^3/year)	- CO_2 emission avoidance (tCO_2/year) - Energy efficiency gain relative to baseline (%) - Spared water usage (m^3/year)	- Site energy savings (MW/year) - CO_2 emission avoidance (tCO_2/year)	- Renewable energy generation (MW/year) - CO_2 emission avoidance (tCO_2/year) - Share of renewable energy sources (%)	- Energy saving on units product - GHG reduction per unit of product - Spared water usage (m^3/year)	- Energy consumption saved (kWh/year) - CO_2e/year avoided - Spared water usage (m^3/year)	- Energy consumption saved (kWh/year) - CO_2e/year avoided - Spared water usage (m^3/year)
Corporate awareness	Average	High	High	Low	High	Average	High

(Source: own results)

The details concerning the different sectors, based on the layers (a)–(d) are presented below.

3.1. Real estate activities and construction[2]

(a) Companies active in the Hungarian real estate markets are the most significant actors both in numbers and issued volume (eight issuers, 249 bn HUF allocated amount). The seven real estate companies typically buy, sell, and develop real estate assets and provide various services with the holdings. With a very similar profile, one construction company has a primary focus on building operations and developments. Issuers are primarily engaged in commercial real estate business; however, the construction and development of residential properties are also included in their activity. In the case of commercial real estate, the sustainability aspects are measured by Energy Performance

[2] Since the business scope of the real estate and construction companies are identical, and we find further similarities in the features of the green bond issuances, this section handles them within one category.

Certificates or EPC (European Commission, 2021) or by the BREEAM, LEED or DGNB standards. LEED is the most widespread benchmark among the Hungarian real estate developers investing in green buildings with eight green bond issuers. Regarding other certificates, seven issuers refer to EPC and BREEAM as eligible schemes for their green buildings, while three also list the DGNB standard.

Table 3: Minimum entry criteria for commercial and residential real estates as of 2022

	LEED	EPC	BREEAM	DGNB
Category	Gold	10% better than minimum EPC BB	Excellent	Gold
Description	60-70 points out of 110 points	10% better than minimum NZEB[3]	Top 10% of buildings (best practice)	Minimum 50% performance index

(Source: LEED, European Commission, BREEAM, DGNB)

(b) When we look at UN SDGs, it is clear that the real estate and construction sector can contribute to the climate goals in direct ways. Most commonly – as part of the *UN SDG 7 Affordable and clean energy* – companies aim to double the rate of improvement in energy efficiency and substantially increase the share of renewable energy in the energy mix. In practice, this can be achieved by constructing or developing buildings that meet green criteria or by implementing investments that lead to improvements in energy efficiency. These measures can also reduce the adverse per capita environmental impact of cities, by paying special attention to air quality and waste management, as per *UN SDG 11 Sustainable cities and communities.*

The frameworks adopted by the issuers are especially useful to demonstrate the sustainability of commercial buildings like offices and retail space.[4] Furthermore, some issuers use the proceeds of bonds to finance clean transportation solutions as they intend to increase e-mobility capacities by installing charging stations and expanding e-car sharing capabilities. Through these investments, companies can also contribute to the above-mentioned UN SDGs, in particular to *SDG 11 Sustainable Cities and Communities* by providing access to safe, affordable, accessible and sustainable transport systems for all.

(c) Real estate developers and construction companies typically use impact indicators related to energy efficiency and the reduction of greenhouse gas (GHG) emissions, like energy efficiency in Primary Energy Demand ($kWh/m^2/year$), site energy savings (MW/year), spared water usage ($m^3/year$), and avoided CO_2 emissions ($tCO_2/year$).

(d) Corporate awareness is above average among these companies. Typically, they have embraced ESG or sustainability strategies and some of them assigned relevant accountabilities to management functions. The reason behind this advance is that real estate development and construction activities are highly standardized with quantitative indicators, so this foundation provides a firm basis for companies to define and present their alignment with the related standards.

[3] In the European Union (EU), the concept of Nearly zero-energy emission building (NZEB) is often used by issuers, as it provides a clear definition of eligible projects and assets. The EPBD defines the NZEB concept, and EU member states have to adopt it in their national legal system. See: Commission Recommendation (EU) 2016/1318 http://data.europa.eu/eli/reco/2016/1318/oj, Directive 2010/31/EU http://data.europa.eu/eli/dir/2010/31/2018-12-24 and EU Taxonomy Compass https://ec.europa.eu/sustainable-finance-taxonomy/tool/index_en.htm

[4] Renovation is also an integral part of this segment, and it can effectively contribute to the greening of the existing Hungarian buildings stock. Under this category, the eligible projects should result at least a 30 percent reduction in Primary Energy Demand, or the building renovation should comply with the applicable requirements for *significant renovations.* See: Directive 2010/31/EU http://data.europa.eu/eli/dir/2010/31/2018-12-24

3.2. Mortgage banks

(a) The first green mortgage bond was issued in August 2021. Since then, three other mortgage banks stepped into the green market, therefore, this asset class can be considered as one of the most topical financing solutions (four issuers, 141 bn HUF issued amount). The applied green definition varies among mortgages banks. One of the bond series has been issued with CBI compliance,[5] but it also contains a reference to the EU Taxonomy. Three bonds are ICMA-compliant with a diverse set of rules. On one side, some mortgage banks require properties to fall within the best 15 percent based on Primary Energy Demand and do not consider the tenor of the related bond. There is also an example for a stricter approach where issuers demand compliance with NZEB or EU Taxonomy (NZEB - 10 percent), depending on the year of construction. Funds from green mortgage bonds can also refinance loans for renovation purposes. From this point of view, we can observe a uniform method among issuers. Renovation of existing buildings should result in a 30 percent improvement in the Primary Energy Demand, which is in line with the CBI methodology and commercial building practices. There are also alternative criteria applied by mortgage banks that use EU Taxonomy regulation (Regulation (EU) 2020/852), the Preferential Green Capital Requirement Treatment of MNB (Preferential capital requirements program for green corporate and municipal financing) or the Energy Performance of Buildings Directive as reference points.

(b) In terms of UN SDGs, the primary goals are similar to what we can identify at the real estate and construction sectors. With the refinancing of green buildings and renovations, mortgage banks can support *UN SDG 7 Affordable and clean energy* by increasing the share of renewable energy and therefore doubling the global rate of energy efficiency improvements. These activities can also help foster *SDG 11 Sustainable cities and communities* by reducing the environmental impact of cities.

(c) Mortgage banks intend to measure the beneficial impacts of green bond issuances by two main indicators. Annual site energy savings (in MW/year) can be calculated using the difference between the national building stock average and the refinanced portfolio. If there are no sufficient data available on all individual buildings in the portfolio, issuers might apply the best 15 percentage rule, leading to a rather conservative outcome. The other indicator is CO_2 emission avoidance (in tons of CO_2/year) which is determined by the multiplication of annual site energy savings and the corresponding carbon emission intensity. This represents a rough estimation of how much greenhouse gas emission has been avoided due to the fact that mortgage banks refinanced mortgage loans backed by green buildings instead of regular, “brown” ones.

(d) There is a relatively high corporate awareness towards sustainability considerations. All mortgage banks set up a dedicated committee to address responsibilities related to the green bond issuances. Moreover, virtually all issuers or their parent companies have a global, company-wide strategy to achieve sustainability-related targets, and in many instances, the corresponding responsibilities are assigned to dedicated management functions.

3.3. Holding companies

(a) Most green investments target the acquisition or construction of new commercial estates or renovation of existing ones. Another substantial part of bond issuances will be invested in the development of e-mobility services to increase the share of zero-emission vehicles and the number of electronic vehicle charging stations. In Hungary, the business activities of the three holding companies cover a broad range: as a mutual area, all of them are interested in real estate either by their operational background or as part of the investment portfolio (three issuers, 20 bn HUF issued amount).

(b) With the completion of the real estate investments and e-mobility expenditures, holding companies aim to contribute primarily to *UN SDGs 7 Affordable and clean energy* and *9 Industry, innovation and infrastructure*. In a strong connection with this – as part of *11 Sustainable cities and communities* goal – issuers are also committed to reducing cities’ adverse per capita environmental impact, by paying special attention to air quality and municipal and other waste management.

(c) The impacts of corporate actions are measured by several metrics, while projects have typically well-defined focuses. For investments that aim to improve the energy efficiency of premises, companies intend to report the level of CO_2 emission avoidance and site energy savings, the capacity of renewable energy production (in MWh/year), and the ratio of green energy within the total consumption. Concerning e-mobility expenditures, on top of the energy-saving

[5] The CBI eligibility criteria for low carbon buildings are determined by the Primary Energy Demand and the tenor of the mortgage bond. For Primary Energy Demand, CBI sets a hurdle rate for every country that represents the best 15 percent of residential buildings from an energy efficiency perspective at a given time.

results, upcoming reports will contain information on the share of electronic cars in the fleet as well as on the number and geographic coverage of new charging stations. For the issuer involved in the vehicle trade business, there are minimum requirements stipulated by the foreign producer company as part of their business cooperation. This issuer published several specific goals that clearly state the expected outcomes. For example, they aim to reach a 30 percent share of renewable sources within the total energy mix, and they have specific commitments such as the efficient reuse of rainwater, the installation of eco-friendly cooling-heating solutions, or lighting systems. These commitments are also in line with the National Energy and Climate Plan. According to this Hungary will increase the share of renewable energy sources to at least 21 percent within gross final energy consumption by 2030 (MIT, 2018). Consequently, this requires significant efforts and sufficient financing since renewable energy sources account for only 13 percent (KSH, 2018).

(d) Sustainability awareness is low among holding companies. There is no data on a comprehensive strategy, dedicated management function, or another form of activity that would pursue environmental goals. At one issuer, we find evidence that the preparation of an ESG strategy is underway. Furthermore, due to the cooperation with a foreign car producer, the company must follow sustainability-related guidelines.

3.4. Manufacturing

(a) Manufacturing is the third most significant major sector in Hungary that issues green bonds, following real estate and construction companies, and financials. These companies invest in capacity expansion, which eventually leads to lower energy intensity, less waste generation and water use in production processes. At the same time, they would also increase the share of renewable energy in their energy mix (four issuers, 92 bn HUF issued amount).

(b) Based on the frameworks, it can be concluded that mainly two UN SDGs are affected positively by the commitments: 6 and 12. These green bond issuances support Clearwater and Sanitation as they can substantially increase water-use efficiency across the sector. More importantly, the goal of (*12) Responsible consumption and production* is also supported, since these investments will lead to less paper or primary aluminum consumption or more energy-efficient meat processing.

(c) Firms in this sector aim to reduce the carbon intensity of their products and lower water and energy use or change the raw material for production. In the case of the energy drink producer, the use of at least 75 percent secondary (recycled) aluminum for can production made the ambition eligible for green bond issuance. Aluminum is infinitely recyclable, and primary aluminum is very carbon intensive, while PET recyclability is limited. This processing method is also in line with the technical screening criteria of the EU Taxonomy, and it is expected to be aligned with the upcoming EU green bond standard as well. The most common impact indicators measure energy saving on a product unit and the GHG reduction per product unit, which primarily reflects energy efficiency improvements. Metrics regarding water usage is also an essential element that issuers will regularly track.

(d) All but one of the issuers have a separate website that presents the company's sustainability efforts and achievements. In addition, most of them appointed a dedicated person responsible for sustainability issues. One of the companies has a comprehensive sustainability strategy with critical milestones, and green bond issuance is an integral part of their sustainability journey. Another issuer made significant investments to secure better wastewater management in the past years.

3.5. Agriculture

(a) According to Eurostat (2020), agriculture is responsible for about 10 percent of the EU's total GHG emissions, which shows that companies of this sector can play a significant role in the decarbonization of the European economies. In Hungary, the share of the agriculture sector's GHG emission in the total emission of the economy is around 7 percent. So far, there has been only one green bond issuance in the agricultural sector in Hungary (1 issuer, 23 bn HUF issued amount). The use of bond proceeds is similar to manufacturing companies: expanding capacity while making unit production more efficient and reducing pollution, waste and water use.

(b) The company can primarily contribute to *UN SDG 7 Affordable and clean energy* with the increase of the share of renewable energy in the global energy mix, and to *12 Responsible consumption and productions* by achieving sustainable management and efficient use of natural resources.

(c) Regarding impact indicators, the one issuer in this sector focuses on energy consumption, measured by avoided annual CO_2 emissions and spared water usage. This is largely in line with the indicators used by the Hungarian manufacturing companies.

(d) The level of corporate sustainability awareness is average, because although the company has a dedicated site related to corporate social responsibility and a person responsible for sustainability, a separate sustainability department and a comprehensive strategy are missing.

3.6. Wholesale and retail trade

(a) The two companies in wholesale and retail trade have a combined issuance volume of 12 billion HUF (2 issuers, 12 bn HUF issued amount). One of the companies operates primarily in trading construction materials, but it also produces building materials. The other issuer is a retail shop chain selling consumer electronics. Issuances aim to finance the acquisition or construction of new main sites and renovation of the existing facilities. As significant projects, companies start to build a new factory and a new central warehouse. A prominent characteristic of the sector is that these companies have an extensive geographical and physical presence with multiple premises in Hungary. To address related climate issues, green bond proceeds are eligible funding sources to renovate these buildings, including the modernization of lighting and heating, doors and window systems.

(b) Wholesale and retail trading companies intend to contribute to several UN SDGs. By the construction, acquisition, or retrofitting of facilities, they can double energy efficiency as per the earlier mentioned subgoal of *7 Affordable and clean energy*; moreover, the application of the latest innovations can help to increase the level of *12 Responsible consumption and production*. The renovation of premises will also improve work conditions contributing to *8 Decent work and economic growth.*

(c) Since most of the investments should result in a lower usage of electricity and natural resources, future assessments will use saved energy consumption (kWh/year) and avoid CO_2 emission (tons/year) as the key metrics. In the case of a new factory, the related issuer intends to apply additional metrics regarding water and waste reuse.

(d) Both issuers have embraced environmental and social awareness in their general corporate philosophy. Green considerations are represented on a high level in the decision-making process. Group-level strategy, dedicated management roles, and committees have been set up, and external experts are also involved in one case. One of the companies realized the environmental responsibility derived from the consumption of the traded goods. It collects electronic waste and out-of- use electrical household appliances from customers and hands them over to specialized companies dealing with recycling of the components.

4. Conclusion

In this paper, the Hungarian green bond market was analyzed. The evaluation is based on the green bond frameworks, each issuer's business profile, and the publicly available data. The main characteristics of the Hungarian green bond market can highlight the current state of the sustainable debt market in the country. In addition, the possible development areas and directions are also outlined based on the existing green bond issuances.

The Hungarian corporate and mortgage bond markets have been developing intensively in the last four years. By the first quarter of 2022, the total amount of green corporate bonds reached about 10 percent of the Hungarian market, and the stock of Hungarian mortgage bonds exceeded 8.7 percent of the local market. These shares are about 3.5 percent and 1.2 percent in the European countries, respectively.

From a sectoral perspective we find that that the most dominant sectors are real estate activities, construction, and finance. Comparing our results with the European markets we highlight, that while utilities and power generating companies make up almost 30 percent of the total European corporate green bond amount issued, these industries are still missing from the Hungarian green bond portfolio. For all cases, real estate and construction sectors have significant shares in green bond market that can be explained by the remarkable GHG emission intensity of buildings and the need of modernization of these real estates.

As the Green Bond Frameworks usually match their targets with the UN SDGs, these goals can suggest the most important commitment areas of the issuers. In our dataset, SDG 7 is the most supported goal, followed by SDGs 11, 9, and 12. This preference emphasized the prevalence of energy efficiency-related projects, while sustainable cities/communities and environmentally conscious industry solutions are also often considered in the frameworks. These investments have paramount importance in reaching specific climate goals.

Regarding the top impact indicators, most issuers plan to use metrics related to pollution prevention, energy efficiency, clean transportation, and water- and wastewater management to present their environmental performance in the form of impact reports.

Concerning corporate awareness, four of the seven sectors involved could be considered as scoring high, two sectors have “average“ scores, and there is only one sector where sustainability awareness deems low, essentially because of lack of data on a comprehensive strategy, dedicated management function or other forms of activity that would pursue environmental goals.

All things considered, we can conclude that green bond issuers started the transition to a net-zero economy as they invest in sustainable projects and assets, set relevant indicators, and create a comprehensive sustainability strategy to be competitive in a net-zero environment in the coming decades.

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Factors influencing intermodal transport efficiency and sustainability

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Abstract

A dynamic development of intermodal transport is observed worldwide, which is related to the increase in the level of transport efficiency and sustainability. That increase presents a decision challenge for the participants of intermodal transport systems. Therefore, there is a need to analyze the factors influencing the efficiency and sustainability of intermodal transport. This article analyzes these factors from the viewpoint of transport chain participants. Ten were identified. The case study of the Polish market was analyzed using a marketing research tool. A questionnaire was developed, and the survey was carried out among the representatives of intermodal terminals located at seaports, rail-road terminals and forwarders. On the basis of collected information, it was possible to set the ranking of the particular factors. It was stated that efficient handling of cargo and transport means in transshipment terminals forms the most important factor from the practitioners' viewpoint.

Keywords

Efficiency, sustainability, intermodal transport, transshipment terminals, factors

1. Introduction

Today, a dynamic development of intermodal transport is observed worldwide. Intermodal transport deals with transport of goods in intermodal loading units (containers, swap-bodies, semitrailers, etc.) using the infrastructure of various transport modes (mainly road, rail (Gasparik, 2020), maritime, aviation (Cokorilo, 2020)) and transport means to carry these units (Čižiūnienė et al., 2020; Jarašūnienė et al., 2019). Handling operations are carried out at transshipment terminals located at seaports (e.g. container and ferry terminals) and inland (e.g. rail-road intermodal terminals), where numerous activities related to the operation of these units are carried out (Filina-Dawidowicz et al., 2020). The transport process is organized by a forwarder (or multimodal transport operator) who plans and organizes needed activities and offers a price to the customer for cargo carriage from sender to recipient (Filina-Dawidowicz and Stankiewicz, 2021).

Globalization and international trade development cause market changes. Moreover, the cargo is moved to greater distances from producers through distributors to consumers. This situation creates new challenges that must be faced by transport activity. On the one hand, the needs of the society should be met. Customers want to receive the cargo according to their requirements. On the other hand, transport activity should be performed leading to minimalization of time and costs of transport processes, as well as emission reduction. These processes have to be accomplished effectively, considering Sustainable Development Goals (The United Nations, 2022).

It should be noted that there are many factors affecting intermodal transport efficiency and sustainability to a variable extent. Along with the development of intermodal transport, new technologies and organizational solutions are developed and implemented to increase the level of quality, efficiency and sustainability of its operation. Therefore, there is a need to investigate the impact of different factors on the efficiency and sustainability of intermodal transport. Thus, this article aims

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to analyze the factors influencing intermodal transport efficiency and sustainability, based on the opinions of intermodal transport chain participants.

2. Criteria

Intermodality is used around the world as a means of promoting the efficiency of travel and intermodal transport (Pazzini et al., 2022). With the development of the transport network, qualitative modality is becoming important, which is based on a sustainable door-to-door intermodal network (Sina Mohri and Thompson, 2022).

For a full assessment, it is necessary to use measured assessment criteria that correspond to the real conditions of use of intermodal transport. For this purpose, the criteria mentioned in the literature are used, which are approved according to the real conditions examined in the works of other authors. One of the most important criteria mentioned in the literature is *transport infrastructure*. It enables the development of intermodal transport opportunities not only internationally but also regionally, reducing social, economic, and political exclusion of the region (Lu et al., 2022). It also allows the level of sustainability to be quantified not only at the regional, but also at the local level (Song et al., 2021). Of course, realistic planning is possible thanks to the developed infrastructure, which ensures the cost-effectiveness effect in intermodal transport (Yannis and Chaziris, 2022). The sustainable and balanced development of intermodal transport is important. Therefore, all elements of the intermodal transport supply chain must be monitored and constant communication between the participants is also required (Wessel, 2019).

Additionally, a very important indicator in the literature is the *condition and structure of vehicles*. Environmental aspects are directly dependent on the condition of the means of transport. This is particularly important in the case of intermodal transport, where interactions between different modes of transport predominate, and where it is necessary to provide for both urban and rural areas (Basso et al., 2021). The transport process itself also requires the appropriate type of vehicle to be used in order to make the most rational use of the above-mentioned infrastructure elements (Facca et al., 2021). *Loading units used in intermodal transport* are inseparable from the type of vehicle and, depending on the volume of freight transported, have a direct impact on the efficiency of intermodal transport (Basallo-Triana et al., 2021).

Interoperability of intermodal transport elements allows for an efficient solution of organizational issues in the freight supply chain, and their timely optimization according to emerging issues (Chen et al., 2022). Therefore, the next factor, *efficient handling of cargo and transport means in intermodal terminals and seaports*, becomes very important for the efficient use of intermodal transport in freight transport. This can be done through a variety of Hub-and-spoke (HS) networks (Kreutzberger and Konings, 2016), by directly monitoring and managing the presence of containers at terminals (Yan et al., 2020), or by implementing a direct management algorithm based on the history of previous cargo transportation (Bergqvist and Monios, 2021). This gives rise to the factor of *educated and qualified staff*. Supply chain management is highly dependent on it (Jiang and Zhang, 2019), and it also influences the prospects for the creation and development of further logistics clusters, which directly affects the efficient use of intermodal transport and improves the quality of freight transport (Rivera et al., 2016).

Another criterion discussed in the literature is the *use of IT or telematics*. These tools allow companies to perform important monitoring and management processes in the cargo transportation process, and allow them to evaluate important nuances as transportation accuracy, adherence to schedules, or prompt solution of transportation problems (Arnold et al., 2012; Dalla Chiara and Pellicelli, 2016; Schmitz et al., 2016). Such solutions enable the use of criteria for the use of *innovative technical and technological solutions*. They not only structure the transport process, but also activate possible optimization options to increase sustainability and efficiency when using intermodal transport (Altuntaş Vural et al., 2020; Agamez-Arias and Mayono-Fuentes, 2017). This also necessitates the implementation of *organizational measures*, which are associated with both technological innovation and human resources. It is the organizational measures that ensure the stable compatibility of intermodal transport, its development prospects and its adaptation to specific freight transport (Akdoğan and Durak, 2016; Aldakhil et al., 2018; Pehlivan et al., 2018).

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Intermodality distinguishes several levels of sustainability that affect the efficiency of the transport process: social, economic and environmental and resource sustainability (Ambra et al., 2021). Therefore, the criterion of *support through national / international regulations, transport policy* becomes important. In order to achieve this qualitatively, and intergovernmental regulatory mechanisms, which have a direct impact on the effectiveness of intermodality itself, are important (Tamannaei et al., 2021). Optimizing models are used to assess this type of regulation, which not only offer intermodality options but also estimate the subsidies applied by individual countries (Hu et al., 2022). This is a rather complex process that requires reliable input data, a large database, and a constant update of the regulatory framework. Therefore, the criterion of *continuous improvement of performed processes* arises. This results in an increase in both material and human costs in the efficiency process (Kramarz et al., 2021). Therefore, current trends are developed or simplified by low-cost models based on factor priority weights (Kumar and Anbanandam, 2020) or by intelligent self-taught methods based on artificial intelligence (Barrachina et al., 2019).

2 Methodology

To investigate the opinions of intermodal transport market representatives, a questionnaire survey was developed. The questionnaire was divided into two sections. The first one consisted of questions that allowed to determine the respondent's profile, including:

1. Gender;
2. Age range;
3. Type of represented company (e.g. intermodal terminal located at seaport, rail-road terminal, forwarder);
4. Work experience.

The second section contained thematic questions, including:

1. What share of orders handled by represented company is related to the service of intermodal transport?
2. What modes of transport are used in the intermodal transport chains serviced by the company?
3. What is the impact of selected factors on intermodal transport efficiency and sustainability?

The survey was conducted during September and October 2021. The questionnaire was prepared in electronic form in Polish and sent to 53 intermodal transport companies located in Poland. The selected companies included container and ferry terminals operating at seaports, rail-road intermodal terminals, as well as freight forwarding companies. The questionnaire was completed by 21 professionals involved in the organization and/or implementation of intermodal transport process. The obtained results were statistically analyzed, and appropriate conclusions were drawn. Based on collected information it was possible to set the ranking of the particular factors.

3. Results

On the basis of conducted literature review the factors influencing intermodal transport efficiency and sustainability were identified. Ten factors were selected for further detailed analysis (Table 1):

Table 1 Factors selected for the analysis

Code	Factor
F1	Density and quality of transport infrastructure
F2	Condition and structure of the transport means (rolling stock)
F3	Condition and structure of intermodal loading units (containers, trailers, etc.)
F4	Efficient handling of cargo and transport means in intermodal terminals and seaports
F5	Educated and qualified staff
F6	Usage of modern IT and telematics solutions
F7	Usage of innovative technical and technological solutions
F8	Usage of innovative organizational solutions
F9	Support through national / international regulations, transport policy
F10	Continuous improvement of performed processes

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The analysis of the replies to the general questions formulated in the first section of the questionnaire revealed that among the 21 respondents there were 18 men (constituting 86% of the respondents) and 3 women (14% of the respondents). The vast majority of the respondents were practitioners aged 25–40, followed by companies' representatives aged 41–55 years old and 1 person under 25. No person over 55 completed the survey.

The position of the respondents was distributed as follows:

- 14 managers (67% of respondents) represented intermodal terminals, of which:
  - 7 people represented intermodal terminals located at seaports (container and ferry terminals),
  - 7 people worked in operation of rail-road intermodal terminals.
- 7 freight forwarders.

It should be emphasized that the vast majority of respondents represented intermodal terminals that are the key nodes of intermodal transport chains, allowing the integration of various modes of transport.

Managers with 5–15 years of work experience constituted the largest group (61% of the respondents) of the tested sample, followed by people with work experience of 16–25 (34%) and less than 5 years (5%). No person with more than 25 years of experience completed the survey.

The questions in the second part of the questionnaire concerned the company operation, as well as factors influencing the efficiency and sustainability of intermodal transport.

Enterprises employing practitioners in the sample were characterized by a diversified share of orders related to intermodal transport (Figure 1):

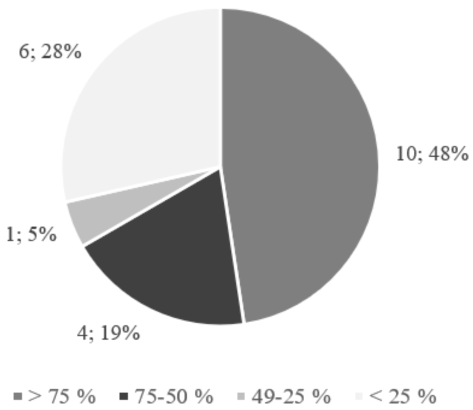

Figure 1 "What share of orders handled by represented company is related to the service of intermodal transport?"

The largest group of responses was obtained from representatives of companies with a share of these orders assumed at a level more than 75% (48% of respondents selected this option). The second largest group were companies with a share of the above-mentioned orders below 25% (28% of respondents). 4 people indicated the companies with a 50–75% share of orders related to intermodal transport, and 1 person chose the range of 49–25%.

Based on the response analysis, it can be noticed that the companies participate in the implementation of intermodal transport chains that involve road, rail and maritime transport modes (Fig. 2). Only two practitioners mentioned that companies are able to service transport chains that include, in addition to the above, air transport and inland navigation (intermodal terminal and freight forwarding company):

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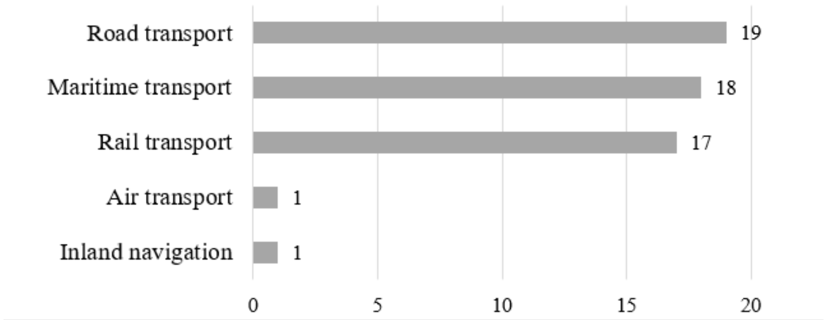

Figure 2 “What modes of transport are used in the intermodal transport chains serviced by your company?"

The respondents were asked to indicate the factors that influence the intermodal transport efficiency and sustainability by ranging them in a Likert-scale (Joshi et al., 2015) from 1 to 5, where 1 – the least important factor, 5 – very important factor. While analysing the opinions of all respondents it was possible to create the ranking of assessed factors (Fig. 3). It can be noted that the factors having the greatest impact on the efficiency of intermodal transport are: efficient handling of cargo and transport means in intermodal terminals and seaports (F4), as well as the density and quality of transport infrastructure of individual modes of transport (F1), and continuous improvement of performed process (F10). Moreover, respondents are convinced that the performed services and processes must be constantly improved, which may be related, inter alia, to the need to expand the existing transport network and improve the quality of processes implemented in the nodes of intermodal transport chains.

According to the respondents, the factors with the least impact are the condition and structure of intermodal loading units (F3) and the support provided by national regulations and international (F9).

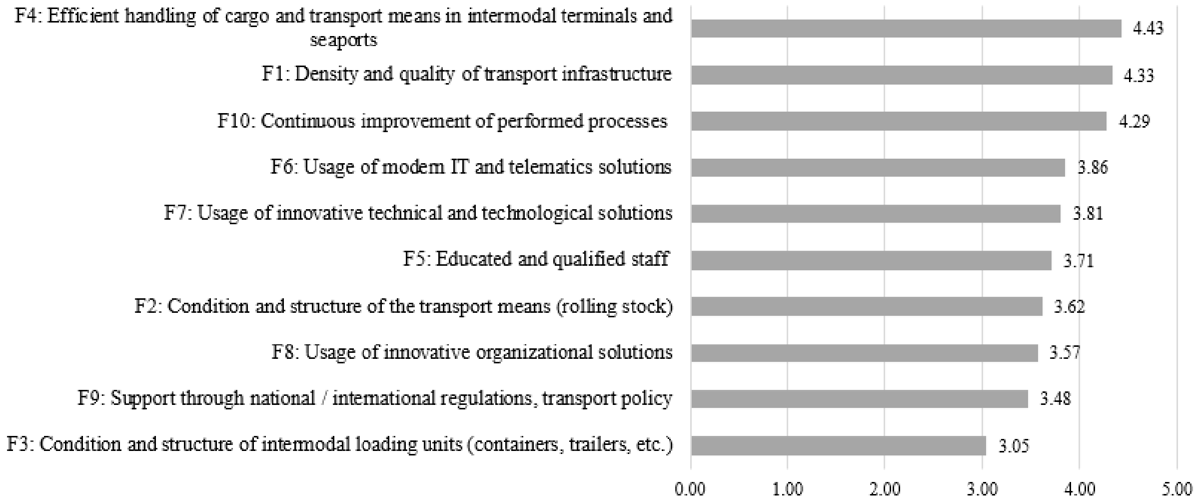

Figure 3. Ranking of factors by the respondents

Each of the above-mentioned factors affects the efficiency and sustainability of intermodal transport, but the most important ones of them focus on technical and technological aspects and organizational issues. Among them there is also the usage of innovative IT and telematics solutions, which improve the efficiency of transport process, as well as handling and storage activities in intermodal transport chains. Therefore, it is necessary to strive for the effective development of these areas with the available resources.

4. Expert assessment

Expert assessment, taking into account all groups of respondents, was carried out to find out about the impact of selected factors on intermodal transport efficiency and sustainability.

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Experts were asked to assess what the impact of selected factors is on intermodal transport efficiency and sustainability in Poland? Experts from three areas of activity were involved in the process: representatives of intermodal terminals located in seaports, representatives of rail-road intermodal terminals, and representatives of freight forwarding companies. Data from 21 expert questionnaires were randomly compiled and calculations performed according Kendall (1970) and Sivilevičius (2011). The results are presented in Table 2.
The concordance coefficient is calculated according to Formula (1) when there are no linked ranks.

(1) $$W = \frac{12S}{n^2\left(m^3 - m\right)} = \frac{26114.5}{21^2(10^3 - 10)} = 0.7178$$

where,

W is the concordance coefficient,

S is the deviations of the values (ranks) of the indicators from the squares of the overall mean of the ranks of the experts,

m is number of experts,

n is number of indicators.

Table 2. Ranking table of received ratings (source: compiled by the authors)

	Factor Encryption Symbol (*m* = 10) *									
	a	**b**	**c**	**d**	**e**	**f**	**g**	**h**	**i**	**j**
$\sum_{i=1}^{n} R_{ij}$	**182**	**89**	**38**	**198**	**114**	**121**	**115**	**70**	**57**	**167**
$\bar{R}_j = \frac{\sum_{i=1}^{n} R_{ij}}{n}$	**8.67**	**4.24**	**1.81**	**9.43**	**5.43**	**5.76**	**5.48**	**3.33**	**2.71**	**7.95**
$\sum_{i=1}^{n} R_{ij} - \frac{1}{2}n(m+1)$	**66.5**	**-26.5**	**-77.5**	**82.5**	**-1.5**	**5.5**	**-0.5**	**-45.5**	**-58.5**	**51.5**
$\left[\sum_{i=1}^{n} R_{ij} - \frac{1}{2}n(m+1)\right]^2$	**4422.25**	**702.25**	**6006.25**	**6806.25**	**2.25**	**30.25**	**0.25**	**2070.25**	**3422.25**	**2652.25**

* Criteria coding: Density and quality of transport infrastructure (a); Condition and structure of the transport means (rolling stock) (b); Condition and structure of intermodal loading units (containers, trailers, etc.) (c); Efficient handling of cargo and transport means in intermodal terminals and seaports (d); Educated and qualified staff (e); Usage of modern IT and telematics solutions (f); Usage of innovative technical and technological solutions (g); Usage of innovative organizational solutions (h); Support through national / international regulations, transport policy (i); Continuous improvement of performed processes (j).

The number of factors influencing the efficiency and sustainability of intermodal transport is $m > 7$. The weight of the concordance coefficient is then calculated according to the formula and a random variable is obtained.

(2) $$\chi^2 = n\left(m-1\right)W = \frac{12S}{nm\left(m+1\right)} = \frac{26114.5}{21 \times 10(10+1)} = 135.6597$$

where,

χ^2 is the criteria.

The calculated value of χ^2 (135.6597) was higher than the critical value χ^2_{kr} (equal to 16.919), which is why the opinion of the respondents is considered harmonized, and the average ranks show the general opinion of the experts.
The lowest value of the concordance W_{min} coefficient was calculated according to the formula. The opinions of all 21 respondents on the 10 factors influencing the efficiency and sustainability of intermodal transport, are still considered to be harmonized at the minimal value.

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(3) $$W_{\min} = \frac{\chi^2_{v,\alpha}}{n(m-1)} = \frac{16.919}{21(10-1)} = 0.0895 < 0.7178$$

Calculations have shown that 21 respondents agree on 10 factors that affect the efficiency and sustainability of intermodal transport and that the views of experts are consistent.

The significance indicators of the factors influencing Q_j are calculated. The obtained data are presented in Table 3:

Table 3. Ranking table (source: compiled by the authors)

Indicator marker	**Factor encryption symbol**										**Sum**
	a	b	c	d	e	f	g	h	i	j	
$\bar{q}_j$	0.1581	0.0773	0.0330	0.1720	0.0990	0.1051	0.0999	0.0608	0.0495	0.1451	1
d_j	0.8419	0.9227	0.9670	0.8280	0.9010	0.8949	0.9001	0.9392	0.9505	0.8549	9
Qj	0.0935	0.1025	0.1074	0.0920	0.1001	0.0994	0.1000	0.1044	0.1056	0.0950	1
Q'_j	0.0426	0.1234	0.1677	0.0287	0.1017	0.0956	0.1008	0.1399	0.1512	0.0556	1
Factor arrangement	9	4	1	10	5	7	6	3	2	8	

Table 3 lists all the factors and their order from most important to least important. Based on expert assessments and calculations, the factors influencing the efficiency and sustainability of intermodal transport are listed below:

1. F3: Condition and structure of intermodal loading units (containers, trailers, etc.);
2. F9: Support through national / international regulations, transport policy;
3. F8: Usage of innovative organizational solutions;
4. F2: Condition and structure of the transport means (rolling stock);
5. F5: Educated and qualified staff;
6. F7: Usage of innovative technical and technological solutions;
7. F6: Usage of modern IT and telematics solutions;
8. F10: Continuous improvement of performed processes;
9. F1: Density and quality of transport infrastructure;
10. F4: Efficient handling of cargo and transport means in intermodal terminals and seaports.

4. Conclusions

Our original research, based on the survey results, it can be concluded that according to the surveyed practitioners, the use of road, sea and rail transport dominates in intermodal transport chains serviced by companies they represent. The factors influencing the efficiency and sustainability of the intermodal transport were analyzed. The case study of the Polish market was analyzed using a marketing research tool, a self-developed questionnaire. On the basis of collected information, it was possible to set the ranking of the particular factors. It was stated that efficient handling of cargo and transport means in transshipment terminals forms the most important factor from the practitioners' viewpoint.

The direction of future research will cover the analysis of intermodal terminals representatives' viewpoint on the implementation of innovations that could influence transport efficiency.

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