CogSust

Cognitive Sustainability

March 2024 Vol. 3. No. 1

ISSN 2939 - 5240

Cognitive Sustainability

Cognitive Sustainability (CogSust) is a double-blind peer-reviewed scientific journal published by CogSust Ltd. (H1116 Budapest Putnok u 9.)

The person responsible for publishing: Mária Szalmáné Csete editor@cogsust.com

The person responsible for editing: Ádám Török info@cogsust.com

CogSust is an online quarterly journal, publication frequency: quarterly, by March, June, September, December.

ISSN 2939-5240

The journal is indexed by:

- Library of Hungarian Scientific Works
- Repository of the Library of Hungarian Academy of Science
- Google Scholar
- Sherpa Romeo
- RePEc (Research Papers in Economics)
- Directory of Open Access Journals
- Crossref
- Semantic Scholar
- ERIH PLUS
- Index Copernicus International
- Dimensions
- Scilit
- Lens

https://doi.org/10.55343/CogSust.90

Exploring the Field of Cognitive Sustainability

Maria Csete Szalmane
0000-0001-7170-9402
Department of Environmental Economics and Sustainability
Faculty of Economic and Social Sciences,
Budapest University of Technology and Economics,
Muegyetem rkp 3., Budapest, Hungary, H-1111
csete.maria@gtk.bme.hu

Abstract

Cognitive Sustainability (CogSust) investigates the links between two research areas: sustainability and cognitive sciences. Sustainability can be viewed as an environmental discipline primarily, but it extends beyond this to encompass an engineering challenge and spans several other disciplines. The main aim of CogSust is to provide a holistic view of how sustainability in a broader aspect can be understood, described (modelled), and optimised for human value creation using the tools of the cognitive sciences. It results in a deeper merge of artificial and biological cognitive systems with engineering applications. This paper aims to show the development of the research field and the journal.

Keywords

Cognitive sustainability, Cognitive science, Sustainability, Multidisciplinarity, Interdisciplinarity, Cross-cutting issues

1. Introduction

Cognitive science is an interdisciplinary field that explores the nature of cognition, which refers to the mental processes and activities related to acquiring, processing, storing, and using information. This field combines insights and methodologies from various disciplines, including psychology, neuroscience, linguistics, philosophy, computer science, anthropology, and more. The primary goal of cognitive science is to understand how the mind works and to develop comprehensive theories that explain various aspects of human cognition. Researchers in cognitive science investigate topics such as perception, attention, memory, language, problem-solving, decision-making, and consciousness. By studying these phenomena, cognitive scientists aim to uncover the underlying mechanisms and processes that govern human thought and behaviour. Cognitive science utilises various research methods, including experiments, brain imaging techniques, computational modelling, and observational studies. The interdisciplinary nature of cognitive science allows researchers to approach complex questions about the mind from multiple perspectives, fostering a holistic understanding of cognition. The insights gained from cognitive science have practical applications in fields such as artificial intelligence, education, human-computer interaction, and clinical psychology.

Sustainability refers to the ability to meet the needs of the present without compromising the ability of future generations to meet their own needs. It involves balancing social, economic, and environmental considerations to ensure long-term well-being for current and future generations. Sustainability is often viewed through three interconnected dimensions. *Environmental sustainability* focuses on preserving and protecting the natural resources and ecosystems that support life on Earth. It involves practices that aim to reduce environmental impact, promote biodiversity, and minimise pollution and waste. *Social sustainability* addresses the well-being of individuals and communities, encompassing the promotion of social equity, justice, and inclusivity. It involves ensuring that fundamental human needs such as education, healthcare, and employment are fulfilled for all members of society. *Economic sustainability* emphasises the responsible use of resources to support economic growth and development over the long term. This includes promoting economic systems that are resilient and equitable and do not deplete resources at a rate faster than they can be regenerated. Achieving sustainability requires a holistic and integrated approach that considers the impact of human activities on the planet and its inhabitants. Sustainability is applied to business, agriculture, urban planning, energy, and resource management in various contexts. The goal is to create systems and practices that endure and support the well-being of current and future generations while respecting the limits of the natural environment.

Cognitive sustainability can enhance innovation by facilitating the identification of problems, the generation of ideas, and the evaluation of solutions. For instance, cognitive skills can help to recognise challenges related to resource use, pollution or social equity. Critical thinking and creativity are pivotal in brainstorming innovative solutions for sustainable development and natural resource management. Cognitive sustainability can help assess the long-term impact of innovations and support decision-making processes concerning sustainability aspects. Cognitive sustainability can drive innovation by developing educational programs that teach critical and sustainability skills and encourage collaboration between engineers and social scientists to develop interdisciplinary solutions. Furthermore, it promotes using artificial intelligence to analyse data and identify patterns that can lead to sustainable solutions.

https://doi.org/10.55343/CogSust.90

The concept of cognition is typically associated with awareness, rationality, subjective experience, and self-awareness in the context of cognitive and psychological processes. While cognition may not directly connect to sustainability, understanding human consciousness and cognitive processes can be relevant to sustainable practices in a broader sense. Understanding the cognitive processes influencing human behaviour and decision-making is crucial for promoting sustainable practices. Research in psychology, behavioural economics, and cognitive science can provide insights into why individuals make certain choices, how they perceive risks and benefits, and what factors influence their attitudes toward sustainability. Consciousness plays a role in environmental awareness and perception. Researchers and policymakers can design effective strategies to promote environmental consciousness and responsible behaviour by understanding how individuals perceive and relate to their environment. Promoting sustainability involves raising awareness and educating individuals about the consequences of their actions on the environment and society. The design of educational programs can benefit from insights into cognitive processes to enhance communication and engagement. Cultural and social dimensions of consciousness influence how societies approach sustainability. Cultural beliefs, values, and norms shape attitudes toward nature, consumption, and the use of resources. Understanding cultural consciousness can inform sustainable practices that align with diverse perspectives. Consciousness is tied to creativity and problem-solving abilities. Encouraging innovative thinking and conscious consideration of sustainable solutions can lead to developing environmentally friendly technologies, systems, and practices.

In summary, while consciousness may not be directly tied to sustainability, understanding human cognition, behaviour, and awareness is essential for implementing effective and meaningful sustainable practices. By incorporating cognitive science and psychology insights, stakeholders can design interventions, policies, and educational initiatives that align with individuals' and communities' values and cognitive processes, contributing to a more sustainable future. In this article, the author investigates the development of the scientific area of cognitive sustainability through related articles published by the Cognitive Sustainability Journal. In the methodology part, the author listed the referring databases that were the basis of the analysis. The results focus on the journal's main characteristics based on the given metrics of the databases.

2. Methodology

The author has investigated the two volumes of the Journal of Cognitive Sustainability (2022 and 2023). The investigation consists of 48 articles in 8 issues. Different statistical tools were used and provided by different indexing agencies. Using these tools, the author could show the development of scientific discipline and the thematic diversity, overlapping of topics, and multidisciplinarity. The journal has already been recognised by the Hungarian Academy of Sciences, Google Scholar (Martín-Martín et al. 2018), the Sherpa Romeo system (da Silva, Dobránszki, 2019), RePEc (Research Papers in Economics) (Coupé, Reed, Zimmermann, 2023), DOAJ (is a unique and extensive index of diverse open access journals from around the world), CrossRef, SemanticScholar, ErihPlus (European Reference Index for the Humanities and Social Sciences) (Lavik, Sivertsen, 2017), Index Copernicus (an online database of user-contributed all information, including profiles of scientists, as well as of scientific institutions, publications and projects established in 1999 in Poland, and operated by Index Copernicus International), Dimension (Data analytics), Scilit (Free and comprehensive content aggregator platform for scholarly publications), Lens (Explore global science and technology knowledge). All data are freely available from the Cognitive Sustainability website.

3. Results

Hungarian Academy of Sciences already recognised the journal as a reviewed scientific English language journal. It is published in Hungary, and it follows an Open Access policy.

Google Scholar indexed all 48 articles and counted 149 citations with a Hirsch index 6. After two years of existence, 149 citations are very promising. The Hirsch index is calculated based on the journal's published papers and the number of citations those papers have received. Specifically, a journal has an h-index of *h* if they have *h* papers that have each been cited at least *h* times. The h-index provides a simple and intuitive measure of a journal's impact. It is widely used in academia to evaluate the scientific output and compare the impact. The distribution of citations is increasing (Fig. 1):

https://doi.org/10.55343/CogSust.90

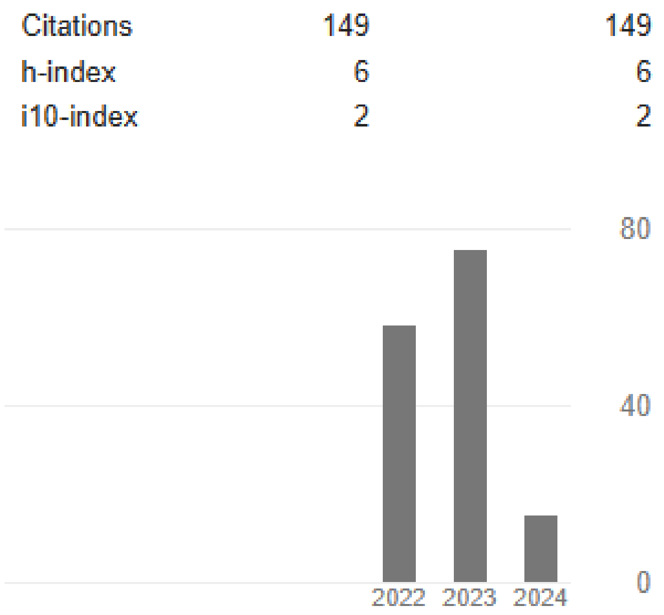

Fig. 1. Distribution of citations in Google Scholar
Source: https://scholar.google.com/citations?user=yZ7RomsAAAAJ&hl=en

According to ErihPlus (European Reference Index for the Humanities and Social Sciences), the journal considered disciplines such as Business and Management, Demography, Economics, Environmental Studies, Human Geography and Urban Studies, Interdisciplinary research in the Humanities, Interdisciplinary research in the Social Sciences, Law, Political Sciences and International Relations, Science and Technology Studies, Social Statistics and Informatics, Sociology. As can be seen, a large variety of scientific disciplines were recognised in the Cognitive Sustainability Journal case, which strongly coincides with the multidisciplinary scope of the journal.

Index Copernicus lists the journal in the following disciplines: Green & Sustainable Science & Technology and Decision Sciences.

In Dimension, all 48 investigated articles are accessible with 66 citations and 1.38 average citations (Fig. 2):

Fig. 2. Distribution of citations in Dimension
Source:
https://app.dimensions.ai/discover/publication?search_mode=content&search_text=cognitive%20sustainability&search_type=kws&search_field=full_search&and_facet_source_title=jour.1442874

https://doi.org/10.55343/CogSust.90

Scilit also recognises the journal as having all 48 open-access papers. The database states that 4.2 % of papers are made in international collaboration, 15 are from Hungary, and the top subjects are very diverse: Transportation, Environmental Engineering, Computer Science, Energy and Fuel Technology.

Lens has already recognised the journal, with 49 papers, and one is already in Online First. Most submissions come from Budapest University of Technology and Economics and the Hungarian National Bank.

4. Analysis

The author can state that different databases have different grouping and segregation methods that automatically and independently categorise the journals. The Lens database shows that citations are not evenly distributed over time. Older articles are attracting more citations that are well known in conservative scientific disciplines (Fig. 3.):

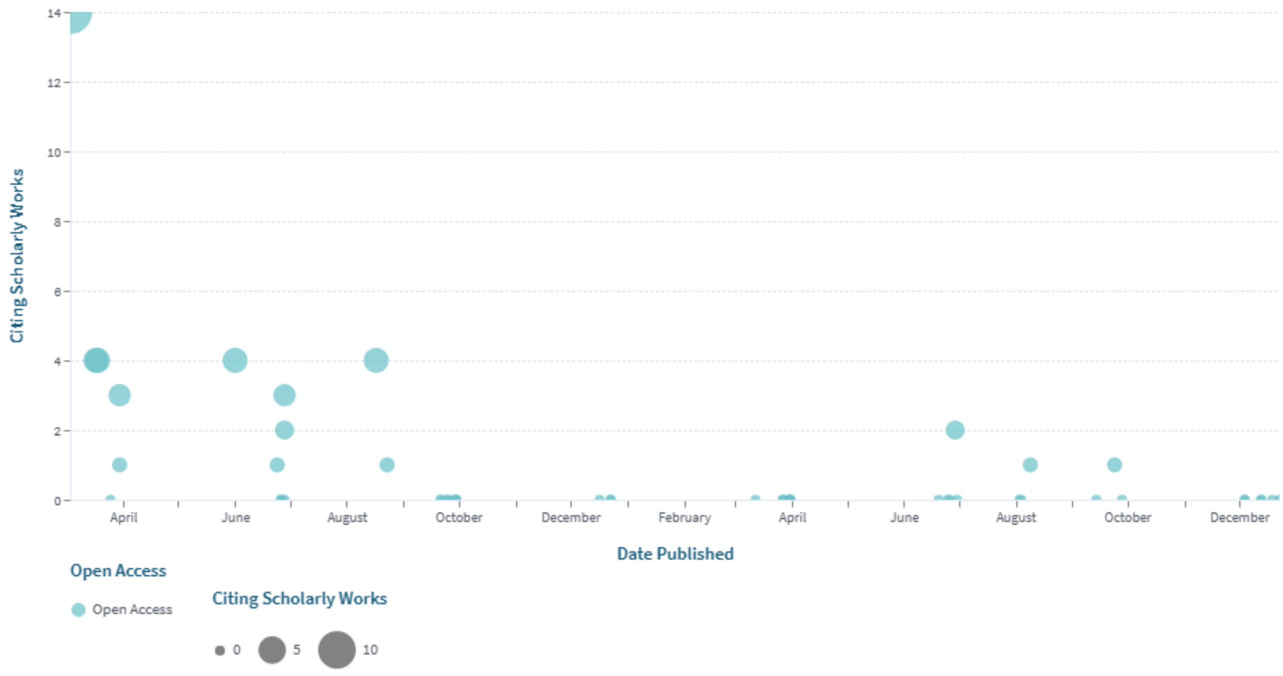

Fig. 3. Distribution of citations in Lens database
Source:
https://www.lens.org/lens/search/scholar/analysis?p=0&n=10&s=date_published&d=%2B&f=false&e=false&l=en&authorField=author&dateFilterField=publishedYear&orderBy=%2Bdate_published&presentation=false&preview=true&stemmed=true&useAuthorId=false&sourceTitle.must=Cognitive%20Sustainability

The field of study is also very broad, and it is in line with the scope of the journal (Fig. 4):

https://doi.org/10.55343/CogSust.90

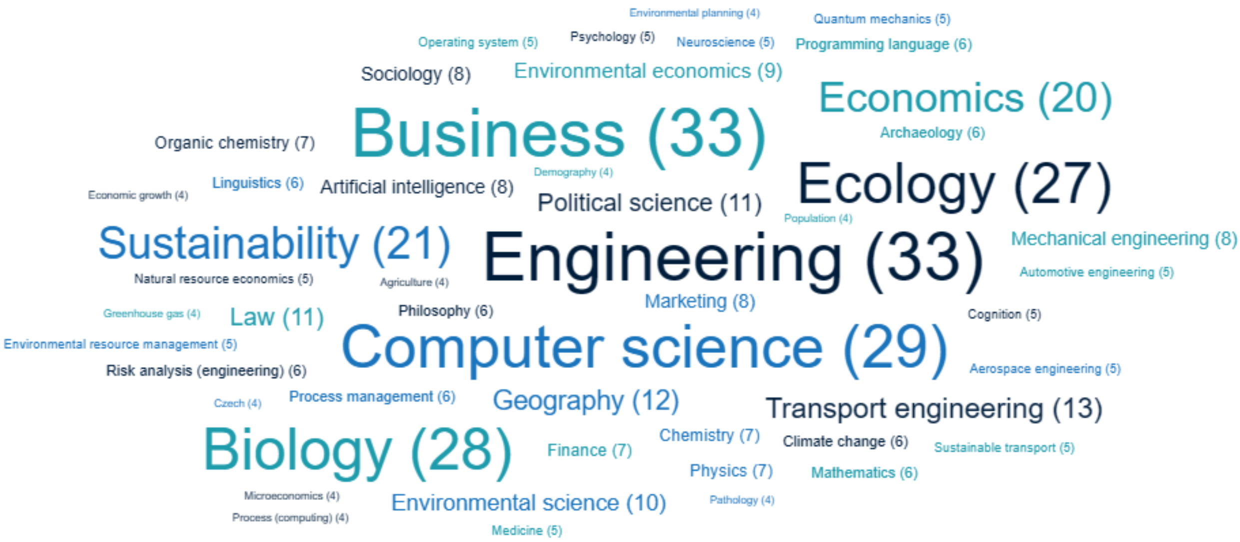

Fig. 4. Distribution of citations in Lens database
Source: *https://www.lens.org/lens/search/scholar/analysis?p=0&n=10&s=date_published&d=%2B&f=false&e=false&l=en&authorField=author&dateFilterField=publishedYear&orderBy=%2Bdate_published&presentation=false&preview=true&stemmed=true&useAuthorId=false&sourceTitle.must=Cognitive%20Sustainability*

The most cited paper in the journal concerns the research that aims to define the concept of cognitive sustainability and explore its validity through an interdisciplinary approach. Results show that digital development allows for extended experiential cognition and can aid in addressing sustainability. The study identifies key dimensions and parameters of cognitive sustainability and highlights its potential for analysing and developing sustainable processes (Zoldy et al., 2022). The second most cited paper is more technology-oriented. It examines the effects of different OME3-5 mixtures on emissions and combustion in a commercial diesel engine. Results show that increasing OME3-5 content reduces PM emissions, improves the NO_x-PM trade-off, and increases brake thermal efficiency. However, there may be challenges with increased NO_x emissions and low heat capacity and viscosity in real-world applications (Virt and Arnold, 2022). The third most cited paper discusses the economy. It provides an overview of the green bond market in Hungary, analysing seven sectors and their support for sustainable development goals. The most supported goal is SDG 7, focusing on pollution prevention, energy efficiency, clean transportation, and water- and wastewater management. Corporate awareness of green issues is high in four sectors (Becsi et al., 2022).

7 Conclusion

In conclusion, Cognitive Sustainability can provide a multidisciplinary background for innovation that can address the most relevant environmental and socio-economic challenges. Cognitive sustainability is an emerging field that examines the intersection of human cognition and sustainability practices. Considering cognitive sustainability, the impact of digital culture and digitalisation on sustainability transition can be examined. On the other hand, cognitive well-being in a sustainable future can put it into perspective. By fostering critical thinking and problem-solving skills, we can create a more sustainable future for ourselves and future generations. A recent study shows that the Cognitive Sustainability Journal has been recognised within the scientific community. However, further research and development are necessary to enhance the research field.

https://doi.org/10.55343/CogSust.90

References

Becsi, A., Varga, M., Loga, M., Kolozsi, P. P. (2022). First steps – the nascent green bond ecosystem in Hungary. *Cognitive Sustainability*. 1(1). DOI: 10.55343/cogsust.11

Coupé, T., Reed, W. R., Zimmermann, C. (2023). Getting seen: Results from an online experiment to draw more attention to replications. *Research Policy*. 52(8), 104841. DOI: 10.1016/j.respol.2023.104841

da Silva, J. A. T., Dobránszki, J. (2019). Preprint policies among 14 academic publishers. *The Journal of Academic Librarianship*. 45(2), 162–170. DOI: 10.1016/j.acalib.2019.02.009

Lavik, G. A. V., Sivertsen, G. (2017). ERIH PLUS–Making the SSH visible, searchable and available. *Procedia Computer Science*. 106, 61–65. DOI: 10.1016/j.procs.2017.03.035

Martín-Martín, A., Orduna-Malea, E., Thelwall, M., López-Cózar, E. D. (2018). Google Scholar, Web of Science, and Scopus: A systematic comparison of citations in 252 subject categories. *Journal of Informetrics*, 12(4), 1160–1177. DOI: 10.1016/j.joi.2018.09.002

Virt, M., Arnold, U. (2022). Effects of oxymethylene ether in a commercial diesel engine. *Cognitive Sustainability*. 1(3). DOI: 10.55343/cogsust.20

Zoldy, M., Szalmane Csete, M., Kolozsi, P. P., Bordas, P., Torok, A. (2022). Cognitive sustainability. *Cognitive Sustainability*. 1(1). DOI: 10.55343/cogsust.7

https://doi.org/10.55343/CogSust.101

Sustainable goods transport – inland navigation

Andrej David
0000-0002-4820-6521
Zilina University
Zilina, Slovakia
andrej.david@uniza.sk

Abstract
Inland navigation plays a crucial role in goods transport, facilitating the movement of goods via rivers and canals. Sustainability in Goods transport involves reducing environmental impact, promoting social responsibility, and enhancing efficiency. Sustainability in goods transport includes optimising transportation routes, investing in fuel-efficient vehicles, and promoting alternative fuels. Green technologies such as GPS tracking and route optimisation software can improve efficiency. Encouraging sustainable packaging materials and carbon offsetting can further reduce environmental impact. Inland navigation can be greener by adopting alternative fuels, improving vessel efficiency, and optimising routes. Maintenance and modernisation of infrastructure, environmental protection measures, and modal shifts from road transport also contribute to sustainability. Various factors influence the performance of inland navigation, including infrastructure, water levels, vessel characteristics, regulations, economic conditions, technological advancements, environmental factors, and social considerations. Integrating sustainable practices and addressing these factors can lead to a more environmentally friendly and efficient goods water transport system. This paper investigates the connections between inland goods transport and sustainability, identifying the main factors. Some basic statistics were collected and analysed to show the performance of inland navigation. The analysis showed that inland navigation is very diverse in Europe, Western Europe is more developed than Eastern European countries. In conclusion, it can be stated that many factors influence the development of Eastern European inland navigation.

Keywords
goods transport, inland navigation, sustainability

1. Introduction

Freight transfer is a service industry involving the coordination and transportation of goods from one place to another on behalf of the shipper. Freight forwarders act as intermediaries between freighters and various transportation services such as shipping lines, airlines, truck companies, and railways (*Naumov, 2018*). The primary function of a freight forwarder is to facilitate the smooth movement of goods from the origin to the final destination and to ensure that the goods reach the recipient in a timely and cost-effective manner. Freight forwarders negotiate rates and secure bookings with carriers for freight transportation through various modes of transport, including sea freight, air freight, road freight and rail freight. Freight forwarders handle all documentation necessary for goods transportation, including freight bills, commercial invoices, export and import permits, customs documents and origin certificates. They also assist in customs clearance procedures, ensure that freight complies with all relevant customs regulations and facilitate the smooth passage of goods through customs checkpoints. Goods transporters usually provide or organise cargo insurance to protect goods from loss, damage or theft during transport. Some freight forwarders provide warehouse and distribution services, including storage, inventory management and order processing, to support their clients' logistics needs. Overall, freight forwarding plays a key role in international trade by simplifying cross-border cargo transport and ensuring that goods reach their intended destinations efficiently and cost-effectively (*Ma et al., 2023*).

Sustainability refers to the ability of future generations to meet their own needs without compromising their ability to meet present needs. It involves a holistic approach that balances economic, environmental and social considerations to ensure long-term viability and resilience. Environmental protection includes reducing resource consumption, pollution and waste generation, preserving biodiversity, and combating climate change by reducing greenhouse gas or NO_x emissions (*Savu et*

https://doi.org/10.55343/CogSust.101

al., 2022*). Sustainability means promoting equitable, inclusive, environmentally responsible economic growth and development (*Lavuri et al., 2023*). It often involves adopting sustainable business practices, investing in renewable energies and green technologies, and promoting fair trade and ethical supply. Sustainability is designed to improve the quality of life of all people by ensuring access to basic needs such as clean water, food, health care, education and housing. It also involves the promotion of social justice, diversity, inclusion and respect for human rights. Achieving sustainability requires cooperation between governments, enterprises, communities, and individuals. It involves making informed decisions and proactively addressing the planet's interconnected problems, such as climate change, resource degradation, biodiversity loss, and social inequality (Scholz et al., 2023). In summary, sustainability is about balancing economic prosperity, environmental protection, and social equity to meet the needs of today's generations without compromising the ability of future generations to meet their own needs.

This paper will focus on sustainable goods transport, especially in inland navigation. The paper's research question is: What possible options for greening inland navigation do we have? Therefore, the author investigated the state-of-the-art scientific literature. The second chapter describes the main challenges of sustainable goods transport. The third chapter shows the performance of inland navigation in the EU. The fourth chapter shows the analysis and conclusion.

2. Sustainable goods transport

Goods transport can be more sustainable through various practices and initiatives to reduce environmental impact, promote social responsibility and improve overall efficiency. Goods transporters can optimise transport routes to reduce fuel consumption, emissions, and transportation costs. This may involve using advanced logistical software to find the most efficient route, combining the transport modes to reduce the number of vehicles on the road and, when possible, promoting the transportation of goods by rail or sea. Good transporters can invest in modern fuel-efficient vehicles for their fleets, such as hybrid or electric vessels (*Majerčák et al., 2024*). Using low-emission vehicles reduces the carbon footprint of goods transport and contributes to environmental sustainability. Implementing alternative fuels such as biodiesel, compressed natural gas (CNG), and hydrogen can help goods transporters reduce dependence on fossil fuels and greenhouse gas emissions from transportation activities. Goods transporters can use green technologies such as GPS tracking systems, route optimisation software and telematics to improve operational efficiency, reduce fuel consumption and reduce emissions. They may encourage clients to use sustainable packaging materials and practices, reducing waste and reducing the environmental impact of goods transport. These include using recycled materials, minimising packaging waste and choosing reusable or biodegradable packaging solutions (*Upadhyay, 2024*). Goods transporters can invest in carbon reduction projects, such as reforestation, renewable energy projects, and energy efficiency projects, to offset carbon emissions from transportation activities. This contributes to reducing the environmental impact of goods and transport and contributes to global efforts to combat climate change. Goods transporters can work with suppliers and transport partners to promote sustainability throughout the supply chain. This includes a strong selection of environmentally and socially responsible suppliers and certifications to demonstrate commitment to sustainability, such as ISO 14001 (environmental management) or ISO 26000 (social responsibility). By implementing these and other sustainable practices, freight forwarding companies can reduce their environmental footprint, improve their social impact and contribute to a more sustainable and resilient global supply chain ecosystem.

Inland navigation, which involves transporting goods and passengers through rivers, canals and other inland waterways, can be more sustainable through various strategies to reduce environmental impacts, improve efficiency and enhance safety (*Maternová et al., 2023*). There are several ways to achieve sustainability in inland navigation. Encouraging alternative fuels such as biodiesel, natural gas liquefied (NGL), and hydrogen can help reduce ship emissions (*Palomba et al., 2017*). Investment in developing and adopting cleaner driving technologies and support for low-emission engines can further contribute to sustainability (*Zalacko et al., 2020*). Designing and reorganising ships to improve energy efficiency and reduce fuel consumption can significantly reduce the environmental impacts of domestic navigation. This may include measures such as the optimisation of the ship's structures, the installation of energy-saving devices and the use of hybrid propulsion systems. The optimisation of logistics and route planning can help to minimise fuel consumption, reduce greenhouse gas emissions and improve the overall efficiency of internal navigation operations. Advanced navigation technologies, route optimisation software, and real-time monitoring systems can help schedule and transport ships and cargo more efficiently (*Nilsson et al., 2009*). Investments in the maintenance, modernisation and expansion of waterway infrastructure, such as boats, dams and navigation channels, can improve navigation's safety, reliability and efficiency (*Maternová et al, 2022*).

https://doi.org/10.55343/CogSust.101

Upgrading infrastructure to accommodate larger vessels and improving connectivity with other modes of transportation can further promote sustainability. Implementing measures to protect and preserve the ecological health of inland waterways can help mitigate the environmental impact of navigation activities. This can include initiatives such as habitat restoration, erosion control, water quality monitoring, and invasive species management to safeguard biodiversity and ecosystem integrity (*Károlyfi et al., 2021*). Encouraging a modal shift from road and rail transport to inland navigation can help reduce congestion, alleviate pressure on road infrastructure, and lower carbon emissions. Offering incentives, such as subsidies or tax breaks, to encourage businesses to choose inland waterway transport for their freight can support this shift toward more sustainable transportation modes.

3. Performance of inland navigation

As shown in Fig. 1, in most cases, the performance of inland waterborne transport has decreased between 2012 and 2021. The attraction of inland navigation dropped, and competition between transport modes became more crucial.

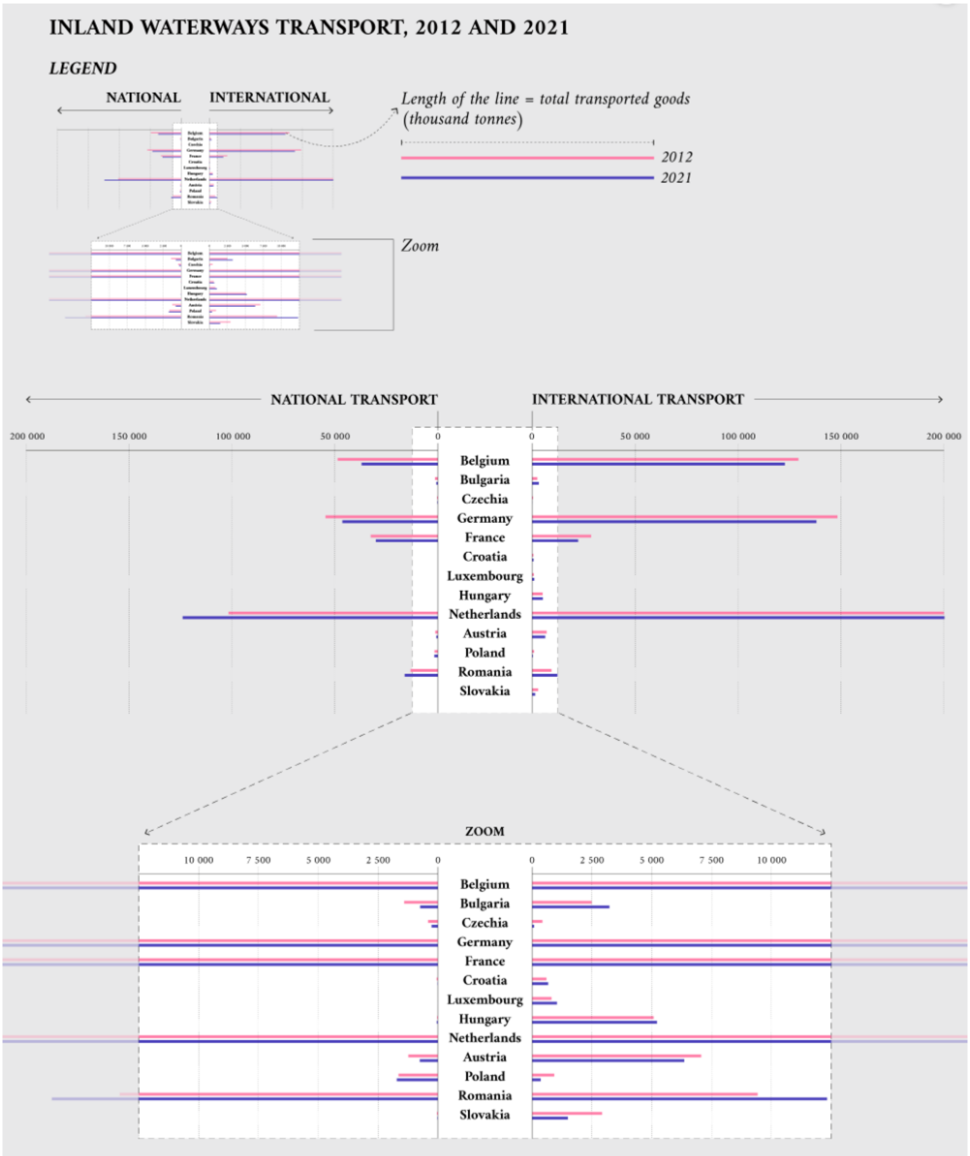

Figure 1 **Performance** (in thousand tonnes) **of Inland Waterway Transport in 2012 and 2021**

Source: Mancino (2023)

Figures 2 and 3 show the spatial distribution of the performance of inland navigation in the EU. The data show that economically more advanced countries are utilising their channel and river systems for goods transport.

https://doi.org/10.55343/CogSust.101

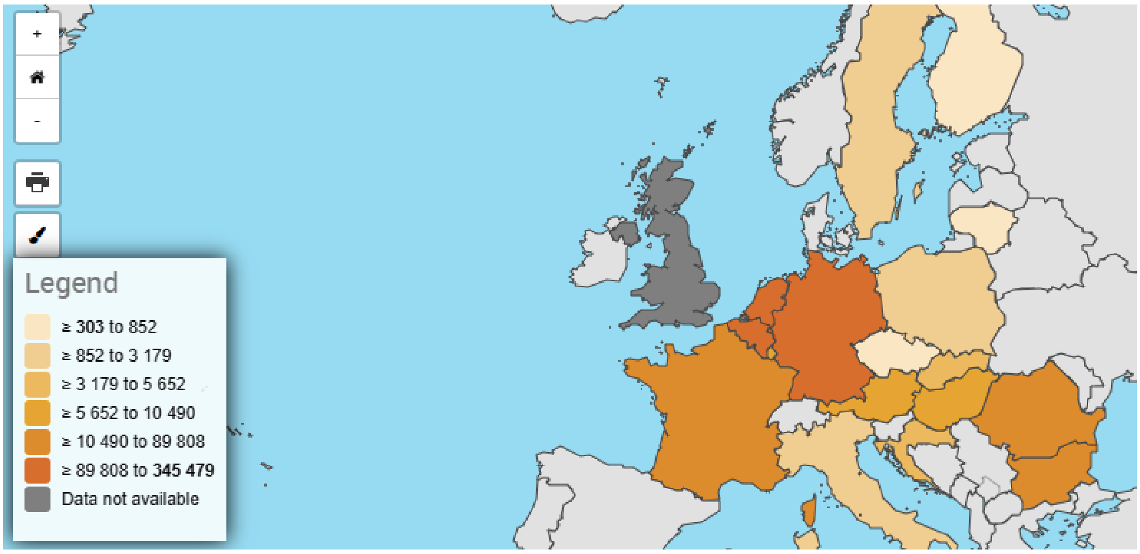

Figure 2 Performance (in thousand tonnes) of Inland Waterway Transport in 2022

Source: Eurostat (2022)

As shown in Figures 2 and 3, the spatial distribution of performance of inland navigation is very diverse. Eastern European countries such as Poland and Hungary could not utilise the geographical advantages. Although France, Germany, the Netherlands, and Belgium have long histories of utilising rivers and building channels,

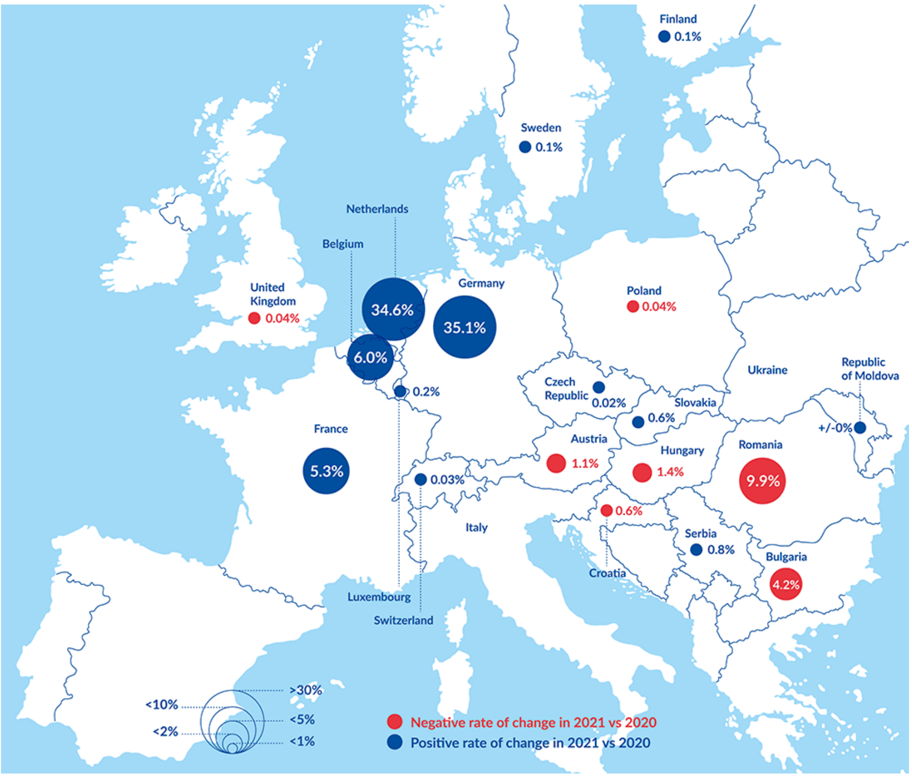

Figure 3 Share of the countries' tonnes-km (tkm) in total transport performance in Europe (in %)

Source: Central Commission for the Navigation of the Rhine (2022)

4. Analysis and Conclusion

Several factors can influence the performance of inland navigation, impacting its efficiency, reliability, safety, and overall effectiveness. The condition and capacity of inland waterway infrastructure, including locks, dams, navigation channels, and

https://doi.org/10.55343/CogSust.101

port facilities, significantly affect the performance of inland navigation. Well-maintained and modernised infrastructure can support efficient navigation, minimise delays, and enhance safety. Fluctuations in water levels due to seasonal variations, precipitation, and hydrological factors can impact navigation conditions, vessel draft, and operational schedules. Adverse weather conditions such as storms, fog, ice, and high winds can also affect the safety and reliability of inland navigation operations. The size, type, and condition of vessels used in inland navigation are crucial in determining performance. Vessel design, propulsion systems, cargo capacity, manoeuvrability, and navigational equipment influence efficiency, speed, and safety during navigation. Regulations, policies, and legal frameworks governing inland navigation, including safety standards, environmental regulations, navigation rules, and trade agreements, can impact performance. Clear and consistent regulatory frameworks that promote safety, environmental protection, and efficiency are essential for the sustainable development of inland navigation. Economic conditions, market demand, trade patterns, and freight rates influence the volume and nature of cargo transported via inland navigation. Changes in economic trends, such as fluctuations in commodity prices, shifts in consumer preferences, or disruptions in global supply chains, can affect the performance of inland navigation. Innovations in navigation technologies, vessel design, propulsion systems, communication systems, and automation can improve the efficiency, safety, and reliability of inland navigation operations. Adopting and integrating advanced technologies can enhance performance and competitiveness in the sector. Environmental factors, such as water quality, sedimentation, erosion, habitat preservation, and climate change, can impact the performance of inland navigation. Addressing environmental challenges and implementing sustainable practices is essential for minimising negative impacts and ensuring the long-term viability of inland waterways. Social factors, including labour availability, workforce skills, training programs, and community engagement, influence the performance of inland navigation. Cultural considerations, such as indigenous rights, heritage preservation, and local customs, may also affect navigation operations in specific regions. Overall, a combination of physical, regulatory, economic, technological, environmental, and social factors shapes the performance of inland navigation, highlighting the need for integrated and holistic approaches to address the diverse challenges and opportunities in the sector.

References

Central Commission for the Navigation of the Rhine (2022). Annual Report 2022 URL: https://inland-navigation-market.org/chapitre/2-freight-transport-on-inland-waterways-2/?lang=en (last visit: 2024.03.14.)

Eurostat (2022): Databrowser URL: https://ec.europa.eu/eurostat/databrowser/view/iww_go_atygo__custom_10583440/default/map?lang=en (last vist: 2024.03.15.)

Károlyfi, K. A., Szalai, D., Szép, J., & Horváth, T. (2021). Integration of BIM in architecture and structural engineering education through common projects. Acta Technica Jaurinensis, 14(4), 424-439. DOI: https://doi.org/mn3s

Lavuri, R., Roubaud, D., Grebinevych, O. (2023). Sustainable consumption behaviour: Mediating role of pro-environment self-identity, attitude, and moderation role of environmental protection emotion. *Journal of Environmental Management*. 347, 119106. DOI: https://doi.org/mmct

Ma, M., Zhang, F., Liu, W., Dixit, V. (2023). On urban co-modality: Non-cooperative and cooperative games among freight forwarder, carrier and transit operator. *Transportation Research Part C: Emerging Technologies*. 153, 104234. DOI: https://doi.org/mmcs

Majerčák, J., Kurenkov, P. V., Ostashevskaya, O. (2024). A Systematic Approach to the Design of Logistics Solutions and a Methodology for their Evaluation in the Field of Greening Freight Transport. *Transportation Research Procedia*. 77, 193–200. DOI: https://doi.org/mmcw

Mancino D. (2023): High-value datasets – mobility in the EU. EUROSTAT. URL: https://data.europa.eu/en/publications/datastories/high-value-datasets-mobility-eu-3

Maternová, A., Materna, M., Dávid, A. (2022). Revealing causal factors influencing sustainable and safe navigation in central Europe. *Sustainability*. 14(4), 2231. DOI: https://doi.org/mmsb

Maternová, A., Materna, M., Dávid, A., Török, A., Švábová, L. (2023). Human error analysis and fatality prediction in maritime accidents. *Journal of Marine Science and Engineering*. 11(12), 2287. DOI: https://doi.org/mmr7

Naumov, V. (2018). Modeling demand for freight forwarding services on the grounds of logistics portals data. *Transportation Research Procedia*. 30, 324–331. DOI: https://doi.org/mmcr

Nilsson, R., Gärling, T., Lützhöft, M. (2009). An experimental simulation study of advanced decision support system for ship navigation. *Transportation research part F: traffic psychology and behaviour*. 12(3), 188–197. DOI: https://doi.org/cjjb3t

Palomba, V., Aprile, M., Motta, M., Vasta, S. (2017). Study of sorption systems for application on low-emission fishing vessels. *Energy*. 134, 554–565. DOI: https://doi.org/mmcx

Savu, S. V., Marin, R. C., David, A., Olei, A. B., Dumitru, I., Tarnita, D., Maternova, A., Savu, I. D. (2022). Reducing NOx emissions through microwave heating of aftertreatment systems for sustainable transport in the inland waterway sector. *Sustainability*. 14(7), 4156. DOI: https://doi.org/mmr9

Scholz, J., Dilger, L. J., Friedmann, M., Fleischer, J. (2023). A Methodology for Sustainability Assessment and Decision Support for Sustainable Handling Systems. *Procedia CIRP*. 116, 47–52. DOI: https://doi.org/mmcv

Upadhyay, R. K., Gupta, J., Khobragade, V. J. (2024). Enhancing Multimodal Transportation in India: Jogighopa Multimodal Logistics Park. In Intelligent Transportation System and Advanced Technology (pp. 123-157). Singapore: Springer Nature Singapore. DOI: https://doi.org/mn3p

Zalacko, R., Zöldy, M., Simongáti, G. (2020). Comparative study of two simple marine engine BSFC estimation methods. *Brodogradnja*. 71(3), 13–25. DOI: https://doi.org/hb7z

https://doi.org/10.55343/CogSust.90

Autonomous Vehicle and Pedestrian Interaction

Leveraging The Use of Model Predictive Control & Genetic Algorithm

Elaa Elgharbi
0000-0002-6913-0351
Lycee Ibn Abbad, Université Cadi Ayyad Faculté des Sciences Semlalia,
Université Mohammed V Agdal Faculté des Sciences
Rabat, Morocco
gharbielaa0@gmail.com

Mate Zoldy
0000-0003-1271-840X
Department of Automotive Technology, Budapest University of Technology and Economics
Budapest, Hungary
zoldy.mate@kjk.bme.hu

Safa Bhar Layeb
0000-0003-2536-7872
LR-OASIS
National Engineering School of Tunis, University of Tunis El Manar,
Tunis, Tunisia
safa.layeb@enit.utm.tn

Abstract

Driving assistance systems and even autonomous driving have and will have an important role in sustainable mobility systems. Traffic situations where participants' cognitive levels are different will cause challenges in the long term. When a pedestrian crosses the road, an autonomous vehicle may need to navigate safely while maintaining its desired speed. Achieving this involves using a predictive model to anticipate pedestrian movements and a strategy for the vehicle to adjust its speed proactively. This research combined model-based predictive control (MPC) with a social-force model (SFM) to effectively control the autonomous vehicle's longitudinal speed. A genetic algorithm (GA) was also integrated into the approach to address the optimisation problem. A comparison between the proposed approach (MPC-GA) and the conventional MPC technique proved the outperformance of MPC-GA.

Keywords
autonomous vehicle, MPC, GA, pedestrian safety, sustainability

1. Introduction

As the number of vehicles continues to rise, so does the potential for increased risks involving road users. Different types of accidents occur worldwide with varying intensities. However, the riskiest of them is vehicle–pedestrian accidents. The combined system of human and artificial intelligence-supported vehicles is relevant in most mobility fields. Pedestrians in the street are vulnerable to a high risk of fatal accidents when encountering vehicles. Various factors, such as age concentration, contribute to this vulnerability. The number of accidents involving pedestrians and vehicles is surging worldwide. Particularly in driving areas with no controlling traffic signs or when pedestrians illegally cross the streets, it becomes crucial to safeguard and protect these insecure commuters.

According to the Centers for Disease Control and Prevention, 3700 people die daily, and millions of people around the world have died in road accidents (CDC, 2023). This concerning number highlights the urgency to address and diminish the number of future collisions of this kind. However, places without safety precautions, such as unsignalized streets and

https://doi.org/10.55343/CogSust.90

uncontrolled crosswalks, are more prone to see such fatalities. Another fact is that most pedestrian accidents happen close to where the victim lives, making residential neighbourhoods riskier.

Autonomous vehicles (AV) have become a breakthrough technology (Zöldy et al., 2020). AVs are classified into five levels based on their level of automation. While most studies have focused on the problem of path planning (Hegedüs et al., 2017) and (Cao and Zoldy, 2022), it is imperative to investigate the ability of AVs' communication with road users and their potential to eliminate human driver's errors. To ensure safety, AVs are expected to drive cautiously around pedestrians, which can encourage pedestrians to engage in careless behaviours like stepping onto the road, forcing AVs to slow down and yield. Hence, inspecting the interaction between AV and pedestrians is required to ensure that pedestrians cross the road safely.

Several challenging opportunities are open in the vehicle-to-pedestrian (V2P) interaction. The most critical of them is to model the behaviour of pedestrian motion when crossing the road. The key is to define AV motion planning. Therefore, the next section 2 provides background information and reviews previous research about pedestrian and AV interaction. Then, the methods and data employed in our approach are thoroughly explained in Sections 3 and 4, respectively. Finally, parameters, settings, findings, and the overall conclusion are presented.

We seek to contribute meaningfully to existing research in this area through our study. The key contributions of this paper are as follows:

- Apply MPC to the AV and pedestrian road crossing scenario with real-time optimisation using the genetic algorithm for tuning MPC problems.
- Improvements were made to the genetic algorithm's parameters, including crossover rate, mutation rate, and the incorporation of roulette wheel selection and elitism to enhance its overall performance.

2. Related works

This section presents the most relevant domains and research results in pedestrian movement modelling, autonomous vehicle motion planning and available modelling and decision-making technologies.

2.1 Residential areas: accidents prone zones

Residential areas, usually referred to as residential neighbourhoods or communities, are distinguished by their principal function as places for habitation. Compared to major thoroughfares, these regions often have a network of streets with lower traffic densities and slower speed limits. Moreover, residential districts are known for their combination of pedestrian and vehicular traffic, which includes neighbourhood commuters, walkers, and children at play.

A thorough investigation (Law, 2020) revealed some elements contributing to why residential areas are more vulnerable to such risk. The increasing frequency of commuting, speeding, and distracted driving are a few contributing causes. Other causes include underage driving, unmanaged highways, and a lack of standard traffic signals. Therefore, several studies recommended imposing a default speed limit in residential areas, such as a speed restriction of 20 mph (32 km/h) as the International Transport Forum recommended, and 30 km/h, according to Kloth (2018).

2.2 Autonomous vehicles

Besides having the potential to enhance sustainability through shared mobility, lower fuel consumption, and better driving patterns, increasing the cognitive level of vehicles leads to increased mobility and safety. Autonomous vehicles can lead the way towards pedestrian safety and efficiency on our roads. Connecting driving support systems and vehicles also increases safety for other mobility participants. The safety of motorcyclists, one of the most vulnerable, can also be greatly increased by, among other things, increasing the use of communication systems (Zöldy, 2023).

According to Palmeiro et al. (2018), it is anticipated that autonomous vehicles will help decrease the occurrence of accidents. This projection is based on their ability to replace fallible human drivers and navigate the road network with enhanced safety. Self-driving cars are a revolutionary technological advancement in the automotive industry. With advanced sensors and artificial intelligence algorithms, these vehicles can operate on roads without human intervention (Torok and Pauer, 2022).

https://doi.org/10.55343/CogSust.90

2.3 Social force model

One of the most popular approaches to pedestrian behaviour modelling is physics-based models. Hence, several methods have been used to simulate the behaviour of pedestrians towards autonomous vehicles, such as the social force model (SFM). This method is a widely used technique for simulating pedestrians, which was first introduced by Helbing and Molnar (1998) to model crowd behaviour in evacuation analysis. The resultant force of a pedestrian is the combination of the psychological and the physical force. Psychological force is used to describe the social properties of the pedestrian. In collision and friction, physical force takes effect (Zhou et al., 2021). These models consider "physical" and "social" forces acting on the agent. Based on this, an agent's movement is driven by a combination of all the forces acting on it at each time step. The basis of the model relied on three main collections of forces acting on an agent: an attracting force drawing the agent towards their goal, a repulsive force away from each agent in the scene, and repulsive forces from all walls and borders in the environment. The motion resulting from the sum of these forces was shown to model human movements in their presented scenarios accurately.

Several authors have studied the V2P interaction in varied scenarios using different approaches. A recent study by Prédhumeau et al. (2022) investigated V2P interaction using SFM and a decision model that predicts such interactions. The simulation was done in controlled experiments in a parking lot at The Ohio State University. Another study by Zeng et al. (2014) analysed pedestrian behaviour at a signalised intersection using the modified social force theory.

In an article by Rashid et al. (2022), an interaction framework between AV and pedestrians was established by employing a rule-based social force model to replicate pedestrian movement during road crossings. Similarly, a modified SFM was suggested for pedestrian crossing by Ren et al. (2014). In their study, the authors suggested some modifications to the SFM by applying the concepts of anisotropy and relative velocity.

2.4 Model predictive control

Notably, model predictive control (MPC) is a category of control algorithms utilising a dynamic process model to anticipate and enhance process performance (Henson, 1998). Yang and Özgüner (2019) studied unsignalized scenarios. The MPC method was used for longitudinal AV speed control and solved using a quadratic programming (QP) toolbox to control pedestrian crowds. The method was supplemented and compared with a proportional integral derivative (PID) controller. Likewise, SFM was used to predict pedestrian motion. Preliminary results of the research clearly demonstrated the benefits of the used MPC solution compared to the classical PID method.

Furthermore, a similar study by Jayaraman et al. (2020) used a behavior-aware MPC model to regulate the AV to navigate safely in crosswalks, proving the efficiency of their suggested model. However, the solving process of NMPC (nonlinear model predictive control) is complex and harder than LMPC (linear model predictive control) and requires sophisticated algorithms.

Besides, a recent paper by Pan et al. (2023) proposes a trajectory planning algorithm that combines A*, the artificial potential field method, and MPC with the addition of a dynamic obstacle potential field in the objective function of the MPC controller. This method enables vehicles to actively avoid collisions with pedestrians and improve traffic safety while maintaining smooth, constraining trajectories.

Overall, the application of MPC is valuable for managing pedestrian-vehicle interactions and facilitating secure pedestrian crossings. Researchers have leveraged MPC to regulate autonomous vehicle behaviour when encountering pedestrians, particularly during road crossings. These studies showcase MPC's potential to enhance AV safety and pedestrian interaction, ensuring smoother navigation and collision avoidance in crosswalks.

2.5 Genetic algorithm

Several studies investigated possible approaches to solve MPC optimisation efficiently. To this end, several algorithms have been proposed to solve the optimal control parameters of MPC, including the Genetic Algorithm (GA). GA is a family of search algorithms inspired by natural selection and genetics, which presents a solution to solve highly nonlinear optimisation problems (Vermuyten et al., 2018).

Moreover, the optimisation of MPC using GA was tested and applied in various cases, such as lane keeping and autonomous vehicle parking. For instance, in Son et al. (2017), GA was used to tune the MPC parameters for a lane-keeping scenario. Results were promising and showed that the optimised MPC exhibited better performance than the human-tuned MPC. Similarly, as suggested by (Arrigoni et al. 2022), a novel genetic algorithm strategy was proposed to solve the NMPC problem for an autonomous vehicle path planner in an urban scenario. The simulation was conducted using the CarMaker environment, and the results demonstrated the successful performance of the model. The GA was crucial in preventing the solution from getting stuck in local minima. Additionally, the results confirmed the feasibility of a real-time controller implementation.

In essence, GA-enhanced MPC improved performance in tasks such as autonomous vehicle control. Some strategies have been proposed to optimise MPC, including Particle Swarm Optimization (PSO) (Abdolahi et al., 2023; Kebbati et al., 2021).

https://doi.org/10.55343/CogSust.90

3. Problem formulation

For the test conducted in this study, a residential area was hypothesised, where streets are non-controlled with traffic lights, and the AV encounters an unsignalized crosswalk. Pedestrians nearing the crosswalk must make decisions regarding crossing or waiting for the AV to pass. To prioritise the safety and comfort of AV riders, the AV employs a pedestrian crossing model to predict pedestrian behaviour and plan its actions accordingly.

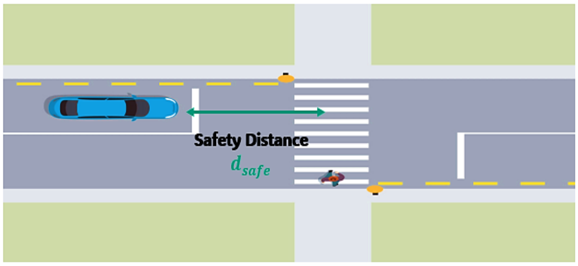

Figure 1 Hypothetical scenario

The proposed approach incorporates a GA to address the numerical solution of the optimal control problem (OCP) within the MPC framework. The method utilises the SFM to handle pedestrian motion while employing MPC to control and regulate the longitudinal speed of the autonomous vehicle.

3.1 Motion Predictions: vehicle dynamics

In our analysis, we consider the AV as a point mass. We focus on the longitudinal vehicle dynamics for crosswalk interactions and adopt a discrete-time kinematic model. Hence, our focus will be dedicated to longitudinal dynamics for the vehicle:

$$M\ddot{s}(t) + \propto \dot{s}(t) = u(t), \qquad (1)$$

where

s – is the longitudinal position,

M – is the vehicle mass,

$\propto$ –is a drag coefficient

$u(t)$ – is the control action.

Thus, let $X = [x_1, x_2]^T = [s, \dot{s}]^T$ be the state vector which comprises the vehicle's position and velocity, denoted by x_1 and x_2, respectively. Furthermore, by rewriting the equation into discretised vehicle dynamics using the Euler method, we have:

$$x(k+1) = Ax(k) + Bu(k), \qquad (2)$$

where

$$A = \begin{bmatrix} 1 & \Delta t \\ 0 & 1 - \frac{\alpha \Delta t}{M} \end{bmatrix}, B = \begin{bmatrix} 0 \\ \frac{\Delta t}{M} \end{bmatrix},$$

Δt – represents the discretisation time step,

$u(k)$ – is the discretised control action.

This process of moving from continuous time to discrete time using the Euler method was proposed by Yang and Özgüner (2019).

3.2 Pedestrian motion prediction

At time *t*, pedestrian motion can be iteratively obtained using the pedestrian dynamics in the equation below, from which the pedestrian state $x_{\mathrm{p}}(k)$ is derived.

$$\ddot{x}_p = \frac{d^2 x_p}{dt^2} = a = \frac{1}{m_P} f_{total} \quad (3)$$

https://doi.org/10.55343/CogSust.90

Furthermore, the model relies on the principles of social force. It is applied to predict the motion of pedestrians under the influence of vehicles. In this model, the movement of each pedestrian is represented as x_p follows the 2D planar point-mass Newtonian dynamics, influenced by a total force f_{total}, comprising various sub-forces (Yang and Özgüner, 2019).

Where $x_p \in R^4$ represents the pedestrian state vector, mainly the positions $(x_P, y_P)$and velocities (v_x, v_y) in (x, y) axes. Whereas m_P is the pedestrian's mass and $f_{total} \in R^2$ is the total force. The velocities and acceleration are expressed as below:

$$\dot{x}_p = v_x \text{ and } \dot{y}_p = v_y \quad (4)$$

$$\dot{v}_x = a_x \text{ and } \dot{v}_y = a_y \quad (5)$$

Hence, the acceleration is equal to: $a_x = \ddot{x}_x$ and $a_y = \ddot{x}_y$ (6)

The total longitudinal force acting on the pedestrian is the sum of two main forces: the attraction force (or destination force), which drives the pedestrian toward their desired goal, and the repulsive force (or vehicle force), which repels the pedestrian from the vehicle. Hence, the total force is equal to:

$$f_{total} = f_{destination} + f_{vehicle} \qquad (7)$$

3.3 Cost function design

Based on the vehicle dynamics previously explained, the future state vector of the vehicle position $x_1(k+n)$ will be obtained. Likewise, the future pedestrian state $x_\mathrm{p}(k+n)$ will be obtained from the previously mentioned pedestrian dynamics.

A safety requirement is incorporated into the MPC constraint architecture to guarantee the safe functioning of the autonomous vehicle and avoid any potential collisions with persons crossing the road. This standard stipulates that, about the longitudinal position of the vehicle, a specific distance designated as d_{safe}" must be maintained between the autonomous vehicle and the pedestrian. To maintain this defined d_{safe}" throughout *N* future steps:

$$|x_1(k+n) - x_p(k+n)| > d_{safe} \qquad (8)$$

This formula ensures that the projected distance between the vehicle's future position and the pedestrian's anticipated location stays within the allowed safety margin. Also, limitations are placed on the velocity, control action and the rate of change of control action due to the physical constraints of the vehicle. Therefore, the following constraints will be considered. For ∀i $= k+1, \ldots\ldots, k+N$, we have:

$$v_{min} < v(k+n) \le v_{max} \; \forall \; n \in \{1,2, \ldots\ldots, N_p\} \qquad (9)$$

$$|u(k+n)| \le u_{max} \; \forall \; n \in \{0,1,2, \ldots\ldots, N_p - 1\} \qquad (10)$$

$$|\Delta u(k+n)| \le \Delta u_{max} \; \forall \; n \in \{0,1,2, \ldots\ldots, N_p - 1\} \qquad (11)$$

The MPC's final objective is to identify the control actions $U = [u(k), u(k+1), \ldots\ldots, u(k+N-1)]^T$ that will ensure that the vehicle meets state and safety constraints. Considering this, the cost function is referred to as follows:

$$U *= arg\ min\ _U \sum_{n=0}^{N_P} w_v \left(v(k+n) - \ v_{0,veh}\ \right)^2 + \sum_{n=0}^{N_P - 1} w_u \left(u(k+n)\right)^2 \qquad (12)$$

where W_u and W_v are the weights of the cost of the velocity and control, respectively. Subject to the previous constraints (2), (7), (8), (10) and (11).

https://doi.org/10.55343/CogSust.90

Algorithm: MPC for longitudinal speed

Input: MPC parameters, initial state and input $u(0)$.

Result: control signal $u*(k)$

Initialization

For each time step k **do**

  obtain x(k) and pedestrian state;

  predict pedestrian motion using pedestrian dynamics;

  solve for $U^* = arg\,min_U \sum_{n=0}^{N_p} w_v \left(v(k+n) - v_{0,veh}\right)^2 + \sum_{n=0}^{N_p-1} w_u \left(u(k+n)\right)^2$;

  if MPC is feasible **then**

    apply $u(k) = U^*(1)$;

  else

    infeasible

  end

end

Figure 2 MPC algorithm

3.4 Model predictive control based on genetic algorithm

The genetic algorithm searches for the optimal control sequences that optimise the cost function and comply with the model constraints. The following sections explain the optimisation process.

3.4.1 Encoding

Each chromosome $(c_i = \{gene_{1,\ldots\ldots,}gene_{Nc-1,}\})$ in the population constitutes a control action $[u(t), u(t+1), \ldots\ldots, u(t+N-1)]$, with i = 1, population size. The selection of each chromosome is done within the defined range of control interval $[u_{\min}, u_{\max}]$ and with $\{\Delta_i u(t+j), j = 1, \ldots\ldots, Nc-1\}$ not exceeding the limit Δu_{max}.

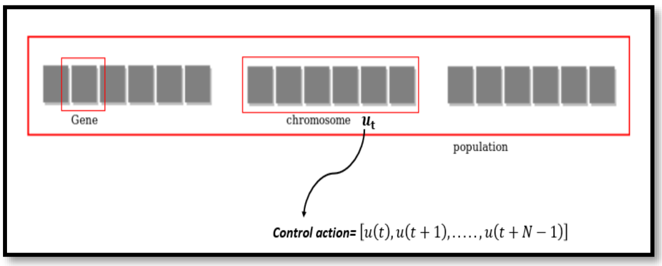

Figure 3 Control input

https://doi.org/10.55343/CogSust.90

3.4.2 Initialisation

- Begin by generating an initial control value within the defined constraint space.
- If the individual adheres to the constraints and terminal constraints, include it in the initial population.
- Continue to iterate through the steps mentioned above until a total of individuals reaches the population size that has been selected.

3.4.3 Evaluation and Selection

- The fitness value for each chromosome is defined as: $\frac{1}{(1+J)}$ (13)
- With J being the value of the cost function of the MPC problem.

3.4.4 Genetic operators

Roulette Wheel Selection

The selection strategy used in this paper utilises the roulette selection algorithm. As a result, individuals with higher fitness levels are more likely to be selected and retained during the evolutionary iteration process. If an individual is denoted as i and its fitness is f_t, the probability that it will be selected is expressed as:

$$P_t = \frac{f_t}{\sum_{t=1}^{n} f_t} \qquad (14)$$

Mutation

Genes are chosen based on their likelihood of mutation. They are subsequently replaced at random while adhering to permissible boundaries defined by control signals $|u(\mathrm{i})| \leq u_{max}$ and limits on the change in control signals $|\Delta u(\mathrm{i})| \leq \Delta u_{max}$.

Crossover

This approach creates two offspring while ensuring that the control signals remain within acceptable constraints.

Elitism

The elite-preservation strategy is implemented to ensure the current population's quality and the MPC algorithm's steadiness. Where the top 1% of high-fitness individuals in the population are retained.

Termination condition

Repeating the preceding step and entire calculation at subsequent control interval k+1.

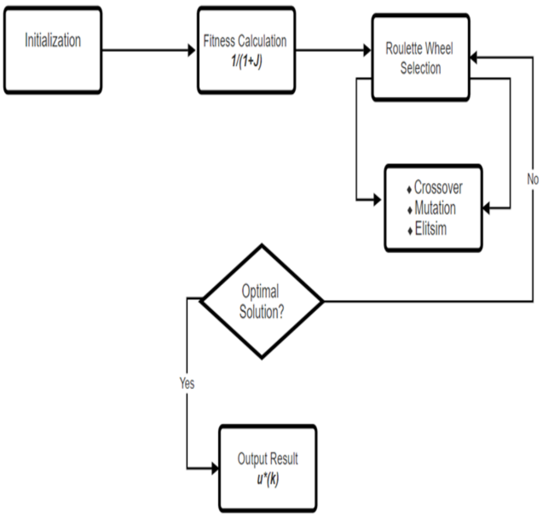

Figure 4 GA flowchart

https://doi.org/10.55343/CogSust.90

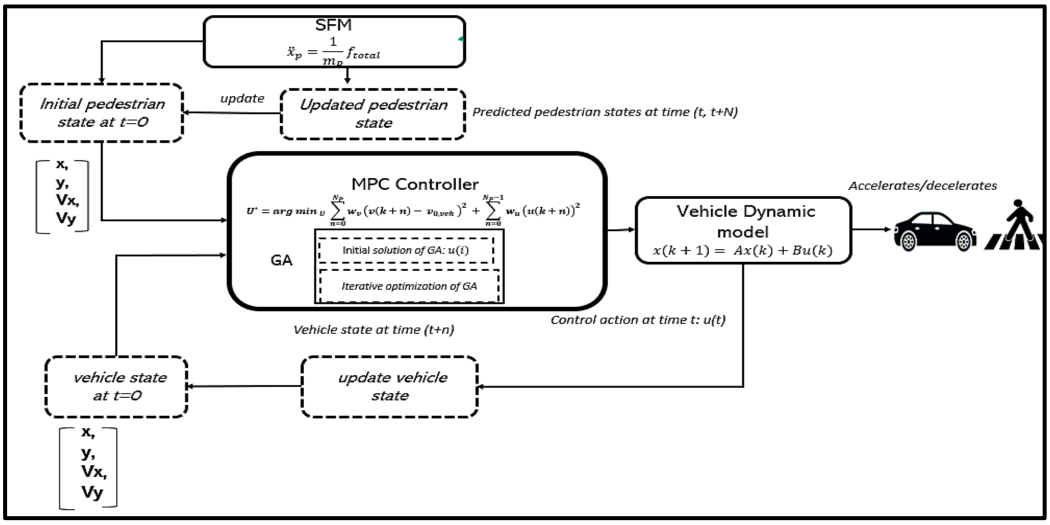

Figure 5 Model diagram

Finally, the overall algorithm is stated as follows:

Algorithm: MPC-GA for longitudinal speed

Input: MPC parameters, initial state and input $u(0)$.
Result: control signal $u*(k)$
Initialization
For each time step k **do**
obtain x(k) and pedestrian state;
predict pedestrian motion using pedestrian dynamics;

for n=0 to N_{p-1} **do**
// Genetic Algorithm Optimization
gen_counter = 0

while gen_counter < MaxGenerations **do**

// generate set of possible control moves
// find the process output for all control moves
// evaluate the fitness for each solution
// apply genetic operators
//repeat until number of generation is reached
gen_counter = gen_counter + 1
end

solve for $U^* = arg\ min_U \sum_{n=0}^{NP} w_v \left(v(k+n) - v_{0,veh}\right)^2 + \sum_{n=0}^{NP-1} w_u \left(u(k+n)\right)^2$;

if MPC is feasible **then**

apply $u(k)= U^*(1)$;

else

// Handle infeasible case (maximum deceleration)

infeasible

end

end

end

Figure 6 MPC-GA algorithm

https://doi.org/10.55343/CogSust.90

4. Parameter settings

To conduct the simulation, CVXPY, a Python-based modelling language for convex optimisation, was chosen to solve the optimisation problem (Diamond and Boyd, 2016). A computer equipped with an Intel Core i5-1135G7 CPU, 8GB of RAM, running on the Windows 11 operating system, and employing Python programming language was used. The tables below contain the values chosen for the parameters based on the literature found in the work of (Yang and Özgüner, 2019) and (Jayaraman et al., 2020).

Table 1 MPC parameters

Symbol	Value	Unit
Vehicle mass M	2000	Kg
Minimum control input u_{min}	-7	m/s^2
Maximum control input u_{max}	7	m/s^2
Minimum control input change Δu_{min}	-5	m/s^3
Maximum control input change Δu_{max}	5	m/s^3
Drag coefficient α	100	-
Minimum speed v_{min}	0	m/s
Maximum speed v_{max}	16	m/s
Safety distance d_{safe}	5	M
Prediction horizon N_{pred}	15	-
Weight on the control w_v	1	-
Weight on control Rate w_u	1	-

https://doi.org/10.55343/CogSust.90

Table 2 GA parameters

GA parameter	Setting used
Population size (default)	100
Crossover rate (default)	0.9
Mutation rate(default)	0.1
Elite count	1%
Maximum number of generations(default)	100

The default value for the number of generations is set to 100, a choice aligned with previous studies (Ahmadpour et al., 2021; Ramasamy et al., 2019; Mohammadi et al., 2018).

Table 3 SFM parameters

Symbol	Value	Unit
Maximum pedestrian speed $v_{p,max}$	2.5	m/s
Maximum pedestrian acceleration $a_{p,max}$	5	m/s^2
Pedestrian mass m_p	80	Kg
$k_{destination}$	300	-
$A_{vehicle}$	200	-
B	2.6	-

5 Results and analysis

For crossover and mutation rates, we used 0.9 and 0.1 at the beginning of the simulation, respectively. Following the guidelines provided by most sources ((Abdolahi et al., 2023; Kebbati et al., 2021; Vermuyten et al., 2018; Arrigoni et al., 2022; Hang et al., 2021), we used (0.7, 0.3) and (0.6, 0.4) as crossover and mutation rates, respectively. Subsequently, we manually adjusted these rates to obtain the optimal combination based on CPU time usage, aiming for computational efficiency across 200 simulation runs. Computer systems require energy for almost all computational tasks involved in running algorithms, which adds to their carbon footprint. Consequently, it highlights how important it is to maximise computational efficiency to minimise environmental impact and promote sustainable computing practices.

https://doi.org/10.55343/CogSust.90

5.1 Step 1: crossover and mutation rates

Step 1 shows the crossover and mutation rates based on GA rate tuning.

Table 4 GA rate tuning

	MPC-GA					
	CPU					
(Crossover, Mutation)	0.9	0.1	0.7	0.3	0.6	0.4
Average	75.3611		74.7704		81.7025	

Hence, based on the results above, the crossover and mutation rates used are 0.7 and 0.3, respectively.

Now, tune the number of generations using different settings: [20, 30, 40, 50, 100]. We kept the population size fixed to its default value (100) and tested the above combinations for 200 simulation runs.

5.2 Step 2: generations number

The CPU time gradually rises with the number of generations. As expected, given that the algorithm runs through additional cycles to evolve a solution, more generations demand more processing power. For every 100 generations, the CPU time rises from 64.087 seconds to 74.770 seconds.

However, the standard deviation (SD) does not follow a strictly linear pattern. For instance, the standard deviation after 20 generations is 3.402, which is relatively high and shows large variations in CPU time across runs. However, the value of SD significantly drops to 1.159 when the number of generations rises to 30, indicating a more steady and reliable performance. After 40 and 50 generations, it rises once more while staying in a modest range.

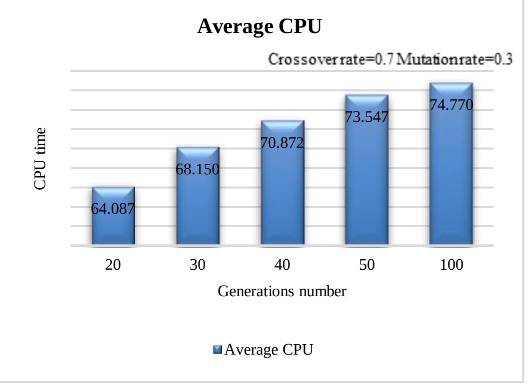

Figure 6 Generation number tuning

In summary, selecting a value with reduced variability, as indicated by a smaller standard deviation, is advantageous. This choice leads to computational performance that is more predictable and consistent, a crucial aspect in maintaining system reliability. Moreover, although running the algorithm with more generations takes longer, the results are more reliable, and the time required for each run is less variable. Hence, the selected number of generations is 30.

5.3 Step 3: population size

The findings show that computational efficiency is significantly affected by the population size. With values of 78.976 seconds and 78.939 seconds, respectively, the average CPU times are particularly close for population sizes 20 and 30. The average CPU time, however, noticeably rises to 87.957 seconds and 87.673 seconds, respectively, when the population reaches 40 and 50. This shows that larger populations have longer average calculation times because they use more processing resources.

https://doi.org/10.55343/CogSust.90

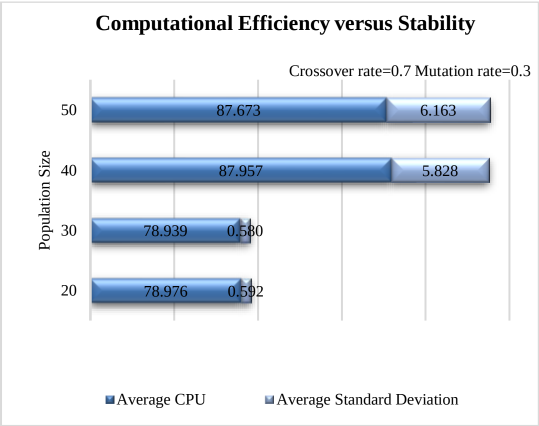

Figure 7 Population size tuning

Moreover, the standard deviations, 0.592 and 0.580 for population sizes 20 and 30, respectively, are very low, suggesting that the CPU time is largely constant and stable between runs. Nevertheless, the standard deviation significantly rises to 5.828 and 6.163, respectively, as the population grows to 40 and 50, respectively. This implies more variation in the computation time across various runs for larger populations.

In summary, the best option is to use a smaller population size (30), as it ensures stable and consistent performance, along with lower average CPU times and standard deviations. This approach reduces unnecessary computational burden, maximises resource efficiency, and lowers energy consumption. As a result, it reduces the carbon footprint associated with prolonged algorithmic processing (IBM Cloud Education, 2023). This result will be very useful, especially when dealing with more complex scenarios and processes that demand higher computational resources.

Table 5 Tuned GA parameters

Tuned Parameters			
Crossover Rate	**Mutation rate**	**Number of Generations**	**Population Size**
0.7	0.3	30	30

6 Comparison between MPC versus MPC-GA

6.1 Quantitative Assessment: RMSE Analysis and Computational Efficiency

Then, a final comparison between the two models using the best combination of GA parameters was done. Furthermore, Total time and root mean squared error (RMSE) were compared to evaluate the performance and efficiency. The total average RMSE over all cycles was calculated as follows:

$$\text{RMSE}=\frac{1}{n}\left[\sum_{i=1}^{n}(y_i-\hat{y})^2\right]^{\frac{1}{2}} \qquad (14)$$

https://doi.org/10.55343/CogSust.90

Table 6 MPC versus MPC-GA performance evaluation

	MPC	MPC-GA
Average elapsed CPU time (s)	89.21	62.71
Total average RMSE for a control method	0.65	0.32

Numerous simulation runs were conducted, and the results consistently showed that MPC-GA had lower RMSE than MPC and significantly reduced CPU processing time. MPC-GA performed better in percentage terms, with an RMSE roughly 50.76% lower (0.32 RMSE) than the MPC. These results confirm the superior performance of MPC-GA and show that it provides a more efficient solution, ultimately resulting in improved overall performance. Simultaneously, MPC-GA contributes to sustainability by adhering to sustainable computing principles outlined by Lannelongue et al. (2023) by reducing processing requirements for running algorithms, consequently minimising energy consumption and resource utilisation.

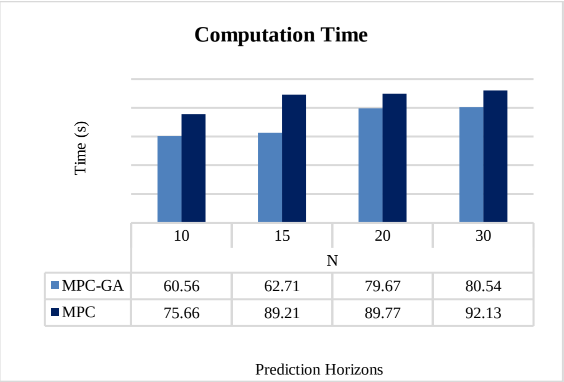

Figure 8 Computation time comparison between MPC and MPC-GA

Furthermore, we examined a comparison analysis between MPC versus MPC-GA, using different prediction horizons, to conduct a more thorough evaluation of the performance of the two models. The outcomes of this comparative assessment show that, regarding time efficiency, MPC-GA outperformed the traditional MPC strategy. When compared to pure MPC, MPC-GA showed much shorter execution times. The percentage improvements in CPU time were observed to be 20%, 29%, 11%, and 13% for prediction horizons of 10, 15, 20, and 30, respectively. This finding highlights how MPC-GA's superior optimisation capabilities can be used to boost overall operational effectiveness.

6.2 Simulation-based evaluation

The evaluation of the simulation results, which utilised Model Predictive Control enhanced with Genetic Algorithm (MPC-GA), reveals a promising outcome. Notably, during simulations involving pedestrian interactions, the autonomous vehicle demonstrated a significant capacity for ensuring safety.

https://doi.org/10.55343/CogSust.90

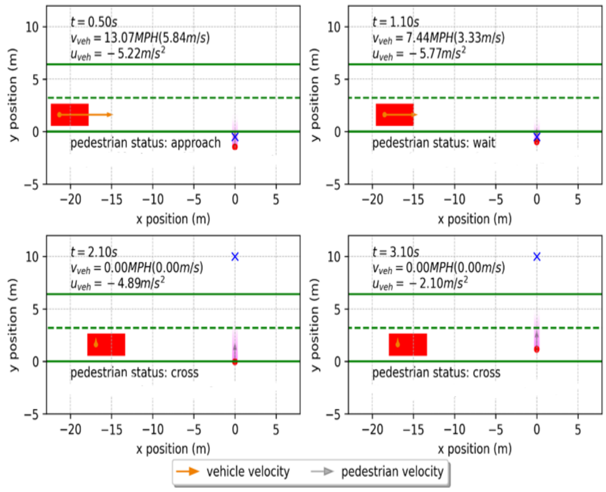

Figure 9 MPC-GA simulation result

When a pedestrian started a crossing, the vehicle promptly and effectively came to a complete stop ($\boldsymbol{V_{veh}} = \mathbf{0}$ m/s), showcasing the robustness of the MPC-GA system. These results underscore the potential of MPC-GA in real-world scenarios, illustrating its ability to prioritise safety and successfully manage interactions with pedestrians. This also demonstrated its robust safety measures, ensuring pedestrians' safety during vehicle interactions. Notably, the vehicle consistently stopped at a safe distance in front of the pedestrian, emphasising its safety commitment.

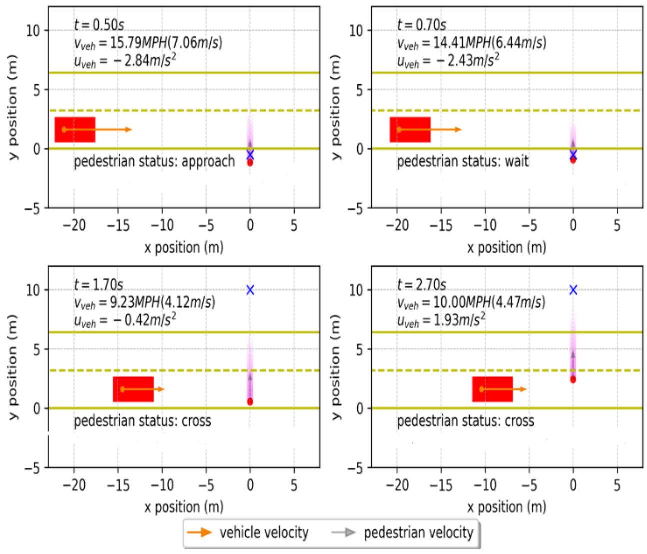

Figure 10 MPC-GA simulation result

We can see no collision between the AV and the pedestrian using MPC. Nevertheless, the AV failed to attempt to stop at a safe distance when the pedestrian was crossing the street. Rather, the AV decreases its speed from 14.41 MPH to 9.23 MPH. In addition, the AV accelerates once more as soon as the pedestrian crosses the driving lane.

6.3 Comparison of Control Actions and state evolution

It is crucial to highlight the significant disparity in control strategies between the two approaches, as shown in the figure below. The control actions employed by MPC-GA displayed notable fluctuations, signifying an ongoing optimisation process involving actively fine-tuning control instruction. This dynamic behaviour played a pivotal role in achieving the abrupt stop. On the other hand, the smoothness of the MPC control actions implied a more cautious and conservative

https://doi.org/10.55343/CogSust.90

approach, emphasising gradual speed reduction to enhance passenger comfort. Thus, the MPC-GA approach emphasised precision and safety, leading to a more sudden stop when required. Hence, our analysis reveals that the choice between MPC-GA and MPC involves a trade-off between speed smoothness and precision. While MPC offers a consistent and comfortable speed profile for passengers, MPC-GA demonstrates a more dynamic behaviour in speed control. The volatility in speed observed in the MPC-GA strategy directly results from the real-time optimisation process. It ensures that the vehicle can swiftly adapt to changing situations, such as pedestrians entering the crosswalk.

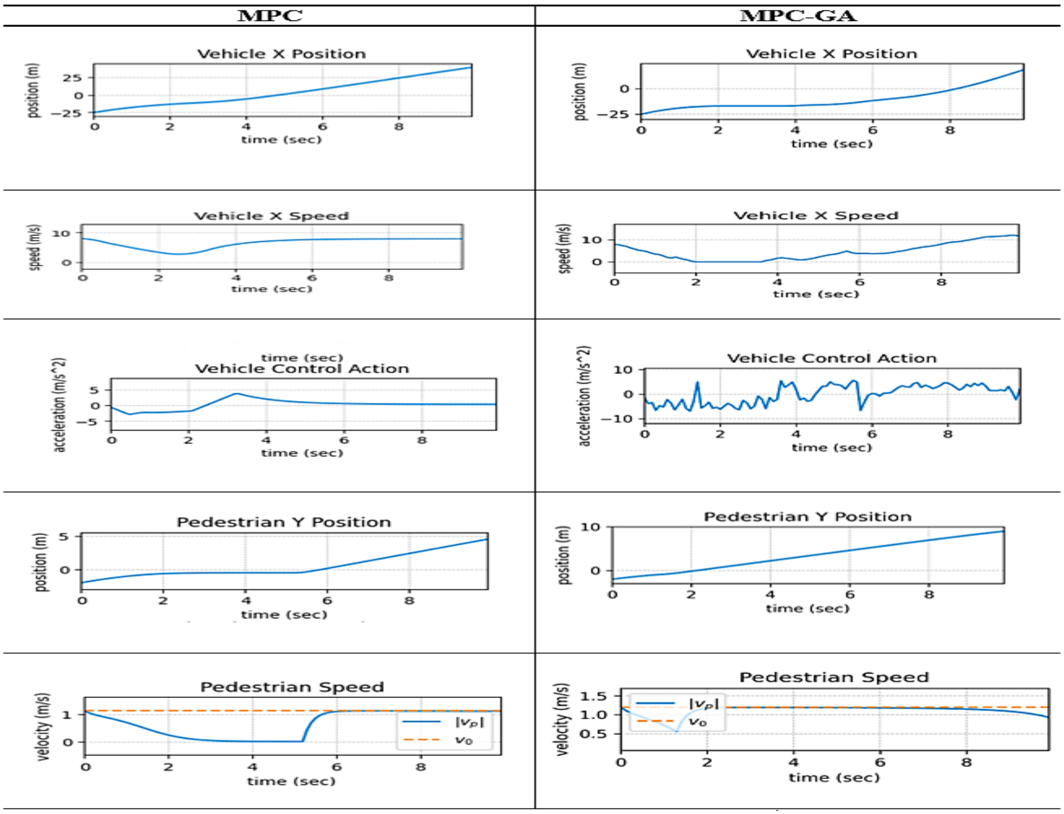

Figure 11 Graphical results comparison of MPC and MPC-GA results

7 Conclusion and future work

One of the most important steps toward sustainability, particularly in promoting sustainable mobility, is the integration of autonomous vehicles into transportation networks. In addition to transforming transportation, these cars can protect pedestrian safety at crosswalks. This paper's investigation is driven by an innovative emphasis on pedestrian safety and sustainability, two essential aspects of contemporary urban living. To achieve this overarching goal, the paper explores the effectiveness of MPC in ensuring pedestrian safety and investigates the potential of integrating GA to optimise MPC for more robust safety outcomes.

To assess pedestrian safety in this context, the SFM was employed, using Newton's second law to simulate pedestrian motion. The study then systematically evaluated the effectiveness and efficiency of both MPC and MPC-GA in ensuring pedestrian safety. MPC was used to model the behaviour of the autonomous vehicle and its interaction with the crossing pedestrian through acceleration and deceleration. Additionally, GA was utilised to optimise the process of solving MPC. Specifically, genetic evolution was used to find the optimal control input in each iteration. The findings underscored the substantial advantages MPC-GA offers, with slightly lower execution times signalling enhanced computational efficiency, which is particularly valuable in complex control systems. The lower running times required in each iteration would reduce the need for energy use and, ultimately, more sustainable computing.

Furthermore, MPC-GA consistently reduced computing times across various prediction horizons, emphasising the efficacy of GA optimisation. This approach also significantly improved predictive accuracy, achieving control objectives more efficiently. Regarding the comparison between simulations, MPC and MPC-GA resulted in safe interactions, with no recorded collisions. However, MPC-GA exhibited a superior interaction response, wherein the autonomous vehicle yielded to pedestrians and came to a full stop when required, underlining an exceptional level of safety. In the case of local emission-free drivetrain solutions like electric cars with increasing safety, it has an overall positive effect on sustainability.

However, the study was conducted and limited to a simulated environment, thereby leaving the influence of real-world factors like unpredictable pedestrian behaviour and varying environmental conditions unaddressed.

Additional research directions could involve investigating programming languages other than Python and evaluating their effects on computer performance, which would expand the study of sustainable computing techniques. Analysing the interactions between various language codes and algorithms may provide ways to maximise computing efficiency, aligning with sustainability objectives by reducing the amount of energy and resources used. Another improvement could be to test the scenario in a more complex road structure to investigate the robustness of MPC-GA to ensure pedestrian safety, which is crucial in sustainable mobility and contributes to smoother traffic flow.

References

Abdolahi, Y., Yousefi, S., Tavoosi, J. (2023). A New Self-Tuning Nonlinear Model Predictive Controller for Autonomous Vehicles. *Complexity*. January 2023:1-9 DOI: https://doi.org/mkpp

Ahmadpour, M. R., Ghadiri, H., Hajian, S. R. (2021). Model predictive control optimisation using the metaheuristic optimisation for blood pressure control. *IET Systems Biology*. 15(2), 41–52. DOI: https://doi.org/mkpq

Alharasees, O., Adali, O. H., Kale, U. (2023, June). Human Factors in the Age of Autonomous UAVs: Impact of Artificial Intelligence on Operator Performance and Safety. *2023 International Conference on Unmanned Aircraft Systems (ICUAS).* IEEE. 798–805 DOI: https://doi.org/mkpr

Arrigoni, S., Braghin, F., Cheli, F. (2022). MPC trajectory planner for autonomous driving solved by genetic algorithm technique. *Vehicle System Dynamics*. 60(12), 4118–4143. DOI: https://doi.org/mkps

Cao H., Zoldy, M. (2022). Implementing B-Spline Path Planning Method Based on Roundabout Geometry Elements. *IEEE Access*. 10. 81434–81446, 2022, DOI: https://doi.org/mkpt

Centers for Disease Control and Prevention. URL: https://www.cdc.gov/injury/features/global-road-safety/

Diamond, S., Boyd, S. (2016). CVXPY: A Python-embedded modeling language for convex optimisation. *Journal of Machine Learning Research*. 17(1), 2909–2913. DOI: https://doi.org/mkpv

Cao, H., and Zoldy, M. (2021). MPC tracking controller parameters impacts in roundabouts. *Mathematics*, 9(12), 1394. DOI: https://doi.org/jc52

Hegedüs, F., Bécsi, T., Aradi, S., Gápár, P. (2017). Model based trajectory planning for highly automated road vehicles. IFAC-PapersOnLine, 50(1), 6958–6964. DOI: https://doi.org/djzn

Helbing, D., Molnar, P. (1995). Social force model for pedestrian dynamics. *Physical Review E*. 51(5), 4282. DOI: https://doi.org/fn55b2

Henson, M. A. (1998). Nonlinear model predictive control: current status and future directions. *Computers & Chemical Engineering*, 23(2), 187–202. DOI: https://doi.org/d6k4cz

IBM Cloud Education (2023, January 9). Why Green Coding is a Powerful Catalyst for Sustainability Initiatives. *IBM*. URL: https://www.ibm.com/blog/green-coding/

Jayaraman, S. K., Robert, L. P., Yang, X. J., Pradhan, A. K., Tilbury, D. M. (2020, July). Efficient behavior-aware control of automated vehicles at crosswalks using minimal information pedestrian prediction model. *2020 American Control Conference (ACC)*. IEEE. 4362–4368 DOI: https://doi.org/mkpw

Kebbati, Y., Puig, V., Ait-Oufroukh, N., Vigneron, V., Ichalal, D. (2021, November). Optimised adaptive MPC for lateral control of autonomous vehicles. *2021 9th International Conference on Control, Mechatronics and Automation (ICCMA).* IEEE. 95–103. DOI: https://doi.org/mkpx

Kloth, M. (2018, March 29). Lower Speed Means Fewer Road Deaths. *International Transport Forum*. URL: https://www.itf-oecd.org/lower-speed-means-fewer-road-deaths

Lannelongue, L., Aronson, H. E. G., Bateman, A., Birney, E., Caplan, T., Juckes, M., ... Inouye, M. (2023). GREENER principles for environmentally sustainable computational science. *Nature Computational Science*. 3(6), 514–521. DOI: https://doi.org/mkpz

Law, A. (2020, November 1). Why Do Most Accidents Occur So Close to Our Homes? *AUGER & AUGER*. URL: https://www.augerlaw.com/blog/why-do-most-accidents-occur-so-close-to-our-homes /

Mohammadi, A., Asadi, H., Mohamed, S., Nelson, K., Nahavandi, S. (2018). Optimising model predictive control horizons using genetic algorithm for motion cueing algorithm. *Expert Systems with Applications*. 92, 73–81. DOI: https://doi.org/mkp2

Palmeiro, A. R., van der Kint, S., Vissers, L., Farah, H., de Winter, J. C., Hagenzieker, M. (2018). Interaction between pedestrians and automated vehicles: A Wizard of Oz experiment. *Transportation Research Part F: Traffic Psychology and Behaviour*. 58, 1005–1020. DOI: https://doi.org/gd6d8h

Pan, W., He, Q., Huang, Y., & Qin, L. (2023). Four-dimensional trajectory planning for urban air traffic vehicles based on improved RRT* algorithm. *IEEE Access*. January 2023 PP(99):1-1 DOI: https://doi.org/mkp3

Prédhumeau, M., Mancheva, L., Dugdale, J., Spalanzani, A. (2022). Agent-Based Modeling for Predicting Pedestrian Trajectories Around an Autonomous Vehicle. *Journal of Artificial Intelligence Research*. 73, 1385–1433. DOI: https://doi.org/mkp4

Ramasamy, V., Sidharthan, R. K., Kannan, R., Muralidharan, G. (2019). Optimal tuning of model predictive controller weights using genetic algorithm with interactive decision tree for industrial cement kiln process. *Processes*. 7(12), 938. DOI: https://doi.org/mkp5

Rashid, M. M., Seyedi, M., Jung, S. (2022). Simulation of Pedestrian Interaction with Autonomous Vehicles Via Social Force Model. Available at SSRN 4017139. DOI: https://doi.org/gpfkdh

Ren, G., Li, H. Y., Lu, L. L., Zhang, T. (2014). Modeling and Simulation for Pedestrian Crossing Based on a Modified Social Force Model. *CICTP 2014: Safe, Smart, and Sustainable Multimodal Transportation Systems*. 3194–3204. DOI: https://doi.org/mkp6

Son, R., Cho, J., Huh, K. (2017). Genetic Algorithm based Parameters Optimisation of Model Predictive Control in Lane Keeping. 한국자동차공학회 춘계학술대회. 333–335.

Torok, A., Pauer, G. (2022). *Cognitive Sustainability*, 1(3). DOI: https://doi.org/jswn

Vermuyten, E., Meert, P., Wolfs, V., & Willems, P. (2018). Combining model predictive control with a reduced genetic algorithm for real-time flood control. *Journal of Water Resources Planning and Management*, 144(2), 04017083 DOI: https://doi.org/mkp8

Yang, D., Özgüner, Ü. (2019). Combining Social Force Model with Model Predictive Control for Vehicle’s Longitudinal Speed Regulation in Pedestrian-Dense Scenarios. arXiv Safety aspects of critical scenario identification for autonomous transport. preprint arXiv:1907.05178.

Zeng, W., Chen, P., Nakamura, H., Iryo-Asano, M. (2014). Application of social force model to pedestrian behavior analysis at signalised crosswalk. *Transportation Research Part C: Emerging Technologies*. 40, 143–159. DOI: https://doi.org/gn2s9q

Zhou, R., Cui, Y., Wang, Y., & Jiang, J. (2021). A modified social force model with different categories of pedestrians for subway station evacuation. *Tunnelling and Underground Space Technology*, 110, 103837. DOI: https://doi.org/gq6ww7

Zöldy, M., Szalay, Z., Tihanyi, V. (2020). Challenges in homologation process of vehicles with artificial intelligence. Transport, 35(4), 447–453. DOI: https://doi.org/f9wq

Zöldy, M. (2023) The era of the cognitive mobility, FISITA - Tecnology and Mobility Conference Europe 2023.09.8.10 Barcelona, URL: https://www.researchgate.net/publication/377718172_The_era_of_the_cognitive_mobility/

https://doi.org/10.55343/CogSust.92

Sustainable transport – development and goals

Konrad Łuczyszyn
West Pomeranian University of Technology
Szczecin, Poland
tluczyszyn2wp.pl@wp.pl

Abstract

Sustainable development is observed worldwide, and one of the most affected fields is the transport sector. Sustainability brings challenges that must be overcome to achieve high safety and comfort and reduce greenhouse gas emissions. By the end of 2030, United Nations members must achieve the assumed sustainability level. This paper investigates whether it is possible to reduce CO_2 emissions completely, especially in the transport sector. The paper focuses on the challenges to obtaining a high sustainability level, as defined by the United Nations. The examples of sustainability in rail and road transport were analysed and described. Results show the benefits, concerns, and problems of the described solutions.

Keywords
Sustainable development, sustainable transport, environment, challenges,

1. Introduction

Nowadays, the dynamic development of transport services requires new solutions. Worldwide awareness has grown, and people have started caring for the planet. There are many ways of taking care, and different sectors require different levels of intervention. Sustainable development has become a priority for sparing the world from poverty, hunger, and pollution. Specifically, sustainable transport development addresses all modes of transportation.

The main goal of sustainable transport is to reduce the emission of greenhouse gases. The constant economic, social and environmental changes require new solutions and quick and accurate decision-making (*United Nations, 2023*).

It should be noted that the number of factors, random variables, and differences influence the pace of changes. This study shows how many challenges are faced during processes, how many factors impact the pace of change, and what benefits and threats are coming from scientific and technical work.

The paper focuses on whether there are any challenges to obtain a high sustainability level defined by the United Nations. What are the benefits, concerns, and problems of the described solutions? What could postpone the high-level sustainability? The second chapter describes the United Nations 2030 Agenda for Sustainable Development. The third chapter describes the role of artificial intelligence. The fourth chapter collects some state-of-the-art examples and case studies. The fifth chapter gives the conclusion.

2. Importance of the 2030 Agenda for Sustainable Development

During the New York summit, all United Nations member states signed the world-changing document, "2030 Agenda for Sustainable Development". The agenda consists of 17 main goals, which are meant to provide significant changes in people's lives and surroundings by using specific tools and taking actions to eliminate poverty, inequality, world instability and other harmful and fatal factors (*Rony et al., 2023*). The entire project is one of the most challenging endeavours in history due to the breadth of its assumptions. By signing the document, world leaders have determined a new route. Thus, it must be demonstrated that every country's government, society and international politics can cooperate and work effectively to fulfil the obligations outlined in the signed document. Also, this project was called a milestone in order to create a beneficial and better world. Since that day, the commitment to its goals has begun.

https://doi.org/10.55343/CogSust.92

2.1 Sustainable transport development

Transport is a specific sector of services area that includes all modes of transport. Road transportation, maritime transportation, air transportation, rail transportation, inland shipping, and pipeline transport are also available. If different modes of transport are combined, we speak about intermodal transportation. Goods in different states of matter (solid, liquid, fluid) are transported, and most can transport passengers (excluding pipelines). The main purposes of sustainable transportation are to reduce the emission of CO_2, to improve the infrastructure and to take care of the safety of goods and passengers (*Majerova, 2022*).

The European Union has expanded the idea of reducing emissions and created a long-term program that assumes that by 2050, the economy will become climate-neutral. Renewable resources must be used, and zero-emission levels must be reached to achieve this aim. It is envisioned that electricity is the future and that carbon dioxide pollution should disappear. Even if there is remaining CO_2, it will be captured, making air clearer (*Directorate-General for Climate Action, 2019*).

2.2. Challenges

Regarding transport sustainability and its development, it is important to emphasise that the most important factors are the economy, society and environment. The price tags, limits and cost standards should be set. Action that requires high initial costs of introducing and developing sustainable solutions has to be a barrier for companies, governments and people as customers. An analysis should be done to check whether the solution is cost-effective compared to its activity and influence. Sometimes, the traditional options are more attractive. Regions differ geographically, demographically and culturally, so the methods and operations must be standardised accordingly (*United Nations, 2023*).

Gathering all necessary regional data makes it possible to start planning the strategy and process. However, unforeseen circumstances and fluctuations may arise, and during the planning phase, it is imperative to consider accountability for unforeseen events. Since the regulations require achieving particular results during development, the efficiency level has to be maintained or improved if possible. The solutions which are part of the sustainable development process should not provide worse results than previous ones. This is one of the reasons why society is a part of projects as well. The balance between what is needed and what must be done must be maintained by finding optimal solutions (*United Nations, 2023*).

Since the Industrial Revolution, civilisation has been overloaded with pollution: gases, dust, and toxic fumes. First, engines were steam-powered, most households were heated with coal and wood, and coal-fired power stations were the main energy providers. The transport industry emits a high percentage of global CO2. Road transport is at the top of the list, producing approximately 74% of all pollution in this field. The challenge is to convince people to use urban transport and produce electricity-powered vehicles (*Mikušová, Torok, Brída, 2018*). Unfortunately, many people do not want to change their behaviour. They find urban transportation uncomfortable, crowded, and badly scheduled and resist changing their habits as long as the old ones work appropriately.

Complexity coming from approaching changes may be disadvantageous. Those responsible for development and implementation must be well-prepared, well-trained and flexible. Initially, the new knowledge may seem overwhelming, and unexpected situations undoubtedly arise, but accepting these challenges is the key to success. Complexity during the first stages may cause troubles, and challenges are not foreseen during the planning phase. Thus, every factor has to be analysed meticulously to avoid additional costs and delays.

In 2020, the COVID-19 pandemic caused global chaos. The transport sector was struck and partially paralysed by the pandemic. The new regulations and restrictions changed the capacity of urban transport. People started using their cars again to avoid possible infection. During this period, the number of people using urban transportation dropped. Funds and workforce shortages hindered research (Transformative Urban Mobility Initiative, 2020). The return from that point has still not been finished.

3. Artificial intelligence as a tool in the development of sustainable transport

As the popularity of artificial intelligence tools has grown, people have managed to introduce them to the transport industry. Road and rail transport benefit the most from applying A.I. tools. In rail transport, to achieve highly prioritised safety, efficiency, and improved operational abilities, artificial intelligence tools have created many solutions relevant to system activity, train bodies, and infrastructure (*Ficzere, 2023*).

https://doi.org/10.55343/CogSust.92

One of the most important changes introduced is the ability of the railway system to manage itself autonomously. This solution requires high-level reliability of the artificial intelligence module, which applies new programming to the train's control system. As a consequence, it increases safety levels and optimises operations and schedules. Optimisation of schedules ensures the most efficient way of employee allocation. A.I. also helps with adequate infrastructure network placement and creation. The infrastructure comprises platforms, rails, traffic lights, monitoring systems and sensors. Embedded nodes send information to each other about approaching trains, and the results are shown as changing traffic lights, but can also be shown as flickering diodes built in the platform or closing gates. It moderately enhances safety and security levels (*Zöldy et al., 2022*). The most important is that those nodes are working under real-time conditions, and delays or breakdowns might happen. Continuous work consumes the capacity and power of parts. It leads to reliability decreasing. Another benefit of A.I. introduction is the ability to predict potential breakdowns and failures in the system, so decreasing reliability will no longer be an issue.

3.1 Benefits and threats coming from artificial intelligence support

As mentioned, benefits are coming from introducing artificial intelligence in rail transport. Most of them relate to enhancing safety and security levels. These technologies can also strengthen decision-making and data analysis. The algorithms use stored data to find optimal solutions, discover patterns, and encounter possible problems and hazardous situations based on patterns. The systems can handle risk assessment and management, so they slightly increase the chances of avoiding problems and hazards in transportation.

However, there are potential threats to the application of A.I. The A.I. technologies are expensive nowadays (2024). Introducing a new AI-based system has to be cost-effective for authorities and companies. Also, the cybersecurity level of technology needs to be enhanced because cyberattacks are becoming more widespread (Ficzere, 2023). People will lose jobs due to highly automated systems, which can be disapproved or even lead to sudden unemployment rate growth. Privacy concerns represent ubiquitous problems. Data registered by sensors and surveillance systems must also be controlled legally and physically. Another problem is that the age of existing infrastructure and systems may make combining and integrating the new technologies with older ones difficult. In the following subchapters, the author collected one example from Budapest in the public transport sector, where A.I. plays an unquestionably important role:

3.2 Metro Line M4 Budapest

For example, the metro line M4 in Budapest provides autonomous service. This service has advantages and disadvantages (*Yang et al., 2023*).

- Less human interaction means less possibility of human mistakes.
- Surveillance system and sensors – real-time events are registered, and data are stored.
- Self-steering – there is no need for humans to control the train. The control system is under the influence of A.I. programs.
- Voice notifications – people are automatically informed about the schedule, next stops, and hazardous situations (crossing safety line on the platform).
- Increased capacity –trains can be more frequent.

Disadvantages of the autonomous metro service:

- Lower social acceptance, in Budapest there was a fake metro driver for a year
- Higher cost of maintenance due to the more sensors and more sophisticated trains,
- No job for people – there is no need to have a human driving train – the higher unemployment rate.

To sum up, based on this example, there are many more advantages than disadvantages. It is impossible to eliminate all disadvantages because the costs can be optimised but not completely eliminated. The disapproval of autonomous trains is also unavoidable. No workplace and lack of technological knowledge frustrate people. Power supplies are necessary to keep the train going, and blackouts happen due to natural failures of plants, natural disasters, and strong winds, which can stop electricity supply. The comfort and safety level during travel is high. There is enough space for hundreds of people; even during peak hours, wagons are not overcrowded, and the chance of derailment is very low.

https://doi.org/10.55343/CogSust.92

4. Examples of sustainability in different modes of transport

This chapter will analyse the two main environmental pollutant subsector of transport. Air transport is the most developing subsector, and road transport is the most significant air polluter.

4.1 Sustainability in air transport

According to statistics, air transport is one of the safest in the world. Between 2013 and 2022, there were 815 accidents, 70 of which were fatal (*ICAO, 2023*). This mode of transport is also one of the most environmentally friendly modes. It is responsible for the production of 2% of global CO_2 emissions. It is responsible for 12% of CO_2 emissions among the other modes. Almost 80% of emissions are caused by flights longer than 1500 km, so short flights generate approximately 20% of total emissions (*Jahanger et al., 2024*).

Despite being one of the most environment-friendly transport modes, even here, progress is constant, and a further reduction of CO_2 is aimed at. Current technologies have been under development, and we have outstanding results nowadays. Engines are powered by fuel made out of natural resources. In the USA in 2021, the first fully carbon dioxide-free flight was introduced.

Another resource that has become more significant recently as a fuel is hydrogen. Hydrogen is believed to be a long-term solution, but there are difficulties with the production of aircraft that can be hydrogen-fueled. Hydrogen in liquid form is stored at a negative temperature of -252°C due to its chemical and physical features. This is a challenge during design to create tanks big enough to transport and safe enough to store hydrogen in a liquid form. From the tanks, it is strictly directed to gas turbines, which power aircraft. The other way of using hydrogen is to send it to fuel cells, which convert it to electricity through a chemical reaction. The reaction produces only water vapour. No harmful gases are emitted.

4.2 Sustainability in Road Transport

Road transport is the most popular mode of transport, which is the reason behind high-level carbon dioxide emissions. Passenger cars accounted for 73% of total emissions 2022 (*Citaristi, 2022*). The dense transport networks, vehicle availability, and production costs make this mode the most popular. Traditional cars are powered by gasoline (naphtha) or gas (petrol), and due to the features and abilities of the engine, they produce CO_2 during combustion. A sustainable approach to road transport might focus on analysing current road networks and systems and determining and selecting the main factors considered in traffic, which could be traffic density, traffic flow, demand for mobility, and emissions.

Sustainability can be achieved by modification of transport networks and infrastructure. Examples of changes are traffic light management, the introduction of velocity limits, the modernisation of current networks and prohibitions relating to an absolute ban on vehicles in particular places. The last solution is used, for example, in Berlin, Germany. The diesel ban was introduced in 2019, and some streets in the city centre require stickers EURO 6. Vehicles powered by diesel can only meet EURO 5 standards, so if these vehicles enter restricted zones, drivers are penalised. Since 2018, five German cities decided to follow this trend, and few others have indicated an interest (*Letmathe and Suares, 2020*).

Sustainable transport development is not only about vehicles but also about network creation. During construction, the landscapes and huge areas change completely, and heavy machinery generates negative impacts. Decision-makers are responsible for finding optimal solutions. Simulations, modelling, and analysis are usually required to achieve optimal solutions. The entire process assumes that during the modelling phase, it is necessary to map the transport network, determine demand, determine and model traffic flow, measure emissions, identify relations in functionality between determined and measured factors, develop the mathematical method, and implement it. The last step is to simulate the process to determine whether the model will work (*Merkisz et al., 2013*).

The automotive industry has developed electric cars and hybrid vehicles powered by an electric motor. Hybrid vehicles do not give up on using internal combustion engines. They combine internal combustion engines and electric motors instead. Many cities have charging stations where people can charge their electric vehicles (*Fig. 1*). Research on new technologies considers current and upcoming regulations. Industries have started to produce cars made of eco-friendly materials from recycling or lightweight metals. Hydrogen cells power fuel cell vehicles and convert hydrogen into electricity (*Meelen and Schwanen, 2023*).

https://doi.org/10.55343/CogSust.92

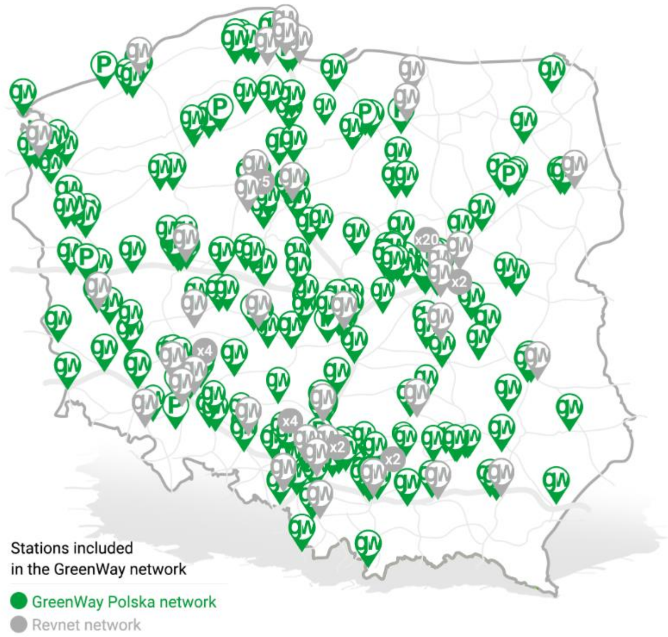

Figure 1. Map of charging stations in Poland
Source: GreenWay Polska (2022)

Unfortunately, the power of electric cars does not allow for long rides, and the charging process is relatively lengthy. Fueling a car with gasoline or petrol (or hydrogen in the future) means faster charging. Hybrid cars are a better option because you can travel much longer distances and change the source.

5. Conclusions

Sustainable transport development is a long-term process with many phases and challenges. Every mode of transport is under development in order to achieve sustainability. World awareness has grown in recent years, resulting in worldwide programs. People responsible for actions and activities take directives and clues into consideration but struggle with economic, social, and environmental challenges. The main task is harmonising every sphere, fulfilling expectations and plans, and finding optimal solutions. Cooperation between government, society and international politics is needed to achieve sustainable transport. Every mode of transportation uses different approaches, but the goal is to achieve climate-neutral transport. In order to reduce carbon emissions, renewable energy resources and gases like hydrogen are promoted to power road vehicles, aeroplanes, and trains. Two main documents were signed based on forecasts, and it was assumed that by 2030 and 2050, the world would fulfil them. However, no one predicted even harder challenges like the outbreak of COVID-19, which delayed the development of sustainable transport. Thus, fulfilling the program by the end of 2030 can be problematic.

References

Citaristi, I. (2022). International energy agency—iea. In The Europa directory of international organisations 2022 (pp. 701-702). Routledge. URL: https://iea.blob.core.windows.net/assets/3c8fa115-35c4-4474-b237-1b00424c8844/CO2Emissionsin2022.pdf

Directorate-General for Climate Action (European Commission) (2019). *Going climate-neutral by 2050*. URL: https://op.europa.eu/en/publication-detail/-/publication/92f6d5bc-76bc-11e9-9f05-01aa75ed71a1

Ficzere P. (2023). The role of artificial intelligence in the development of rail transport. *Cognitive Sustainability* 2(4). DOI: https://doi.org/mk6m

GreenWay Polska (2022): GreenWay acquires Rawicom EV and the Revnet network of 70 charging stations. *GreenWay.* URL: https://greenwaypolska.pl/en-PL/blog/media/greenway-acquires-rawicom-ev-and-the-revnet-network-of-70-charging-stations

ICAO (2023): Accident Statistics. *ICAO.* URL: https://www.icao.int/safety/iStars/Pages/Accident-Statistics.aspx

Jahanger, A., Ozturk, I., Onwe, J. C., Ogwu, S. O., Hossain, M. R., & Abdallah, A. A. (2024). Do pro-environmental interventions matter in restoring environmental sustainability? Unveiling the role of environmental tax, green innovation and air transport in G-7 nations. Gondwana Research, 127, 165-181. DOI: https://doi.org/mk6s

Letmathe, P., Suares, M. (2020). Understanding the impact that potential driving bans on conventional vehicles and the total cost of ownership have on electric vehicle choice in Germany. *Sustainable Futures* 2, 100018. DOI: https://doi.org/gnbwpx

Majerova J. (2022). Cognitive rationality and sustainable decision based on Maslow's theorem: A Case study in Slovakia. *Cognitive Sustainability* 1(1). DOI: https://doi.org/jf2k

Meelen, T., Schwanen, T. (2023). Organisations as users in sustainability transitions: Embedding Vehicle-to-Grid technology in the United Kingdom. *Energy Research & Social Science*, 106, 103303. DOI: https://doi.org/mk6n

Merkisz J., Merkisz-Guranowska A., Jacyna M., Kozak M., (2013) Development of sustainable road transport system. Urban Transport XIX. Wit press. URL: https://www.researchgate.net/publication/267758913_Development_of_sustainable_road_transport_system

Mikušová, M., Torok, A., & Brída, P. (2018). Technological and economical context of renewable and non-renewable energy in electric mobility in Slovakia and Hungary. In International Conference on Computational Collective Intelligence (pp. 429-436). Cham: Springer International Publishing. DOI: https://doi.org/mk6k

Rony, Z. I., Mofijur, M., Hasan, M. M., Rasul, M. G., Jahirul, M. I., Ahmed, S. F., ... & Show, P. L. (2023). Alternative fuels to reduce greenhouse gas emissions from marine transport and promote U.N. sustainable development goals. *Fuel* 338, 127220. DOI: https://doi.org/gr6vqn

Transformative Urban Mobility Initiative (2020): COVID-19 and Sustainable Mobility Observations and documentation of first developments. URL: https://www.transformative-mobility.org/wp-content/uploads/2023/03/2020_05_TUMI_COVID-19-and-Sustainable-Mobility-sMtB7P.pdf

United Nations (2023): Implementation of the Sustainable Development Goals in Poland. The 2023 National Report. URL: https://hlpf.un.org/sites/default/files/vnrs/2023/VNR%202023%20Poland%20Report.pdf

Yang, S., Wu, J., Sun, H., & Qu, Y. (2023). Trip planning for a mobility-as-a-service system: Integrating metros and shared autonomous vehicles. *Transportation Research Part E: Logistics and Transportation Review* 176, 103217. DOI: https://doi.org/mk6r

Zöldy M., Szalmáné Csete M., Kolozsi P., Bordás P, Török A. (2022). Cognitive sustainability. *Cognitive Sustainability* 1(1). DOI: https://doi.org/htfq

https://doi.org/10.55343/CogSust.96

Investigating energy management of hybrid vehicle technologies to promote sustainable mobility paradigms

Imre Zsombók
0000-0002-6073-1732
AK-S Ltd.
Budapest, Hungary
zsombok@ak-s.hu

Abstract

Analysing contemporary passenger cars' energy consumption and environmental impacts is a critical research area. This is particularly relevant in urban transport's dynamic and unpredictable environment, where vehicles' fuel consumption and emissions vary considerably. An in-depth understanding of such fluctuations is essential for innovative, efficient, environmentally friendly vehicle technology. In the present research, I investigated a 1.4-litre petrol hybrid vehicle, focusing on its energy supply chain under real-world urban driving conditions. The study focuses on policies that can promote the development of sustainable mobility, improve energy efficiency and reduce environmental pollution. The results can help to optimise hybrid vehicle technologies in an environmentally conscious way and explore possible new avenues for sustainable transport solutions.

Keywords

consumption, driver behaviour, hybrid vehicle efficiency, sustainable mobility

1. Introduction

Modern vehicle on-board diagnostic (OBD) systems provide a sufficient quantity and quality of data to accurately measure and monitor vehicle condition, fuel consumption and other key parameters. Extracting and analysing this data provides deeper insights into the vehicle's internal energy flows and the underlying reasons for their fluctuations. The use of CAN data for better understanding vehicle behaviour is a key element in increasing the cognitivity of mobility (Zöldy and Baranyi, 2023). Using the data collected via the OBD connector allows us to objectively assess vehicle performance and efficiency in different driving scenarios (Szabó M., 2022).

One of the main aims of this research was to explore the impact of driver behaviour on vehicle energy consumption. Driving style, such as acceleration, gear changes and braking habits, significantly influences vehicles' fuel consumption and emissions. Conducting measurements and analyses under real traffic conditions enabled a comparison of how these factors affect vehicle energy flow and overall performance.

The following section presents the research methodology, the data collection and analysis process, and a detailed analysis of the results. The aim is to provide a comprehensive picture of how we can influence the energy efficiency of vehicles by consciously modifying driving behaviour and how the data that can be extracted through OBD can help reduce the environmental footprint of vehicles.

In simple terms, to calculate the overall efficiency (η) of any given car, it is necessary to consider several factors that determine the overall efficiency of the vehicle's energy use. The calculation of the overall efficiency allows a comparison of the vehicle's energy consumption and the resulting work (1):

$$\eta = (\text{Output mechanical energy} / \text{Input energy}) * 100\%, \quad (1)$$

where 'Output mechanical energy' is the work or energy that the vehicle eventually converts into kinetic energy, and 'Input energy' is the total energy that the vehicle derives from fuel or electric battery. This formula helps us understand how efficiently the vehicle can convert energy into useful work, such as moving the vehicle (Hartlieb, 2009).

A vehicle's overall efficiency results from the interaction between vehicle characteristics and technology, the driver, the environment and the road. This means that in addition to the technical parameters of the vehicle, such

https://doi.org/10.55343/CogSust.96

as the efficiency of the engine and drivetrain, the driver's driving style (Török, 2011), environmental conditions, and the characteristics of the route (Meszaros, Torok, 2014). also play a significant role (Yeom, 2022), (Fig 1):

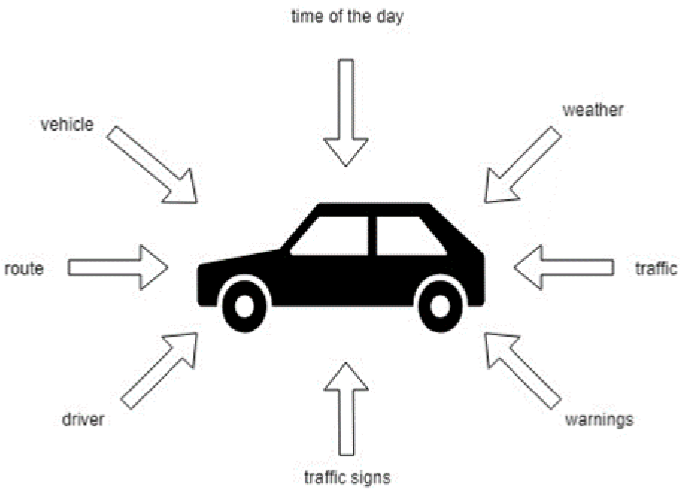

Fig. 1 External factors affecting consumption
Source: Zöldy, Zsombók 2019

These factors presented in Fig. 1 are analysed in more detail below. Vehicle characteristics and technology refer to the design and efficiency of vehicle components, including the engine, transmission, aerodynamics and tyre condition.

Driver: the driver's driving style, including acceleration and braking, can significantly impact fuel consumption and vehicle efficiency.

Environmental conditions such as temperature, wind, and road affect energy consumption.

Route: route characteristics, including hills, curves and traffic density, also affect the overall efficiency of the vehicle.

To conclude the effectiveness of performance-enhancing measures in the overall context of vehicles, it is necessary to consider a wide range of influencing factors due to their highly complex nature. In contrast to simulation studies (Tollner and Zöldy, 2023), where all parameters can be freely specified, real-world street conditions offer fewer variables that can be controlled and measured. Traffic, weather conditions, and traffic light behaviour can be measured and observed but cannot be controlled or held constant. However, it is precisely these factors that make street measurements particularly comparable to consumer driving habits, which simulation studies often ignore. Even though these tests occur in real-life conditions, they occur in an artificially created environment, i.e., within a measurement journey. Therefore, the conditions must be defined by an appropriate test design so that the data collected are representative of the test object (Zhang et al., 2023).

The parameters to be considered for a realistic test include the choice of vehicle, route and participants and the conditions under which the test is conducted. Given that this study aims to represent findings accurately, the study design is largely driven by European car traffic statistics. In the vehicle selection, the vehicle class, energy efficiency, powertrain and power-to-weight ratio had to be defined so that the selected vehicle corresponds to the representative data for European passenger cars as indicated in the paper (Table 1):

Table 1 Parameters of the tested vehicle

Vehicle class	middle category
Weight/power	0.069 kW/kg
Consumption (factory)	12.7 kWh/100 km
Drive chain	hybrid, DSG gearbox

Similar requirements apply to the route, which must correspond to the average car user's profile. Roads are divided into internal, external, highway and motorway sections. A mean distribution is defined for these road types

https://doi.org/10.55343/CogSust.96

based on vehicle use surveys on roads around Budapest. On this basis, a test track with all road types in the Budapest area was defined for the measurement (Fig 2):

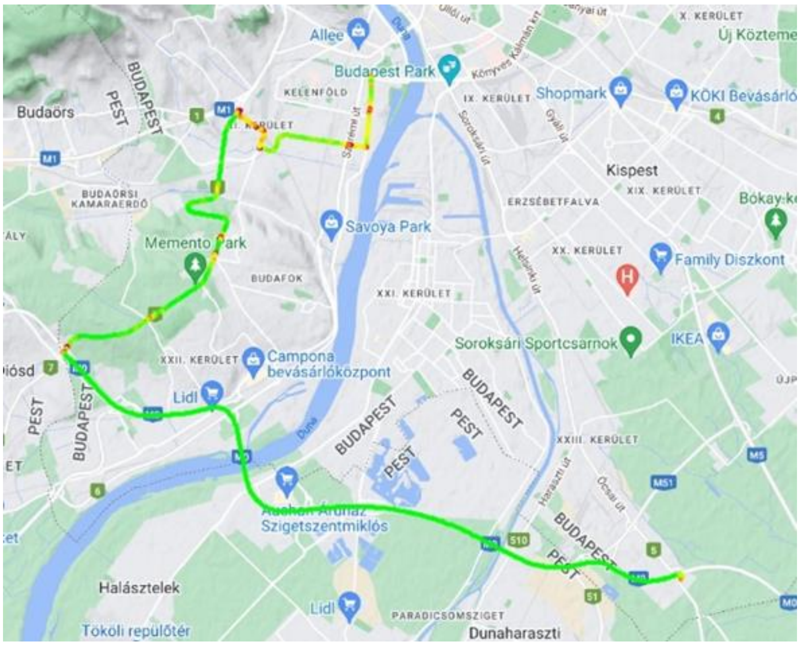

Fig. 2 The test route
Source: own edition

The third parameter is the size and nature of the group of participants. Here, it is important to balance the number of participants needed and the feasibility of the measurement trips to provide a good representation of European motorists based on the selected characteristics. These characteristics should be selected so that they can be determined before the participants are selected. A specific distribution can already be taken into account during the acquisition process. Age, gender, and annual management performance are used as characteristics by managers. These characteristics are divided into two or three categories. The representation of these characteristics for European car drivers is shown in Fig 3 and provides a guide for selecting test subjects (Zsombok and Zöldy, 2023):

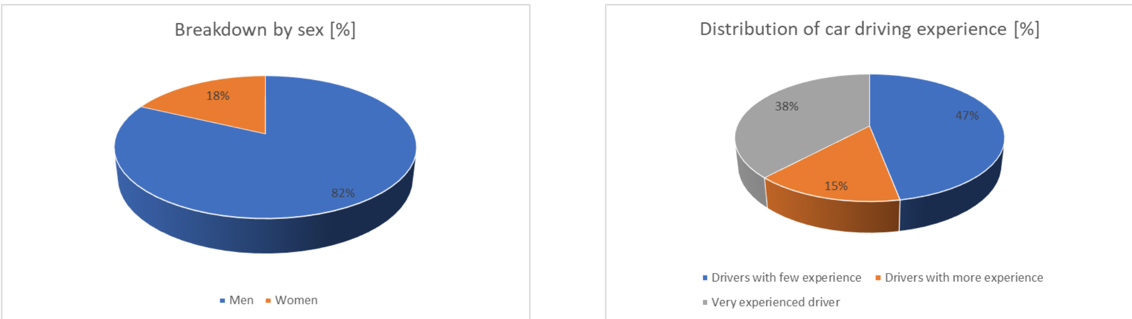

Fig. 3 Characteristics of test characteristics for European car drivers

The number of participants required is a function of the permutation of the characteristics, the precision required for the test, and the time needed to carry out the measurement paths. Permutation also allows for a representative distribution of characteristics when constructing subgroups. The required sample size is determined based on a prior assumption of the expected effect size under the hypothesis of a uniform distribution to achieve the desired precision (Bortz, 2005). The effort estimate is derived from the study design and depends mainly on the number of measurement runs that can be performed in one day. Other factors that influence the study's outcome are the effects of vehicle and participant habituation and conditioning and the variation in traffic according to the time of day. To minimise habituation effects, participants make two trips after the introduction. In addition, to ensure the

https://doi.org/10.55343/CogSust.96

same vehicle and traffic conditions for all participants, the measurement trips were always carried out at the same time of day after the vehicle had been preconditioned. The tests were carried out during the morning hours. The drivers were asked to drive according to their normal driving habits. Only the driver was sitting in the car during the measurements. All tests were repeated five times.

2. Power flow and resistance measurements in the participants' experiment

An HEV was used for the study, and data recording devices were used to record thermal, electrical, and mechanical power flows, resistances, vehicle position, and data from the vehicle environment and driver-vehicle interaction. All signals are recorded synchronously over time in two data acquisition systems. While measuring these data individually or on a test bench is standard practice, measurement trips in real traffic have specific requirements and conditions that must be considered. It is particularly important to process the different data synchronously (Li et al., 2024).

To minimise calculation errors in determining power flows, signals should be corrected to consider the sometimes significantly different transmission times. Since the repetition of measurement paths is practically impossible or only possible at a high additional cost, the risk of instrument outages should be minimised by using redundancies. Power flows were balanced for the whole vehicle, from fuel energy content to the power measured on the wheels. Fuel energy duration was determined using a measurement system for fuel volume variation and temperature measurements (Duhr et al., 2021).

The energy conversion heat losses of the internal combustion engine were derived from data measured at the temperature measurement points of the cooling system and the exhaust system. The energy required to operate the auxiliaries was determined from the torque data of the respective consumers. Here, in addition to the power data on the pulley on the main shaft, the air conditioning compressor shaft and the steering servo pulley, it was impossible to measure the alternator torque directly due to installation constraints. The power consumption was therefore determined by comparing the power required to operate the pulley on the crankshaft, the air conditioning compressor, the power steering pump and the engine auxiliaries. In the electrical on-board network, the electrical output power of the relevant consumers, the battery, and the alternator were determined by point current and voltage measurements (Fig. 4):

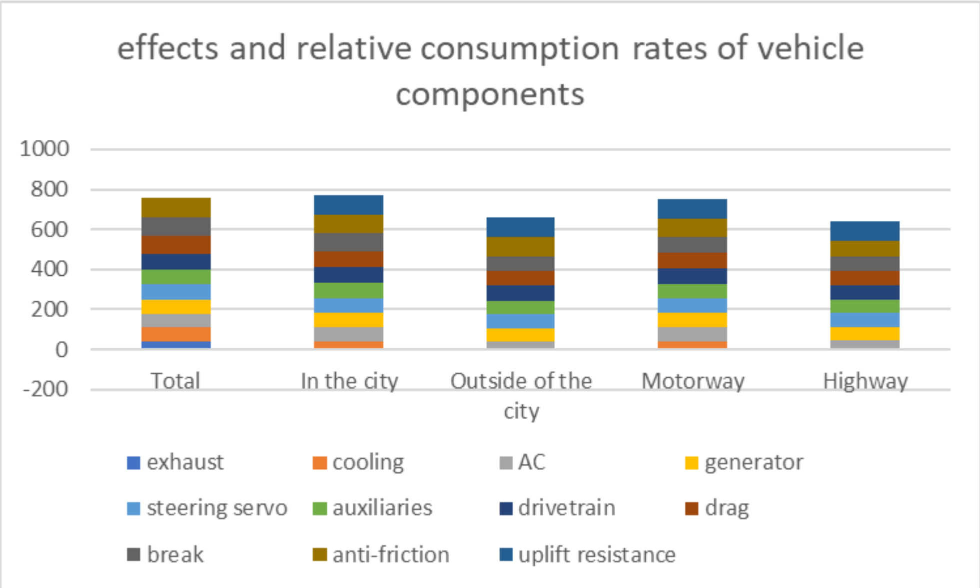

Fig. 4 Relative consumption distributions of each component and countermeasure

https://doi.org/10.55343/CogSust.96

$$P_{\text{fuel}} + (P_{\text{mode}}) = P_{\text{effective}} + P_{\text{cooler}} + P_{\text{exhaust}} + P_{\text{aux}} + P_{\text{steering control}} + P_{\text{Drive chain loss}}, \quad (2)$$

where:

- P_{fuel} – Fuel power: the power provided by the fuel.
- P_{mode} – Operating power: the power added by the air.
- $P_{\text{effective}}$ – Effective power: the effective power of the engine.
- P_{cooler} – Cooling capacity: the power dissipated by the cooling system.
- P_{exhaust} – Exhaust power: the power carried by the exhaust gases.
- P_{aux} – Ancillary equipment power: the power consumed by the ancillary equipment.
- $P_{\text{steering control}}$ – Servo losses: losses of the servo pump.
- $P_{\text{Drive chain loss}}$ – Drivetrain losses: losses in the transmission system.

The significant driving resistances and power loss during braking are quantified according to the equation. The rising values are compared to the measured power of the car on the axle. The air pressure was corrected for the measured outside temperature and ambient pressure to determine the drag. The road slope was calculated by integrating the vehicle's roll rate with the body roll angle, measured and corrected using a laser inclinometer. Rolling and acceleration resistance were derived from the vehicle's brake pad parameters and measured driving dynamics data. The skid resistance was determined from the wheel slip and torque combination measured at the wheel hubs. Brake energy was determined by measuring brake torques and wheel speeds.

$$P_{\text{wheel}} = P_{\text{air resistance}} + P_{\text{rolling resistance}} + P_{\text{pitching resistance}} + P_{\text{sliding resistance}}, \quad (3)$$

3. Power flows and consumption fluctuations under real traffic conditions.

The research was conducted between September and October 2023, with 12 participants. The study analysed energy losses during car use and distribution along different road sections. The average values of the consumption shares from vehicle components and driving resistances were calculated based on the distance travelled by the participants on each road. The results reflect the average values of typical driving behaviour under the test conditions.

The findings reveal that 33% of energy is lost across all road types, 8% is lost due to the operation of auxiliary equipment, and 2% is lost due to mechanical friction in the drivetrain. Of the 23% of energy remaining at the wheel, 6.5% is distributed to rolling resistance, 8% to drag and 8.5% to losses during braking. Of the auxiliaries, 2% is consumed by the air conditioning compressor, 2% by the power steering servo and 2% by the alternator. In the vehicle's electrical system, the biggest energy consumers are the air-conditioning fan (0.2%) and the cooling fan (0.1%), while the other electrical devices together account for 1% of the energy consumption.

Variations in consumption rates can be observed on each road section. Particularly high rates of braking losses are observed in urban and peri-urban areas. In urban areas, this is due to the high frequency of braking, while in peri-urban areas, it is due to the high kinetic energy, which is reduced by braking at the beginning of settlements and intersections. In addition, road sections outside urban areas tend to be more sloping overall, leading to a negative sign of slope resistance. The drag shows a characteristic behaviour depending on speed, leading to increasing consumption values on road sections with higher average speeds. The auxiliaries have lower energy consumption on such road sections, resulting from the almost constant energy demand of the equipment and the increasing total energy demand depending on the road section speed. A comparison of the different road sections shows that 17% more fuel is used in urban areas, 6% less in peri-urban areas, and 4% less on motorways. The relative variations in consumption between participants are shown in Figure 6.

For all road sections, the relative fuel consumption ranges from 33% overall, with a deviation of +/-6.5%. The variation varies according to the type of road, with the largest variation of +/-10.2% in the extra-urban areas, with a range of 55%, and the smallest variation on the national roads. The fluctuations show an asymmetric distribution towards higher consumption regardless of the road type. This can be explained by the fact that consumption can theoretically be increased indefinitely while there is a lower limit to the minimum consumption. The energy-loss

https://doi.org/10.55343/CogSust.96

group presents relative consumption fluctuations. The “Energy conversion” group includes losses that occur during the conversion of the chemical energy of the fuel into mechanical energy, including exhaust gas and cooling losses, as well as the energy demand of auxiliary power equipment. This group shows the largest variance of all the road sections studied (Fig. 5):

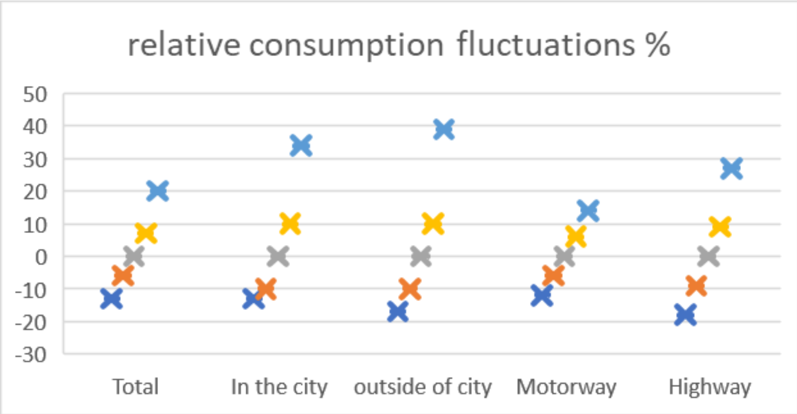

Fig. 5 Relative consumption differences by route type, test series are marked with different colours
Source: own measurement

Resource losses correlate with the amount of fuel consumed, reflected in the fluctuations. In contrast to the low variability in driveline and transmission losses, high variability in braking losses is observed between participants, especially on extra-urban and motorway sections. For losses due to comfort and safety (auxiliaries and on-board network), the effect of reduced energy consumption of auxiliaries on higher speed road sections is again observed, which also affects the consumption variations. The fluctuations due to passing resistances are low and are dominated mainly by the speed-dependent effect of air resistance, leading to higher fluctuations when the speed range on the road type is wider.

4. Summary and outlook

In a series of measurements, average values for European passenger car traffic were determined to examine the distribution of losses in real-world use of an actual conventional vehicle.

In addition, the average values of the consumption variations between different drivers on the same route were also determined. The distribution of losses shows that an average vehicle's “tank to wheel” efficiency is around 23% over average wear and tear. The influence of drivers on average consumption is +/-6.5%, with a maximum variance of 33%. These variations depend on driving style and variations in consumption effects from braking.

The dispersion of consumption values can be considered conservative. The value of the inter-participant variation in fuel consumption indicates the range of theoretically achievable values for the average driver’s consumption-optimised driving style.

Further studies have tested the usefulness of exploiting such potentials using driver assistance functions. For this purpose, driving data collections from real-world measurement trips can be used as input for a simulation in which different consumption optimisation functions are implemented, and the effects of the functions can be inferred by comparing them with the original driving data. In addition to the consumption-saving potentials, the time demand and the constraints on individual driving styles resulting from the intervention of different assistance functions can be evaluated.

https://doi.org/10.55343/CogSust.96

References

Bortz, J. (2005). *Statistik Human Sozialwissenschaftler* 6th edition. Springer Verlag, Berlin.

Duhr, P., Christodoulou, G., Balerna, C., Salazar, M., Cerofolini, A., Onder, C. H. (2021). Time-optimal gearshift and energy management strategies for a hybrid electric race car. *Applied Energy*. 282, Part A. 115980. DOI: https://doi.org/mpk6

Hartlieb, S (2009).: Untersuchung von Fahrversuchsdaten auf demographisch signifikante Merkmale zur Identifikation von Fahrern und Situationen, Studienarbeit am Institut für Verbrennungsmotoren und Kraftfahrwesen, Universität Stuttgart, November 2009

Li, C., Xu, X., Zhu, H., Gan, J., Chen, Z., Tang, X. (2024). Research on car-following control and energy management strategy of hybrid electric vehicles in connected scene. Energy. 293, 130586. DOI: https://doi.org/mpk7

Meszaros, F., & Torok, A. (2014). Theoretical investigation of emission and delay based intersection controlling and synchronising in Budapest. Periodica Polytechnica Transportation Engineering, 42(1), 37-42. DOI: https://doi.org/mpk8

Tollner D., Zöldy M. (2023). Dynamic Data extraction from vehicles through OBD connector. *2023 IEEE 2nd International Conference on Cognitive Mobility (CogMob)*. 189–194.

Török, Á. (2011). Investigation of road environment effects on choice of urban and interurban driving speed. International Journal for Traffic and Transport Engineering, 1(1), 1-9.

Yeom, K. (2022). Learning model predictive control for efficient energy management of electric vehicles under car following and road slopes. *Energy Reports*. 8, Supplement 15. 599–596. DOI: https://doi.org/mpk9

Zhang, H., Peng, J., Dong, H., Tan, H., Ding, F. (2023). Hierarchical reinforcement learning based energy management strategy of plug-in hybrid electric vehicle for ecological car-following process. *Applied Energy*. 333, 120599. DOI: https://doi.org/gr9gch

Zöldy, M., Baranyi, P. (2023). Definition, Background and Research Perspectives Behind The Cognitive Mobility Concept. *Infocommunications Journal*, Special Issue: Internet of Digital & Cognitive realities. 35–40. DOI: https://doi.org/j4pc

Zöldy, M., Zsombók, I. (2019). Influence of external environmental factors on range estimation of autonomous hybrid vehicles. *System Safety: Human-Technical Facility-Environment*, 1(1), 472-480. DOI: https://doi.org/mpmb

Zsombok I. (2021) Járművek fogyasztása és hatótáv becslő rendszerei , OGÉT 2021.04.18. URL: https://ojs.emt.ro/oget/article/view/453

Zsombok, I., Zöldy, M.(2023). Modelling, Simulation and Validation of Hybrid Vehicle Fuel Consumption. *Acta Polytechnica Hungarica*. 20(5). 61–74. DOI: https://doi.org/kv2x

https://doi.org/10.55343/CogSust.94

Reporting on Sustainability

Stephan Kühnel
HTW Dresden
Dresden, Germany
stephan.kuehnel@htw-dresden.de

Abstract

This paper presents the development and an overview of two related professional standards on sustainability reporting. As there is currently no requirement to apply these standards, 'this topic is out of the scope of the present discussion. Corporate reports applying the standards are expected for periods beginning or after 1 January 2024. From a methodological perspective, the paper relies on the due process of the standard setter for developing the standards and analyses of selected contributions. Implications for application and further development are highlighted.

Keywords

Sustainability, IFRS S2

1. Introduction

This paper addresses the development of international reporting standards on sustainability. The focus will be on IFRS (International Financial Reporting Standards Foundation) Sustainability Disclosure standards, which have been published in June 2023 (https://www.ifrs.org/issued-standards/ifrs-sustainability-standards-navigator/ (content as of 13 September, 2023). Currently, this reporting is non-mandatory for companies (For example, a study conducted in the USA reported a general lack of knowledge on one or more reporting framework(s) and related working experience with practising accountants (*Bakarich et al., 2023*). As there are two standards, *IFRS S1: General Requirements for Disclosure of Sustainability-related Financial Information* and *IFRS S2: Climate-related Disclosures*, their relationship shall be discussed first. The standard setter ISSB attempts to issue a series of sustainability-related standards. IFRS S1 is used as a methodological umbrella that contains general material applicable to all types of sustainability disclosures. IFRS S2 is more specific and focuses on climate-related disclosures only. Put differently, IFRS S1 may be directly applied to topics other than climate-related disclosures without further guidance.

Consequently, there is a certain overlap between the two standards for climate-related disclosures. This paper focuses on IFRS S2. The ISSB had issued the respective exposure drafts of IFRS S1 (Further information on the project is available at https://www.ifrs.org/projects/work-plan/general-sustainability-related-disclosures/ (content as of 7 March 2023) and IFRS S2 (Further information on the project is available at https://www.ifrs.org/projects/work-plan/climate-related-disclosures/ (contents as of 7 March 2023) in 2022.

The objective was to develop standards that provide a comprehensive global baseline of high-quality sustainability-related disclosures to meet users' information needs of general-purpose financial reporting (Exposure Draft IFRS S2.BC15). Please note that References related to a standard are structured as follows: "IFRS S1" is the name of the standard. The sections of a standard are numbered, i.e. IFRS S1.25 is section 25 of IFRS S1. Appendices are used with capital letters, e.g. "IFRS S1.B" is appendix B of IFRS S1. "BC" stands for the basis of conclusions. This is a significant initiative, as the ISSB puts **financial implications** at the heart of its efforts.

2. IFRS S1

IFRS S1 focuses on sustainability-related risks and opportunities of a reporting entity (IFRS S1.1). The approach starts from the perspective of primary users of annual reports and seeks to provide additional information, i.e., for estimating the related risks and opportunities of these users' investment decisions. Correspondingly, the reporting entity shall be the same as the general purpose financial statements (IFRS S1.20, B38). The document covers disclosures on the following topics (IFRS S1.25):

a) ***Governance** processes, controls and procedures that a reporting entity uses to monitor and manage risks and opportunities related to sustainability* Disclosures on governance shall cover the identity of the body or individual responsible for sustainability-related risks and opportunities, policies or comparable documents (IFRS S1.26(a)(i)), skills and competencies for oversight (IFRS S1.26(a)(ii)), frequency of internal reporting, methodology for assessing sustainability-related risks and opportunities (IFRS S1.26(a)(iii)), related targets and a description of management's role (IFRS S1.26(a)(iv)).
b) *Sustainability **strategy**, i.e. the chosen approach for addressing these risks and opportunities (IFRS S1.28)* There is no specified time horizon, so disclosures shall cover a short-, medium- and long-term perspective and consider the reporting entity's planning horizon (IFRS S1.29(d)). Disclosures on strategy include a description of risks and opportunities (IFRS S1.29(a)), effects on the business model and the value chain of the reporting entity (IFRS S1.29(b)), effects on strategy and decision-making (IFRS S1.29(c)), financial implications and the stability or resilience of the strategy vis-a-vis significant sustainability-related risks (IFRS S1.29(e)). They cover

https://doi.org/10.55343/CogSust.94

the impact of sustainability-related risks and opportunities on the reporting entity's business model, strategy, and cash flows (*IFRS S1.34*); qualitative or quantitative data may be used for this purpose (*IFRS S1.41*).

c) ***Risk management** processes that the reporting entity applies to identify, assess, and manage sustainability-related risks* Disclosures on the risk management cover identified risks and opportunities, their time horizons and an explanation of how the time horizons relate to the entity's strategic planning horizons (IFRS S1.30(a)-.30(c))

***Metrics and targets**, i.e. information to track the performance of the reporting entity concerning sustainability-related risks and opportunities (IFRS S1.45).* The reporting entity discloses the definition of the metric, a validation by an external body (if applicable) and an explanation of the method to calculate targets and inputs, including significant assumptions and limitations of the method (IFRS S1.50(a)-.50(d)).

The presentation shall follow the **fair presentation** principle, i.e. disclose information that is relevant, representationally faithful, comparable, verifiable, timely and understandable (IFRS S1.11, .15(a)). Furthermore, additional disclosures may be required (*IFRS S1.15(b)*). Another aspect is materiality. Information is considered relevant or material if omitting, misstating or obscuring it would be expected to influence the decisions of the primary users of general-purpose financial reporting (*IFRS S1.18*), (*Turner et al., 2023*).

3. IFRS S2

IFRS S2 focuses on climate-related disclosures. Its objective is to provide information about the reporting entity's exposure to climate-related risks and opportunities, its effect on the entity's cash flows, and its access to finance or cost of capital over the short, medium, or long-term (IFRS S2.2).

Figure 1: Structure of IFRS 2, based on IFRS 2.5–37
Source: Compiled by the author

The core aim of the draft is to enable disclosures on the following topics:

a) ***Governance***
b) Disclosures shall allow the primary users of the reporting to understand the governance processes, controls and procedures used to monitor and manage climate-related risks and opportunities (*IFRS S2.5*). They cover the identity of the body or individual responsible for sustainability-related risks and opportunities, policies and comparable documents, skills and competencies for oversight, frequency of internal reporting, methodology for assessing sustainability-related risks and opportunities, related targets and a description of management's role (*IFRS S2.6*). As the requirements are similar to those of IFRS S1, duplication of information should be avoided. The requirements in this regard have been closely aligned by the standard setter on purpose.
c) ***Strategy** and decision-making*

https://doi.org/10.55343/CogSust.94

The reporting entity discloses information about significant climate-related risks and opportunities that are expected to affect its prospects (*IFRS S2.9(a)*). There is no specified time horizon, so disclosures shall cover a short-, medium- and long-term perspective (*IFRS S2.10(d)*).

i. **Risks and Opportunities**
Disclosures cover climate-related risks and opportunities and their effects on the reporting entity's strategy and decision-making (*IFRS S2.10, 14*).

ii. **Impact** on statement of financial position, financial performance and cash flows
Information on the impact of risks and opportunities on the financials of the reporting entity is to be provided; this covers current and committed investment plans as well as funding sources (*IFRS S2.8(d)*).

iii. **Climate Resilience**
Information on the ability of the reporting entity's flexibility in adapting to significant shall be presented (*IFRS S2.8(e), and 22(a)(iii)*). The presentation may be based on a scenario analysis (*IFRS S2.22*).

d) ***Risk Management***
The objective is a description of the process/processes by which climate-related risks and opportunities are identified, assessed, prioritized, and managed (*IFRS S2.24*). Disclosures cover the identification of risks and opportunities, the method of prioritization, input parameters and any changes since the last reporting (*IFRS S2.25*).

e) ***Metrics and Targets***
Disclosures are intended to demonstrate how the reporting entity assesses its performance, including progress towards its targets. Information covered is **cross-industry** (e.g. greenhouse gas emissions with related risks and opportunities, investments, impact on management compensation - *IFRS S2.28(a)*. Cross-industry disclosures enable comparison of aspects of climate-related risks and opportunities—or their implications for financial position, financial performance and future cash flows—applicable to assessing enterprise value for entities, typically regardless of their industry, business model or economic activities. (*IFRS S2.BC75–BC78*) as well as **industry-specific** (*IFRS S2.28(b)*).
Furthermore, other metrics used by the **board** or management to measure progress towards the targets, plus the **definition of the targets (***IFRS S2.28(c)*) are to be disclosed. Two examples of industry-specific metrics shall be presented. Information is based on Appendix B of the standard. The first example is the appliance manufacturing industry, which is defined as companies designing and manufacturing household appliances and hand tools.

Metrics and Targets include **greenhouse gas emissions,** per Draft IFRS S2. A they encompass carbon dioxide (CO_2), methane (CH_4); nitrous oxide (N_2O); hydrofluorocarbons (HFCs); nitrogen trifluoride (NF_3); perfluorocarbons (PFCs); and sulphur hexafluoride (SF_6). There are three levels of analysis, which are all covered by the new standard (cf. Exposure Draft IFRS S2.A):

- Scope 1 emissions are **direct** greenhouse gas emissions that occur from sources that are owned or controlled by an entity. For example, emissions from combustion in owned or controlled boilers, furnaces, vehicles, or emissions from chemical production in owned or controlled process equipment are covered.
- Scope 2 emissions **are indirect greenhouse gas emissions from generating electricity purchased, heat,** or steam an entity consumes. Purchased electricity is defined as electricity that is purchased or otherwise brought into an entity's boundary. Scope 2 emissions physically occur at the facility where electricity is generated.
- Scope 3 emissions are indirect emissions outside of Scope 2 emissions that occur **in the value chain** of the reporting entity, including **both upstream and downstream** (Please note that upstream and downstream emissions are those that happen before and after the emissions of the reporting entity, e.g. by suppliers and by customers) emissions. They include:

(1) purchased goods and services;
(2) capital goods;
(3) fuel- and energy-related activities not included in Scope 1 emissions or Scope 2 emissions;
(4) upstream transportation and distribution;
(5) waste generated in operations;
(6) business travel;
(7) employee commuting;
(8) upstream leased assets;
(9) downstream transportation and distribution;
(10) processing of sold products;
(11) use of sold products;
(12) end-of-life treatment of sold products;
(13) downstream leased assets;
(14) franchises; and
(15) investments

https://doi.org/10.55343/CogSust.94

Scope 3 emissions could include the extraction and production of purchased materials and fuels, transport-related activities in vehicles not owned or controlled by the reporting entity, electricity-related activity (transmission and distribution losses), outsourced activities, and waste disposal.

Table 1: Industry-Specific Metrics per IFRS S2 for Appliance Manufacturing

TOPIC	METRIC	CATEGORY	UNIT OF MEASURE	CODE
Product Lifecycle Environmental Impacts	Percentage of eligible products by revenue certified to an energy efficiency certification	Quantitative	Percentage (%) by revenue	CG-AM-410a.1
	Percentage of eligible products by revenue certified to an environmental product lifecycle standard	Quantitative	Percentage (%) by revenue	CG-AM-410a.2
	Description of efforts to manage products' end-of-life impacts	Discussion and Analysis	n/a	CG-AM-410a.3

ACTIVITY METRIC	CATEGORY	UNIT OF MEASURE	CODE
Annual production [2]	Quantitative	Number of units	CG-AM-000.A

Source: https://www.ifrs.org/content/dam/ifrs/publications/pdf-standards-issb/english/2023/issued/part-b/ifrs-s2-ibg-volume-2-appliance-manufacturing-part-b.pdf (version as of June 2023)

The second example is the Food Retailers and distributors industry. It comprises companies engaged in wholesale and retail sales of food, beverage, and agricultural products.

Table 2: Industry-Specific Metrics per IFRS S2 for Food Retailers & Distributors

Topic	Metric	Category	Unit of Measure	Code
Fleet Fuel Management	Fleet fuel consumed, percentage renewable	Quantitative	Gigajoules (GJ), Percentage (%)	FB-FR-110a.1
Air Emissions from Refrigeration	Gross global Scope 1 emissions from refrigerants	Quantitative	Metric tons (t) CO_2-e	FB-FR-110b.1
	Percentage of refrigerants consumed with zero ozone-depleting potential	Quantitative	Percentage (%) by weight	FB-FR-110b.2
	Average refrigerant emissions rate	Quantitative	Percentage (%)	FB-FR-110b.3
Energy Management	(1) Operational energy consumed, (2) percentage grid electricity and (3) percentage renewable	Quantitative	Gigajoules (GJ), Percentage (%)	FB-FR-130a.1
Management of Environmental & Social Impacts in the Supply Chain	Revenue from products third-party certified to environmental or social sustainability sourcing standards	Quantitative	Presentation currency	FB-FR-430a.1
	Discussion of strategy to manage environmental and social risks within the supply chain, including animal welfare	Discussion and Analysis	n/a	FB-FR-430a.3
	Discussion of strategies to reduce the environmental impact of packaging	Discussion and Analysis	n/a	FB-FR-430a.4

Activity Metric	Category	Unit of Measure	Code
Number of (1) retail locations and (2) distribution centres	Quantitative	Number	FB-FR-000.A
Total area of (1) retail space and (2) distribution centres	Quantitative	Square metres (m^2)	FB-FR-000.B
Number of vehicles in commercial fleet	Quantitative	Number	FB-FR-000.C
Tonne-kilometres travelled	Quantitative	Tonne-kilometres	FB-FR-000.D

Source: https://www.ifrs.org/content/dam/ifrs/publications/pdf-standards-issb/english/2023/issued/part-b/ifrs-s2-ibg-volume-22-food-retailers-and-distributors-part-b.pdf (version as of June 2023)

https://doi.org/10.55343/CogSust.94

4. Reaction of Constituents to the Exposure Draft and Consequences for the Issued Standards

Reactions to the Exposure Drafts generally indicated support for the objective. However, some issues have been raised. Based on selected responses published, the areas of concern are highlighted:

- The proposed disclosure requirements in the Exposure Drafts are **extensive** and represent more than what is currently regarded as a minimum set of disclosures based on current market practices and capabilities. (*CPA Australia, 2022:2*). The ISSB needs to consider the **readiness and capability of preparers** and how this may impact the widespread adoption of certain aspects of the proposed standards. (*CPA Australia, 2022:2*).
- It can be a matter of significant judgment to determine what proportion of risk or opportunity could be attributed to any sustainability-related matter. Deloitte would welcome the standard that allows entities to provide estimates and ranges in their disclosures and suggests providing qualitative information when entities cannot provide quantitative information. (*Deloitte, 2022:3*). The latter point is addressed directly by KPMG, who acknowledge that management of the reporting entity may face challenges in **deriving information from operations outside of its control** (timely access to information, quality and reliability of data, aligning measurement techniques with other parties, identifying appropriate estimates and approximations when data is not available; *KPMG, 2022:11*).
- **Scope 3 disclosures** are important, as emissions represent most greenhouse gas emissions for most companies, but they are also extremely challenging. Therefore, ACCA recommends further field testing to assess the impact of the requirements and provide further application guidance (*ACCA, 2022:4*).
- **Industry-specific metrics** are highly problematic. The ISSB suggests that insight should be provided into the performance of the drivers of climate-related risk and opportunity related to specific industries, business models or economic activities (*Exposure Draft IFRS S2.BC31*). The industry definition applied by the ISSB follows the US perspective, which raises the question of applicability in other jurisdictions (*ACCA, 2022:3*). One approach suggested would be to perform a field test for their usefulness (*CPA Australia, 2022:3*). Another view taken by respondents is to redesign the entire Appendix B as non-mandatory (*Financial Reporting Council,2022:2*). What conglomerates that operate in more than industry shall do is not specified (*Deloitte, 20.7.2022, p.2*).
- How and if reports are to be **audited** must be determined (*CPA Australia, 2022:4*).
- **Wording** generally needs to be improved. The proposed standard shall be **clear, concise, understandable and accessible** for all expected audiences (*Financial Reporting Council, 2022:2* with references to climate-related targets, strategy, business model),

The ISSB has reacted in several statements to the criticisms and concerns voiced. Major decisions have been made in February 2023 (*ISSB 2023d*). A summary follows below:

- IFRS S1 and S2 will become effective starting January 2024; there is additional guidance on the transition (*IFRS 1.E1-.E6, IFRS 2.C1-C5*).
- There is guidance on the international applicability of the (US) SABS standards to identify metrics and disclosures if they meet the information needs of investors (*ISSB (May 2023e)*).

Further implications can be derived from a staff paper that was published in February 2023 serving the preparation of an ISSB meeting (*ISSB, February 2023c*):

- IFRS S1 and S2 shall address proportionality. There will be a mechanism that addresses the use of available reasonable and supportable information without undue cost or effort and consideration of an entity’s skills, capabilities and resources. The two aspects are covered in the first two columns of Exhibit 4. It shall be noted that only selected topics will be affected.
- A temporary (“adoption”) relief for reporting entities will exist. This covers several measures:
  (i) Sustainability-related financial disclosures need not be presented at the same time as the financial statements,
  (ii) comparative information is waived for the financial year of the initial application,
  (iii) reporting on Greenhouse Gas Scope 3 may be postponed.
- “Unable to do so” is explained in the context of scenario analysis, see below.
- Additional guidance and educational material will be prepared.

https://doi.org/10.55343/CogSust.94

Table 3: Summary of ISSB decisions per February 2023

Topic	Mechanisms to address proportionality		Adoption relief	Additional clarifications/ mechanisms to facilitate application	
	Reasonable and supportable …without undue cost or effort	Consideration of skills, capabilities, and resources		'Unable to do so'	Guidance, educational material, and other
Determination of anticipated financial effects	X	X		X[2]	X
Climate-related scenario analysis	X	X			X
Measurement of Scope 3 GHG emissions	X		X		X
Identification of risks and opportunities	X				X
Measurement of Scope 1 and Scope 2 GHG emissions			X		X
Determination of the scope of the value chain	X				X
Determination of current financial effects				X[2]	X
Calculation of metrics in particular cross-industry metric categories	X				X
Other areas			X		X

Source: ISSB, February 2023c.

"Unable to do so" reflects the negative component of reasonable and supportable information available at the reporting date without undue cost or effort (*ISSB, February 2023c*). Information is analyzed, used in scenario analysis, and considered in management decisions involving judgments. This is assumed to be the basis for sustainability reporting.

https://doi.org/10.55343/CogSust.94

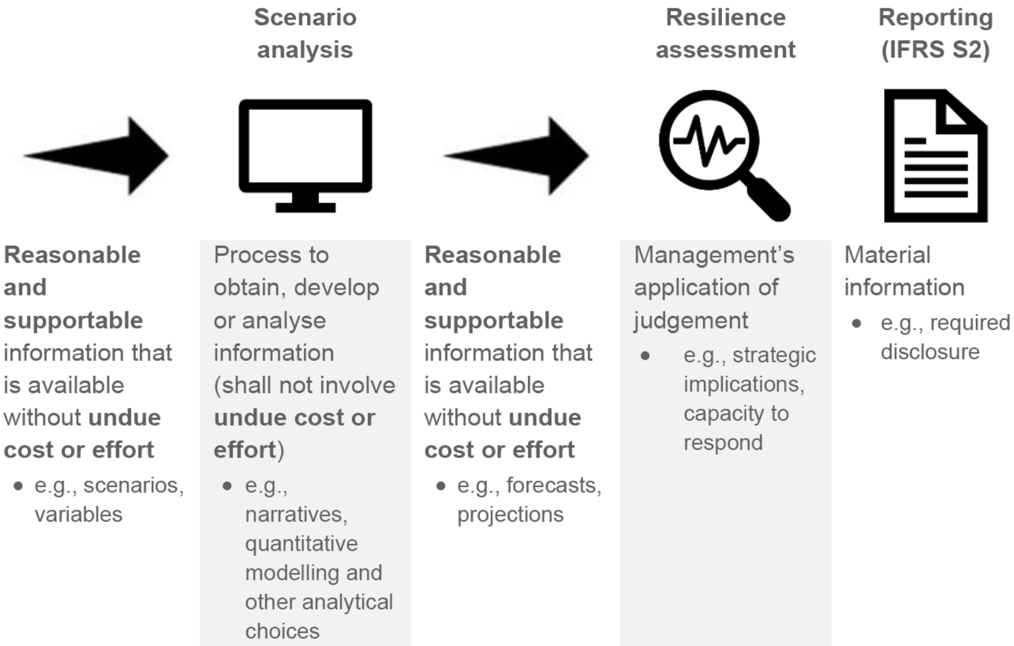

Figure 2: "Reasonable and supportable information that is available at the reporting date without undue cost or effort" as applied to scenario analysis
Source: ISSB, February 2023c

5. Perspectives for the Issued Standards

Both standards, IFRS S1 and IFRS S2, have been issued in June 2023. The standard setter emphasizes that sustainability/climate-related disclosures are expected to be published alongside financial statements in the same reporting package by the reporting entity. The objective is to create a regulation applicable worldwide (*ISSB, 26 June 2023f*).

Judging from the changes between the draft and final standard documents, few changes have been made regarding the underlying concepts. The structure of the standards generally has been modified. The Basis for the Conclusion also comments on the standard setter's decisions during the finalization. To give a very short summary while focusing on IFRS S2:

- The need for information has been re-confirmed (*IFRS S2.BC3*).
- The core concepts have been retained from the draft documents (*IFRS S2.BC17*).
- The cost vs. benefits of implementation must be monitored (*IFRS S2.BC47*).

As section 4 of this paper indicates, the ISSB has received considerable feedback about the draft documents. There is a clear understanding that implementation issues and modifications – especially regarding metrics – are to be expected. A separate project has been set up for the international aspects (https://www.ifrs.org/projects/work-plan/international-applicability-of-the-sasb-standards/ (content as of 13 September 2023). The ISSB seems to stick to the SASB standards (Sustainable Accounting Standards Framework) while leaving the question of international applicability partly open, i.e. the objective seems to be to gather feedback from constituents and practice.

Following the initiatives from the February 2023 staff paper, a Transition Implementation Group will be created to support reporting entities and other constituents (*ISSB, (26 June 2023f*). Of course, the overall standard project is not complete. Thus, additional aspects of climate-related disclosures may be expected.

In the end, what the future holds for the two sustainability disclosure standards remains to be seen. From the conceptual perspective, a logical and systematic conceptual basis can be recognized. Implementation will "meet" reality when the reporting entities quantify the information requirements of the standards and required processing. The objective seems to focus on existing data (cf. cost-benefit-argument). However, complexity is expected to increase significantly when the focus is to include other participants from the value chain.

https://doi.org/10.55343/CogSust.94

References

ACCA (July 2022). *ED IFRS S2 Climate-related Disclosures*. Exposure draft issued by ISSB in March 2022: Comments from ACCA. URL: https://www.ifrs.org/projects/completed-projects/2023/climate-related-disclosures/exposure-draft-and-comment-letters/#view-the-comment-letters, entry no. 371 or https://ifrs-springapps-comment-letter-api-1.azuremicroservices.io/v2/download-file?path=611_66055_association-of-chartered-certified-accountants--ac-tech-cdr2003-ifrs-s2-climate-disclosures-acca.pdf

Bakarich, K. M., Hoffmann, M., Marcy, A.S. (2023). Accountants' Views on Sustainability Reporting: A Generational Divide. *Current Issues in Auditing.* 17(1), A22–A35. DOI: 10.2308/CIIA-2022-003.

CPA Australia (28 July 2022). *Submission on the International Financial Reporting Standards' (IFRS) Sustainability Disclosure Standards*. URL: https://www.ifrs.org/projects/completed-projects/2023/climate-related-disclosures/exposure-draft-and-comment-letters/#view-the-comment-letters, entry no. 642 or https://ifrs-springapps-comment-letter-api-1.azuremicroservices.io/v2/download-file?path=611_66326_chartered-accountants-australia-and-new-zealand----final-joint-submission---issb-consultations--publication-.pdf

Deloitte (20 July 2022). *ED/2022/S2 Climate-related Disclosures*. URL: https://www.ifrs.org/projects/completed-projects/2023/climate-related-disclosures/exposure-draft-and-comment-letters/#view-the-comment-letters, entry no. 56 or https://ifrs-springapps-comment-letter-api-1.azuremicroservices.io/v2/download-file?path=611_65740_deloitte-deloitte-comment-letter-ed-ifrs-s2.pdf

Exposure Draft IFRS S1: General Requirements for Disclosure of Sustainability-related Financial Information, published March 2022

Exposure Draft IFRS S2: Climate-related Disclosures, published March 2022

Financial Reporting Council (22 June 2022). ISSB's Exposure Draft for IFRS S2 Climate-related Disclosures. https://www.ifrs.org/projects/completed-projects/2023/climate-related-disclosures/exposure-draft-and-comment-letters/#view-the-comment-letters, entry no. 18 or https://ifrs-springapps-comment-letter-api-1.azuremicroservices.io/v2/download-file?path=611_65702_financial-reporting-council-frc-comment-letter---ifrs-s2---signed.pdf

IFRS S1: General Requirements for Disclosure of Sustainability-related Financial Information, published June 2023

IFRS S2: Climate-related Disclosures, published June 2023

ISSB – International Sustainability Standards Board (2023a). *Climate-related Disclosures* (Project). URL: as of March 7, 2023 https://www.ifrs.org/projects/work-plan/climate-related-disclosures/; as of December 30, 2023: https://www.ifrs.org/projects/completed-projects/2023/climate-related-disclosures/

ISSB (17 February 2023d). ISSB ramps up activities to support global implementation ahead of issuing inaugural standards end Q2 2023. *IFRS*. URL: https://www.ifrs.org/news-and-events/news/2023/02/issb-ramps-up-activities-to-support-global-implementation-ahead-of-issuing-inaugural-standards-end-q2-2023/

ISSB (2023b). *General Sustainability-related Disclosures* (Project). URL: as of March 7, 2023: https://www.ifrs.org/projects/work-plan/general-sustainability-related-disclosures/; as of December 30, 2023: https://www.ifrs.org/projects/completed-projects/2023/general-sustainability-related-disclosures/

ISSB (26 June 2023f). ISSB issues inaugural global sustainability disclosure standards. *IFRS.* URL: https://www.ifrs.org/news-and-events/news/2023/06/issb-issues-ifrs-s1-ifrs-s2/

ISSB (December 2023g). *International Applicability of the SASB Standards* (Project). URL: as of September 13, 2023: https://www.ifrs.org/projects/work-plan/international-applicability-of-the-sasb-standards/; as of December 30, 2023: https://www.ifrs.org/projects/completed-projects/2023/international-applicability-of-the-sasb-standards/

ISSB (February 2023c). *ISSB Meeting: General Sustainability-related Disclosures and Climate-related Disclosures* (Project), Proportionality and support for those applying IFRS S1 and IFRS S2 (Topic), 3D&4C (Agenda Reference). URL: https://www.ifrs.org/content/dam/ifrs/meetings/2023/february/issb/ap3d-4c-proportionality-and-support-for-those-applying-ifrs-s1-and-ifrs-s2.pdf

ISSB (May 2023e). *Exposure Draft: Methodology for Enhancing the International Applicability of the SASB® Standards and SASB Standards Taxonomy Updates*. URL: https://www.ifrs.org/content/dam/ifrs/project/international-applicability-sasb-standards/ed-issb-2023-1-international-applicability-sasb-standards.pdf

KPMG – Klynveld Peat Marwick Goerdeler (29 July 2022). *ED/2022/S1 General Requirements for Disclosure of Sustainability-related Financial Information and ED/2022/S2 Climate-related Disclosures*. https://www.ifrs.org/projects/completed-projects/2023/climate-related-disclosures/exposure-draft-and-comment-letters/#view-the-comment-letters, entry no. 383 or https://ifrs-springapps-comment-letter-api-1.azuremicroservices.io/v2/download-file?path=611_66067_kpmg-international-limited-kpmg-comment-letter-on-issb-exposure-drafts-ed-2022-s1-general-requirements-ed-2022-s2-climat.pdf

Reporting Standards URL**:** *https://www.ifrs.org/issued-standards/ifrs-sustainability-standards-navigator/*

https://doi.org/10.55343/CogSust.94

Turner, L., Weirich, T. R. (2003). Expanding the Concept of Materiality to Environmental, Social, and Governance: Audit Issues and Implications. *Current Issues in Auditing.* 17(1), A50–A58. DOI: 10.2308/CIIA-2022-010.