SILESIAN UNIVERSITY OF TECHNOLOGY PUBLISHING HOUSE

SCIENTIFIC PAPERS OF SILESIAN UNIVERSITY OF TECHNOLOGY 2023
ORGANIZATION AND MANAGEMENT SERIES NO. 169

ANALYSIS OF THE ENVIRONMENTAL IMPACT OF THE VERTICAL PARKING SOLUTION USING LIFE CYCLE ASSESSMENT

Jolanta BARAN[1], Iwona ŻABIŃSKA[2*]

[1] Silesian University of Technology; Jolanta.baran@polsl.pl, ORCID: 0000-0003-3144-8257
[2] Silesian University of Technology; Iwona.Zabinska@polsl.pl, ORCID: 0000-0002-9368-4311
* Correspondence author

Purpose: The purpose of this article is to present the results of an analysis of the environmental impact of an innovative vertical parking solution, the so-called smart parking lot.
Design/methodology/approach: The Life Cycle Assessment (LCA) method was used for the analysis. The study was conducted in accordance with the recommendations of ISO 14040/44. Calculations were carried out using SimaPro software and the Ecoinvent database.
Findings: The analysis identified significant issues in the life cycle of a smart parking lot, i.e., parameters indicating the greatest potential environmental impact of the solution, in categories such as climate change, ozone depletion, carcinogenesis, eutrophication, acidification, use of mineral and metal resources, and fossil fuels.
Practical implications: The results presented can be taken into account at the stage of developing eco-innovative technical solutions.
Originality/value: The problem of an insufficient number of parking spaces forces the search for optimal urban, economic and environmental solutions for the construction of parking lots. Research results presented in the article represent the first phase of a broader project on the analysis of the environmental impact of selected parking solutions.

Keywords: Life Cycle Assessment, environmental impacts, parking.

Category of the paper: research paper.

1. Introduction

The literature on the subject (Hu, Wen, 2012; Krivda et al., 2014; Pilepic et al., 2019; Sego et al., 2021; Wang et al., 2016; Yetiskul, Senbil, 2018) and the survey research conducted by the authors of this article (Baran et al., 2021) show that the ever-increasing number of vehicles is affecting the deterioration of road capacity and the difficulty of parking a car. The study in question showed that the problem of insufficient parking spaces mainly affects large cities and people living in multi-apartment buildings, as well as those commuting by car. Based on a review of the literature (Duda-Wiertel, 2018; Wang et al., 2021; Yaacob et al., 2020), it can also be concluded that the search for a vacant parking space contributes to higher emissions of air pollutants, increases vehicle operating costs, and takes up more and more time for drivers and passengers. The parking space problem forces the search for optimal solutions that take into account the constraints of plot size, the high price of land, construction costs and environmental pollution. Different expectations of different social groups, such as drivers vs. urban residents (Baran et al., 2021) are also worth mentioning. Due to emerging urban, economic and environmental issues, there is growing interest in modern technical solutions for parking structures and parking management (Severino et al., 2021; Biyik et al., 2021; Jog et al., 2015; Polycarpou et al., 2013; Krieg et al., 2018; Thomasa, Kovoorb, 2018; Kotb et al., 2017; Slezok, Luczak, 2015; Issrani, Bhattacharjee, 2018; Block et al., 2020; Mendoza-Silva et al., 2019; Al-Turjman, Malekloo, 2019; Khalid et al., 2021; Kalašová et al., 2021; Lin et al., 2017). Given the above, the implementation of new parking solutions should look at all dimensions of sustainability, the assumptions of a circular economy and the results of the latest research on smart cities and future mobility (Bukowski et al., 2018; Górniak, 2016). There are studies in the literature on the effects of providing parking spaces on land use and the associated loss of open space and biodiversity (Russo et al., 2019; Ibrahim, 2017). Nevertheless, there is a lack of research on assessing the environmental impact of existing parking solutions in categories such as climate change, ozone depletion, carcinogenesis, eutrophication, acidification, use of mineral and metal resources, and fossil fuels, just to give an example. Research should address the entire life cycle of parking lots, that is, from design, through operation, to decommissioning. The most effective is the analysis carried out at the earliest possible stage of product design, since, according to the so-called eco-design paradox, the possibility of reducing environmental impact over the life cycle decreases as the design process progresses. Such analysis is possible through the use of analytical tools, such as Life Cycle Assessment (LCA).

Research results presented in this article represent the first phase of a broader project on the analysis of the environmental impact of selected parking solutions. The first phase research is concerned with incorporating an extended environmental life cycle perspective into the design and determining the environmental and social profile of a vertical parking solution, i.e., an innovative system of so-called smart parking lot (Fig. 1). It takes about 33 m^2, which means that two standard parking spaces can accommodate 6 to 16 vehicles.

Figure 1. An example of a smart parking lot.

Source: http://smartparking-systems.pl/realizacje/.

Vertical parking lots are becoming increasingly popular due to their vast space savings. They also provide the highest level of security for both parking and property protection, as the car remains in a secure parking structure preventing unauthorized access. Vertical parking lots allow parking spaces to be found relatively quickly; therefore, they do not generate additional costs related to vehicle operation and emissions (Baran, Tandos, 2021; Pashte et al., 2016; Ślęzok, Łuczak, 2015).

2. Material and methods

The analysis of the environmental impact of the innovative vertical parking solution, the so-called smart parking lot, was performed using the Life Cycle Assessment (LCA) method. The method allows to comprehensively analyze the environmental impact of a product throughout its life cycle, i.e., from the acquisition of raw materials and materials, through the production process, distribution to use and management of post-consumer waste. The analysis was carried out following the recommendations of ISO 14040/44 in four steps (ISO, 2006a, 2006b):

- Definition of purpose and scope;
- Analysis of a set of inputs and outputs;
- Life cycle impact assessment;
- Interpretation.

The study was based on the following:

- PN-EN ISO 14040:2009, Environmental management – Life cycle assessment – Principles and structure;
- PN-EN ISO 14044:2009, Environmental management – Life cycle assessment – Requirements and guidelines;
- ISO/TS 14048 Technical specification, Environmental management – Life cycle assessment – Data documentation format;
- Data obtained from the manufacturer of parking solutions.

The analysis also used databases implemented in SimaPro, mainly Ecoinvent version 3.7.1. Ecoinvent (Ecoinvent, 2020) is a database containing LCI (Life Cycle Inventory) data on energy, transportation, waste management, building materials, chemicals, detergents, paper, as well as agricultural products and processes.

3. Analysis of a set of inputs and outputs

Input-output set analysis involves collecting data for specific unit processes. The data for input materials, utilities used, output emissions and waste can come from measurements, calculations or estimates. This is a critical point in the analysis, as the accuracy and correctness of the data determine the uncertainty of the final result.

With regard to the functional unit, the following processes are included in the life cycle of a smart parking lot:

- Process 1 – Steel from the cradle.
- Process 2 – Transport of steel to gate.
- Process 3 – Steel cutting.
- Process 4 – Welding.
- Process 5 – Drilling.
- Process 6 – Coating.
- Process 7 – Trial assembly and disassembly.
- Process 8 – Packaging of finished elements.
- Process 9 – Transport to client.
- Process 10 – Building the foundation.
- Process 11 – Assembly at the client's site.
- Process 12 – Typical use.
- Process 13 – Disassembly at the client's site.
- Process 14 – Transport of used steel to recycling.
- Process 15 – Recycling of steel waste.

The data for the identified unit processes comes from manufacturer estimates and measurements. With the processes described in the Ecoinvent database, the range from cradle to gate and subsequent life cycle stages are captured.

Table 1.
Process modeling data

No.	Modeled processes	Ecoinvent database processes
Cradle-to-gate processes		
1	Steel	Steel, low-alloyed {GLO}| market for | Cut-off, U
2	Electricity	Electricity, medium voltage {PL}| market for | Cut-off, U
3	Heating	Heat, central or small-scale, other than natural gas {Europe without Switzerland}| market for heat, central or small-scale, other than natural gas | Cut-off, U
4	Diesel	Diesel {Europe without Switzerland}| market for | Cut-off, U
5	Drinking water	Tap water {Europe without Switzerland}| market for | Cut-off, U
6	Oils and lubricants	Lubricating oil {RER}| market for lubricating oil | Cut-off, U
7	Cotton textile, woven cotton	Textile, woven cotton {GLO}| market for | Cut-off, U
8	Welding	Welding, arc, steel {GLO}| market for | Cut-off, U
9	Paints	Chemical, organic {GLO}| market for | Cut-off, U
10	Copper wires	Wire drawing, copper {GLO}| market for | Cut-off, U
11	LEDs	Light emitting diode {GLO}| market for | Cut-off, U
12	Packaging film	Packaging film, low density polyethylene {RER}| production | Cut-off, U
13	Packaging cardboard	Containerboard, linerboard {RER}| market for containerboard, linerboard | Cut-off, U
14	Cement	Cement, unspecified {Europe without Switzerland}| market for cement, unspecified | Cut-off, U
15	Sand	Sand {RoW}| market for sand | Cut-off, U
16	Gravel	Gravel, round {RoW}| market for gravel, round | Cut-off, U
Transport processes		
17	Transporting steel to the gate	Transport, freight, lorry >32 metric ton, euro5 {RoW}| market for transport, freight, lorry >32 metric ton, EURO5 | Cut-off, U
18	– Transporting finished elements to the client – Transporting used steel for recycling	Transport, freight, lorry 16-32 metric ton, euro5 {RER}| market for transport, freight, lorry 16-32 metric ton, EURO5 | Cut-off, U
Output processes		
19	Scrap steel	Scrap steel {Europe without Switzerland}| market for scrap steel | Cut-off, U
20	Wastewater	Wastewater, average {Europe without Switzerland}| market for wastewater, average | Cut-off, U
21	Waste mineral oil	Waste mineral oil {Europe without Switzerland}| market for waste mineral oil | Cut-off, U
22	Waste yarn and waste textile	Waste yarn and waste textile {GLO}| market for waste yarn and waste textile | Cut-off, U
23	Waste paint on metal	Waste paint on metal {RoW}| market for waste paint on metal | Cut-off, U
24	Waste packaging film	Waste polyethylene {PL}| market for waste polyethylene | Cut-off, U
25	Waste paperboard	Waste paperboard {PL}| market for waste paperboard | Cut-off, U
26	Waste concrete	Waste concrete {Europe without Switzerland}| market for waste concrete | Cut-off, U
27	Waste – LEDs	Waste electric and electronic equipment {GLO}| market for | Cut-off, U

Source: Own work.

4. Analysis of a set of inputs and outputs

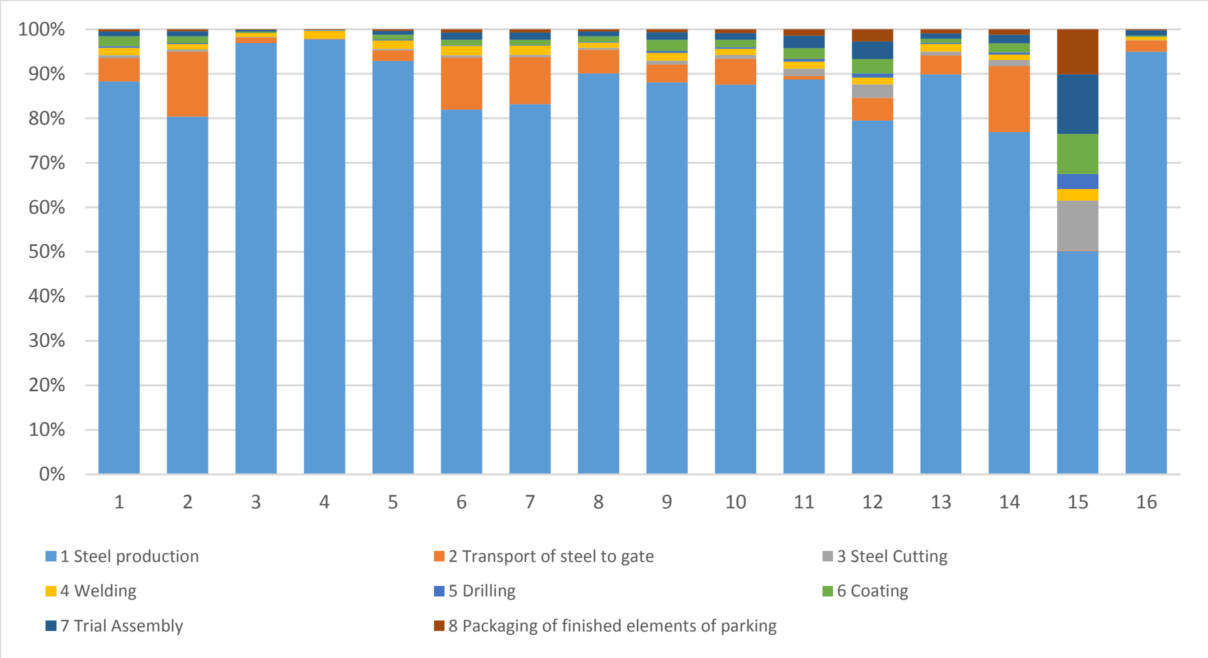
The collected data, presented in Chapter 3, was evaluated for the magnitude and significance of potential environmental impacts of the product system throughout its life cycle. The evaluation was carried out using SimaPro software, along with LCIA methods and the Ecoinvent database. This Life Cycle Assessment phase consists of mandatory elements, including characterization, and optional elements, such as normalization and weighting. Characterization involves calculating the degree of each classified input/output's contribution to their respective environmental footprint impact categories and aggregating the contributions within each category. This requires linearly multiplying the data on a set of inputs and outputs by the characterization factors for each given substance and given environmental footprint impact category. An important concept is the impact category, or aspect of the environmental footprint (e.g., a product has the potential to affect impact categories, such as climate change, ozone depletion, carcinogenicity, eutrophication, acidification, use of mineral and metal resources, as well as fossil fuels, etc.), and the environmental footprint category, or the environmental footprint category.

The collected data was analyzed in two stages:

- “Cradle-to-gate”, which covers all processes from the extraction of raw materials to the moment the product leaves the gate of the industrial plant; it is an analysis conducted to determine the environmental impact of production;
- “Gate-to-grave”, which takes into account processes from use to end-of-life; used to determine a product's environmental impact from the moment it leaves the manufacturing plant.

4.1. Cradle-to-gate stage

Figure 2 shows the results of the analysis in terms of impact categories after the characterization stage. The results in all impact categories are scaled to 100%.



Key: 1. Climate change; 2. Ozone depletion; 3. Human toxicity – non-carcinogenic effects; 4. Human toxicity – carcinogenic effects; 5. Respiratory particulates / inorganic substances; 6. Ionizing radiation – human health effects; 7. Ionizing radiation – ecosystem effects (interim); 8. Photochemical formation of ozone; 9. Acidification; 10. Terrestrial eutrophication; 11. Aquatic eutrophication – fresh water; 12. Aquatic eutrophication – seawater; 13. Ecotoxicity for fresh water; 14. Land use; 15. Resource depletion – water resources; 16. Resource depletion – mineral resources, fossil resources.

Figure 2. Environmental characterization from cradle to gate in terms of environmental impact for each component after the characterization stage.

Source: Own study.

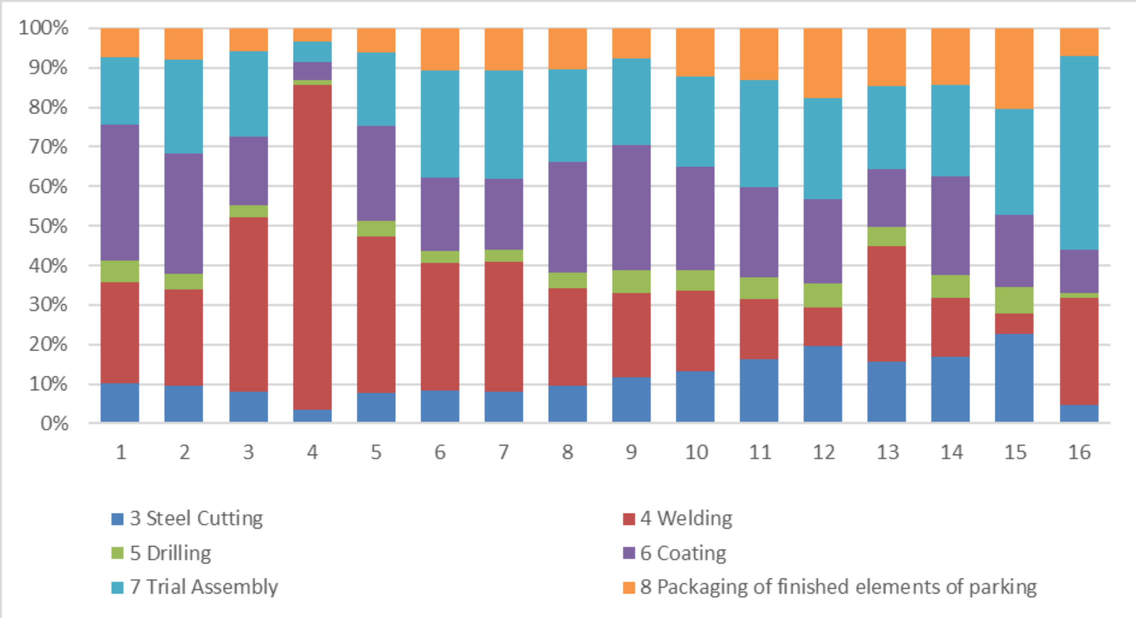
The data presented (Figure 2) shows that in all categories analyzed, steel production has the greatest impact on the environment. The lowest impact is in the category of the depletion of water resources (50.1%), and the highest in the category of human toxicity – carcinogenic effects (97.7%). Notably, the impact in each category applies to the entire steel production process, and therefore also to the use of electricity and thermal energy, transportation processes and metallurgical processes.

The steel-to-gate transport is particularly evident in categories such as depletion of the ozone layer (14.6%), land use (14.8%), ionizing radiation – effects on ecosystems (10.6%). In the case of the impact category, the depletion of water resources is further marked by the impact of the processes of steel cutting (11.3%), coating (9.01%), trial assembly and disassembly (13.4%) and packaging (10.1%). The important issue is, however, that these impacts relate only to a specific impact category and can be interpreted with reference to a single impact category due to the fact that these are characterization results.

After the weighing stage, steel production has the potential greatest impact on the following categories:

- Human toxicity – carcinogenic effects (91.6 Pt);
- Human toxicity – non-carcinogenic effects (17.8 Pt);
- Ecotoxicity for freshwater (3.64 Pt).

To isolate the results for the production process itself, the process of making steel and transporting the steel to the gate were excluded from the analysis at the characterization stage. Figure 3 shows the results of this operation.



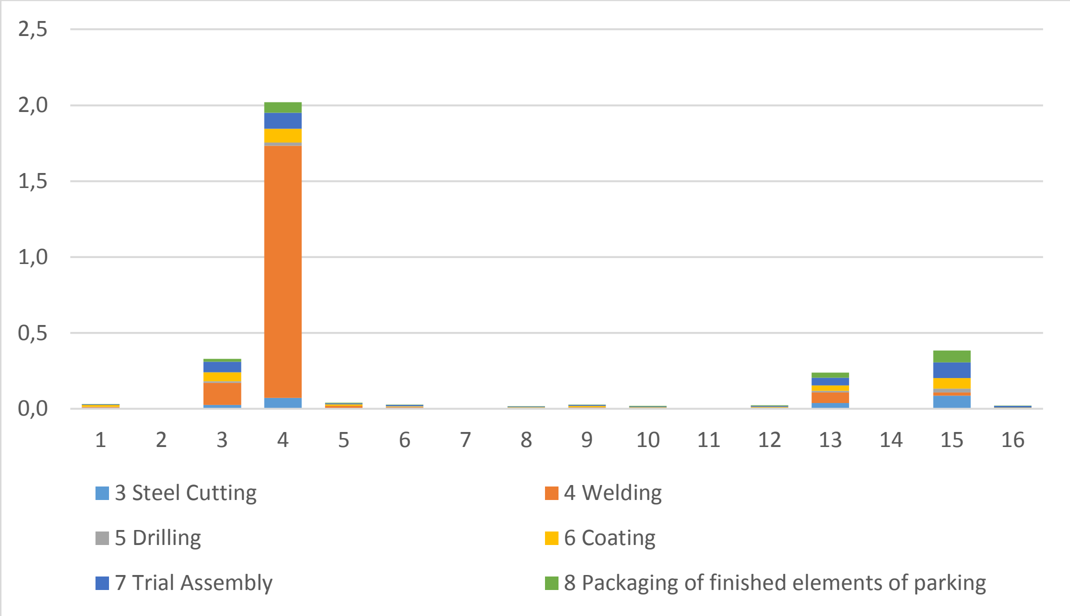
Key: 1. Climate change; 2. Ozone depletion; 3. Human toxicity – non-carcinogenic effects; 4. Human toxicity – carcinogenic effects; 5. Respiratory particulates / inorganic substances; 6. Ionizing radiation – human health effects; 7. Ionizing radiation – ecosystem effects (interim); 8. Photochemical formation of ozone; 9. Acidification; 10. Terrestrial eutrophication; 11. Aquatic eutrophication – fresh water; 12. Aquatic eutrophication – seawater; 13. Ecotoxicity for fresh water; 14. Land use; 15. Resource depletion – water resources; 16. Resource depletion – mineral resources, fossil resources.

Figure 3. Environmental characterization of the production of smart parking elements in relation to environmental impact for individual components after the characterization stage (excluding steel and steel transport).

Source: Own study.

An analysis of the processes directly related to the production of the smart parking lot highlights primarily the impact of the welding process in the category of human toxicity – carcinogenic effects (82.2% in this impact category) and the impact of the trial assembly and disassembly process in the category of depletion of mineral and fossil resources (48.9% in this category).

As can be seen from the analysis of the weighing results, the processes directly related to the production of smart parking lots have the greatest impact on the environment in the category of human toxicity – carcinogenic effect. In this category, the greatest impact is associated with the welding process (Figure 4).



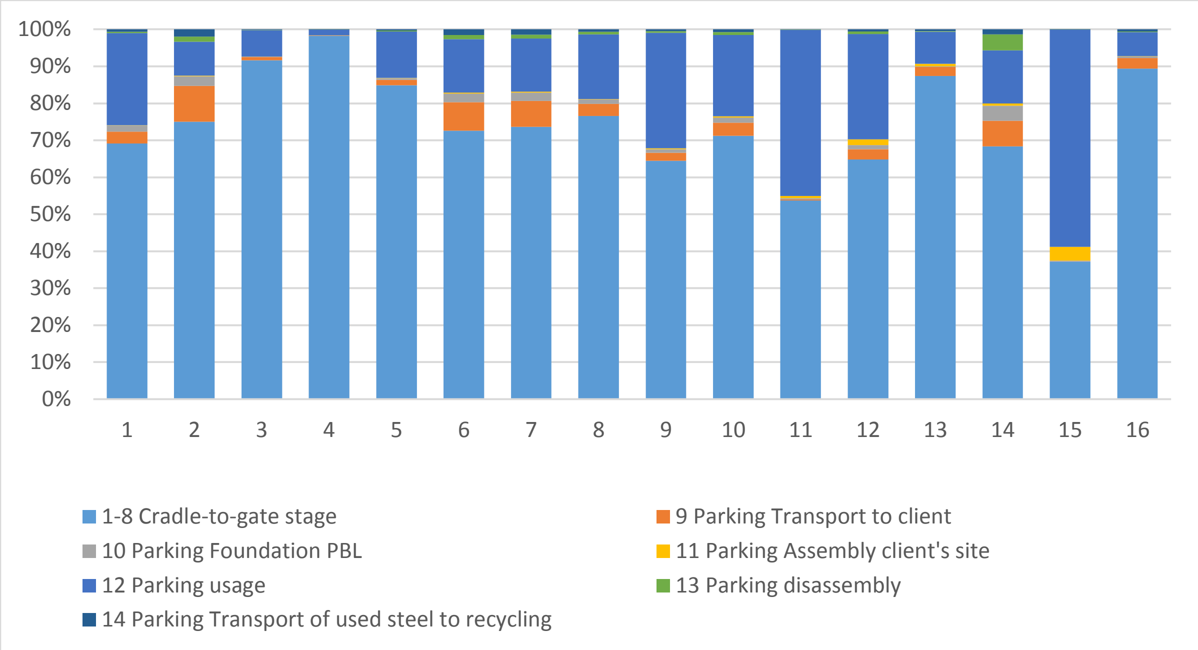
Key: 1. Climate change; 2. Ozone depletion; 3. Human toxicity – non-carcinogenic effects; 4. Human toxicity – carcinogenic effects; 5. Respiratory particulates / inorganic substances; 6. Ionizing radiation – human health effects; 7. Ionizing radiation – ecosystem effects (interim); 8. Photochemical formation of ozone; 9. Acidification; 10. Terrestrial eutrophication; 11. Aquatic eutrophication – fresh water; 12. Aquatic eutrophication – seawater; 13. Ecotoxicity for fresh water; 14. Land use; 15. Resource depletion – water resources; 16. Resource depletion – mineral resources, fossil resources (Table 1).

Figure 4. Environmental characterization of the production of smart parking lots in relation to environmental impact for individual components after the weighing stage (excluding steel and steel transport).

Source: Own work.

4.2. Life cycle stages

Figure 5 shows the results of the smart parking lot life cycle analysis. The inventory data for the life cycle stages after the cradle-to-gate stage are described in Chapter 3. The results presented in all impact categories are scaled to 100%. This presentation of the results does not make it possible to determine whether it is 100% low impact or high impact, but it does highlight the relationships of the processes to each other for each category – this is how the results after the characterization stage are graphically presented. Following the characterization stage, the cradle-to-gate stage impact (described in Section 4.1) is dominant for all categories.



Key: 1. Climate change; 2. Ozone depletion; 3. Human toxicity – non-carcinogenic effects; 4. Human toxicity – carcinogenic effects; 5. Respiratory particulates / inorganic substances; 6. Ionizing radiation – human health effects; 7. Ionizing radiation – ecosystem effects (interim); 8. Photochemical formation of ozone; 9. Acidification; 10. Terrestrial eutrophication; 11. Aquatic eutrophication – fresh water; 12. Aquatic eutrophication – seawater; 13. Ecotoxicity for fresh water; 14. Land use; 15. Resource depletion – water resources; 16. Resource depletion – mineral resources, fossil resources.

Figure 5. Environmental characterization of the life cycle of a smart parking lot in terms of environmental impact for each component following the characterization stage.

Source: Own work.

5. Conclusions

The results of the calculations presented in this article can inspire decisions that, at the design stage, can help effectively reduce environmental impact. In particular, they can form the basis for the development of eco-innovative technical solutions. The results of the calculations show that, considering the total life cycle impact of a vertical parking lot, the greatest environmental burden arises at the cradle-to-gate stages – that is, from the acquisition of raw materials to the manufacturing stage. The carbon footprint for the stage is 54,300 kg CO_2 eq, which is 69.08% of the total life cycle impact in this category. The impact in this category is also relatively large at the use stage of vertical parking – 2.5% of the total carbon footprint. The environmental characterization of smart parking lot production in terms of environmental impact for individual components after the weighing stage (excluding steel and steel transport) shows the greatest impact of the welding process in the category of human toxicity – carcinogenic effect (82.2%). Other impact categories standing out with a significant share are resource depletion – water resources, human toxicity – non-carcinogenic effect, and freshwater ecotoxicity. These impacts are due to the consumption of materials and energy, air emissions and generated pollutants. In all categories analyzed, steel production has the greatest environmental impact – calculated from cradle to gate. The lowest impact is in the category of the depletion of water resources (50.1%), and the highest in the category of human toxicity – carcinogenic effects (97.7%). Notably, the impact in each category applies to the entire steel production process, and therefore also to the use of electricity and thermal energy, transportation processes and metallurgical processes. The steel-to-gate transport is particularly evident in categories such as depletion of the ozone layer (14.6%), land use (14.8%) and ionizing radiation – effects on ecosystems (10.6%). In the case of the impact category, the depletion of water resources is further marked by the impact of the processes of steel cutting (11.3%), coating (9.01%), trial assembly and disassembly (13.4%) and packaging (10.1%).

Based on the LCA results obtained for the vertical parking lot, it can be recommended to consider applying design strategies for cleaner production and use, and improving energy efficiency. In the context of a circular economy, it is worthwhile to undertake further research on assessing the life cycle impact of various parking solutions on the environment. The result of the research and comparative analysis can be the development of design options to support decision-making.

Acknowledgements

This paper was financed from the resources of the Silesian University of Technology, project no. BK-274/ROZ1/2023 (13/010/BK_23/0072).

References

1. Al-Turjman, F., Malekloo, A. (2019). *Smart Parking in IoT-enabled Cities: A Survey. Sustainable Cities and Society,* pp. 101608, 2019.
2. Baran, J., Miklis, A., Żabińska, I. (2021). Research Towards Sustainable Parking Solutions. *Multidisciplinary Aspects of Production Engineering, 4(1),* pp.376-386. Retrieved from: https://doi.org/10.2478/mape-2021-0034.
3. Baran, J., Tandos, D., Żabińska, I. (2021). Comparative Analysis of Selected Car Parks. *Multidisciplinary Aspects of Production Engineering, 4(1),* pp.365-375. Retrieved from: https://doi.org/10.2478/mape-2021-0033.
4. Biyik, C., Allam, Z., Pieri, G., Moroni, D., O'Fraifer, M., O'Connell, E., Olariu, S., Khali, M. (2021). Smart Parking Systems: Reviewing the Literature, Architecture and Ways Forward. *Smart Cities, 4,* pp. 623-642.

5. Bock, F., Di Martino, S., Origlia, A. (2020). Smart Parking: Using a Crowd of Taxis to Sense On-Street Parking Space Availability. *IEEE Transactions on Intelligent Transportation Systems, vol. 21, no. 2,* pp. 496-508, doi: 10.1109/TITS.2019.2899149.
6. Bukowski, A., Nóżka, M., Smagacz-Poziemska, M. (2018). How do parking practices structure urban territorial communities? *Urban Development Issues, 59,* pp. 5-16. DOI: 10.2478/udi-2018-0024.
7. Duda-Wiertel, U. (2018). Consequences of accessibility parking space change in vulnerable city centre area. *Transport Miejski i Regionalny, 7,* pp. 12-17. Stowarzyszenie Inżynierów i Techników Komunikacji Rzeczpospolitej Polskiej. Retrieved from: https://tmir.sitk.org.pl/wp-content/uploads/2019/07/gazeta07_2018_druk.pdf.
8. Ecoinvent Association (2020). ecoinvent database, v3.7.1. Retrieved from: https://www.ecoinvent.org.
9. Górniak, J. (2016). The sense of the city logistics in selected European cities. Comparative analysis. Resear*ch Reviews of Czestochowa University of Technology. Management, 24(1),* pp. 140-151. Retrieved from: http://www.zim.pcz.pl/znwz.
10. http://smartparking-systems.pl/realizacje/, 23.05.2021.
11. Hu, H.B., Wen, Z.K. (2012). *Study on public parking problems and countermeasures*. Proc. SPIE 8350, Fourth International Conference on Machine Vision (ICMV 2011): Computer Vision and Image Analysis; Pattern Recognition and Basic Technologies, 8350. Retrieved from: https://doi.org/10.1117/12.920110.
12. Ibrahim, H. (2017). *Car Parking Problem in Urban Areas, Causes and Solutions*. 1st International Conference on Towards a Better Quality of Life, 2017, Available at SSRN. Retrieved from: https://ssrn.com/abstract=3163473 or http://dx.doi.org/10.2139/ssrn. 3163473.
13. ISO (2006a). *Environmental management - life cycle assessment - principles and framework. ISO 14040:2006*. Geneva: International Organization for Standardization (ISO).
14. ISO (2006b). *Environmental management - life cycle assessment - Requirements and guidelines. ISO 14044:2006*. Geneva: International Organization for standardization (ISO).
15. ISO/TS 14048, Zarządzanie środowiskowe – ocena cyklu życia – format dokumentowania danych.
16. Issrani, D., Bhattacharjee, S. (2018). *Smart Parking System Based on Internet of Things: A Review, Computing Communication Control and Automation (ICCUBEA).* Fourth International Conference, pp. 1-5.
17. Jog, Y., Sajeev, A., Vidwans, S., Mallick, C. (2015). Understanding smart and automated parking technology. *International Journal of u-and e-Service, Science and Technology, 8(2),* pp. 251-262. ISSN: 22079718.
18. Kalašová, A., Culík, K., Poliak, M. (2021). Otahálová, Z. SmartParking Applications and ItsEfficiency.*Sustainability,13,* 6031. Retrieved from: https://doi.org/10.3390/su13116031.

19. Khalid, M., Wang, K., Aslam, N., Cao, Y., Ahmed, N., Khan, M.K. (2021). From Smart Parking Towards Autonomous Valet Parking: A Survey, Challenges and Future Works'. *Journal of Network and Computer Applications, vol. 175,* 102935. Retrieved from: https://doi.org/10.1016/j.jnca.2020.102935.
20. Kotb, A.O., Shen, Y., Huang, Y. (2017). Smart Parking Guidance, Monitoring and Reservations: A Review. *IEEE Intelligent Transportation Systems Magazine, 9(2),* pp. 6-16, DOI: 10.1109/MITS.2017.2666586.
21. Krieg, J.G., Jakllari, G., Toma, H., Beylot, A.L. (2018). Unlocking the smartphone's sensors for smart city parking. *Pervasive and mobile Computing, Vol. 43,* pp. 78-95.
22. Krivda, V., Mahdalova, I. (2014). *Video Analysis of Conflict Situations and Parking Problem.* AMM, 505-506, 1055-1060. https://doi.org/10.4028/www.scientific.net/amm.505-506.1055.
23. Lin, T., Rivano, H., Le Mouël, F. (2017). A Survey of Smart Parking Solutions. *IEEE Transactions on Intelligent Transportation Systems, vol. 18, no. 12,* pp. 3229-3253, doi: 10.1109/TITS.2017.2685143.
24. Mendoza-Silva, G.M., Gould, M., Montoliu, R., Torres-Sospedra, J., Huerta, J. (2019). An Occupancy Simulator for a Smart Parking System: Developmental Design and Experimental Considerations. *ISPRS International Journal of Geo-Information, 8,* p. 212.
25. Pashte, P., Narkhede, V., Nade, S., More, S., Maske, Y.L. (2016). Design and analysis of rotary automated car parking system. *International Journal for Scientific Research & Development, 4(04),* pp. 28-31. Retrieved from: http://www.ijsrd.com/articles/IJSRDV4I40121.pdf, 19.10.2021.
26. Pilepic, D., Sigurnjak, J., Cucukovic, A. (2019). Parking problem in the centre of the city of krk with suggestions of variant solutions. *Zbornik Veleucilista U Rijeci-Journal Of The Polytechnics Of Rijeka, 7(1),* pp. 359-373.
27. PN-EN ISO 14040:2009, Zarządzanie środowiskowe – Ocena cyklu życia – Zasady i struktura.
28. PN-EN ISO 14044:2009, Zarządzanie środowiskowe – Ocena cyklu życia – Wymagania i wytyczne.
29. Polycarpou, E., Lambrinos, L., Protopapadakis, E. (2013). *Smart parking solutions for urban areas.* IEEE 14th International Symposium on" A World of Wireless, Mobile and Multimedia Networks (WoWMoM), pp. 1-6, ISBN: 978-1-4673-5827-9.
30. Russo, A., van Ommeren, J., Dimitropoulos, A. (2019). The Environmental and Welfare Implications of ParkingPolicies. *OECD Environment Working Papers, No. 145.* Paris: OECD Publishing. Retrieved from: http://dx.doi.org/10.1787/16d610cc-en.
31. Sego, D., Prazen, A., Olivari, L. (2021). Characteristics of parking problems in urban cities - case study of the city of sibenik with proposals for solving the problem. *Zbornik Veleucilista U Rijeci-Journal Of The Polytechnics Of Rijeka, 9(1)*, pp. 401-419.

32. Severino, A., Curto, S., Barberi, S., Arena, F., Pau, G. (2021). Autonomous Vehicles: An Analysis Both on Their Distinc-tiveness and the Potential Impact on Urban Transport Systems. *Appl. Sci., 11,* 3604
33. Ślęzok, M., Łuczak, K. (2015). Intelligent building, automated car parking system. *Scientific Papers of Silesian University of Technology. Organization and Management Series, 77,* pp. 217-226.
34. Thomasa, D., Kovoorb, B.C. (2018). A Genetic Algorithm Approach to Autonomous Smart Vehicle Parking system. *Procedia Computer Science, Vol. 125,* pp. 68-76.
35. Wang, W., Zhong, H., Zeng, Y., Liu, Y., Chen, J. (2021). A Carbon Emission Calculation Model for Roadside Parking. *Int. J. Environ. Res. Public Health, 18,* 1906. Retrieved from: https://doi.org/10.3390/ijerph18041906.
36. Wang, Y.L., Wang, X., Zhang, M.C. (2016). Current Situation and Analysis of Parking Problem in Beijing. 6th International Conference on Green Intelligent Transportation System and Safety (GITSS). *Green Intelligent Transportation System And Safety, 138,* pp. 777-785.
37. Yaacob, N.F.F., Mat Yazid, M.R., Abdul Maulud, K.N., Ahmad Basri, N.E. (2020). A Review of the Measurement Method, Analysis and Implementation Policy of Carbon Dioxide Emission from Transportation. *Sustainability, 12*, 5873.
38. Yetiskul, E., Senbil, M. (2018). Parking Problem in Ankara and Policy Recommendations. *Megaron, 13(2),* pp. 250-262.