Environmental aspect of investment in solar system in example of business providing public services. Case from Slovak Republic

Jakub Sieber[1]

[1] University of Economics in Bratislava, Faculty of Business Economy with seat in Košice, Department of Corporate Financial Management, Tajovského 13, 04130 Košice, Slovak Republic

jakub.sieber@euba.sk

https://doi.org/10.53465/EDAMBA.2021.9788022549301.431-442

Abstract: This paper focus on environmental investment made in small firm in solar system. Based on literature review and recently introduced financial mechanism of European Union for membership states to recover and help countries to become more efficient, digitalized, and face climate changes after COVID-19 crisis, it becomes crucial to point out that not all "green solutions" might yield sustainable advantages. Case from Slovak Republic shows that investment in solar system made in 2017 is dropping its competitive advantage when we calculate Life Cycle Assessment. Paper is dealing with national policies declared by state authorities in Slovak Republic and also European Union with tendency to lower emissions of CO2. When assuming that goals of state authorities and EU are reachable in field of energetic mix, in this particular case the firm will be leaving higher carbon footprint 10 years after investment in solar panels as it did not invest in solar system. In 2017, the savings in the carbon footprint of the surveyed company in LCA in absolute terms amounted to 1551 tons, or 0.03 tons per kWh, but by assumptions, in 2027 carbon footprint will be higher by 0,005 ton per kWh despite operating own solar system.

Keywords: Renewable Resources, Life Cycle Assessment, Carbon Footprint

JEL classification: *Q20, Q42, Q40*

1 Introduction

This paper uses case study of small business operating solar system while providing services. Primary research objective of this paper is to illustrate environmental aspect of investment, particularly the change in carbon footprint of examined business and how it varies depending on the national primary energy mix when compared to year the solar system. In addition to primary objective there are supportive objectives to enumerate direct emissions of firms depending on its activities and carbon footprint.

Study also deals with plans of Slovak Republic to achieve specific targets to decrease carbon footprint, how the primary energy mix should be transformed according to National "Recovery Plan". According to official international and national documents, as its later referred on, there is a plan to change primary energy mix of Slovak Republic in favor of renewable resources. Use of the simple Life-cycle assessment might provide a better look at planned massive investments towards national primary energy mix of Slovak Republic and its environmental aspects.

The whole world recently experienced and is still experiencing repercussions and challenges in regard to COVID-19 pandemic. Spread of the global pandemic threw a bit of oblivion on environmental crisis the world is also dealing with. Extreme changes of the weather are giving foretaste, that after facing COVID-19 challenges humanity might be entering another possible crisis - at the climate level.

2 Literature review

Carbon dioxide (CO2) is the primary cause and driver of global warming, according to several recent studies. (Xu et al., 2021; Xiao-Ming et al., 2021) The phenomenon of global warming refers to the continual rise in the temperature of the planet's oceans, atmosphere, and land. (Tuel – Eltahir, 2020) Carbon footprint (CF) is a new measure of sustainability as it is able to determine the overall impact of society activities on climate change (Delre et al., 2019) and as a consequence of global actions done to slow down impacts on the environment while maintaining increasing production, the focus of discussion has recently turned to the CF minimization. (Ødegaard, 2016; Xu et al., 2017) CF is defined as "the total amount of carbon dioxide emissions, directly and indirectly, caused by an activity or that accumulated over a product lifetime". (Lombardi et al., 2017) As described in study of Maktabifard et al. (2020) aiming at the energy neutrality is reasonable in terms of the CF provided that the total CF is not increased.

As reported by British Petroleum Company (2020) the biggest global CO2 contributors are China, United States, European Union, India, and Russia. European Union (EU) introduced and approved financial aid to member states in total allocation of EUR 806,9 bn. in years 2021 – 2027 as NextGenerationEU. This unprecedent and highest financial help to member states should help national economies to recover after COVID-19 with emphasis on digitalization, transformation to sustainable production, but more importantly, 30% of the budget is intended to be used for engagement with climate crisis and its consequences, what represents EUR 242 bn. As recent research suggests that investment into climate-friendly policy initiatives may help the world move closer to a net-zero emissions pathway, as targeted in the 2020 European Green Deal. (European Commission, 2019; European Commission, 2021)

All activities financially supported by EU to decrease CF, to meet net-zero emissions are reflected at National levels of individual member states. As concluded in study by Mekonnen et al. (2016) energy scenarios are mainly developed based on forecasts of future energy demand and on expectations regarding the swiftness with which humanity will shift away from fossil fuels to renewable energy.

Slovak Republic as member of EU elaborated and approved Recovery Plan, which is covenanted to fulfill NextGenerationEU goals in years 2021 – 2027. As stated in chapters 1.4.2 and 1.6.2 of Slovak National Recovery Plan (2021) investments tend to support the construction of new renewable energy capacities and the modernization of existing ones with goal producing electricity from renewable resources in the total volume of 220 MW of installed capacity as contribution to the reduction carbon intensity of energy and support the achievement of the EU target.

Recent findings of EU Joint Research Center (JRC) (2021) says although nuclear as a source of energy produces very low greenhouse gas emissions, the management of nuclear waste raises doubts about sustainability. Slovak ministry of Economy also stated in energetic and climatic documents (2019) to avoid using coal as energetic resource and gradually abandon from non-liquid fossil fuels as coal.

In accordance with mentioned investments there should be also considered Life Cycle Assessment (LCA), a well-established methodology for assessing the energy and environmental performances associated with all stages of a system's life cycle regulated by the international standards of ISO. (Beccali et al., 2016) However, the LCA method provides a limited basis for evaluating future technology improvements and changes in economic and energy structure as it only reflects current or historical realities. (Huang and Eckelman, 2020; Chen et al., 2021). It is important to bear in mind, that LCA does not consider changes in technology in its analysis – all the results of LCA are based on the indicators and values set in the past. According to several authors, the term 'life cycle' refers to supply chains of products and does not consider consumption patterns. Most studies use a product as a research object, in form of a good, service, or product service system. (Bieser and Hilty, 2018; Pohl et al., 2019)

In case of LCA, the first step in doing a LCA is collecting data on the environmental impact of the different processes involved, from extracting raw materials to transforming them in a factory (Campoy, 2009). As mentioned by Zink-Geyer (2016) LCA results in a set of environmental impact indicators per product or service. As stated by Joint Research Center (2021) when selecting between two or more choices, decision makers may use LCA to compare and choose the product or method that has the least impact on the environment and human health. It gives a comprehensive picture of environmental consequences across all phases of the life cycle, identifying hotspots that may be improved in the process to meet environmental goals. As defined by Suski et al. (2020) consumption is defined as an economic transaction that results in market activity in the articles of consequential LCA. Discussions and advances in the field of LCA on the consequential approach are key contributions. Consumption reduced to the act of buying, on the other hand, is shallow when contrasted to a holistic, integrated approach to assessing sustainable consumption. According to the European Commission's Better Regulation Toolbox (2015), LCA is well adapted to offer complete, integrated environmental evaluations that aid in the establishment of national and international regulations.

The development of a complete LCA (including manufacturing, operation, and end-of-life) for complex systems can be a time and human resources intensive exercise.

(Beccali et al., 2016) For this reason, to have simplified and quick calculation tools for assessing the energy and environmental aspects of energy resource during their life cycle seems useful to support researchers, designer and decisionmaker to understand advantages and disadvantages. As described by Suski et al. (2020) The development of LCA might be considered an easy task in one regard - It always aligns with other disciplines and methods, such as mechanical engineering to describe material and energy flows in the production system or economics in the case of consequential LCA. Therefore, to develop LCA to raise questions of consumption, reviewing concepts in other disciplines is commonly used methodological approach.

3 Methodology

This part of paper describes methodology of research, it summarizes methodological framework, objectives, used methods, data sources, and pre-defined assumptions.

Assessments based on energy modeling usually fail to consider the environmental profiles of energy systems as they mainly focus on energy use and direct emissions. (Chang et al.,2017) Although energy models may include some environmental aspects through emission factors. Soft- and hard-linking approaches are used to hybridize models. (Huang and Eckelman, 2020) In soft linking approaches, the results are transferred from one model to another, while in hard-linking approaches, the models are integrated into one comprehensive model. In this case study the hard-linking approach was used. In this paper is used a general methodological framework for LCA according to ISO 14040 as illustrated in figure 1 below.

Primary objective of this study is to describe environmental aspects of an investment in case study, particularly how CF of firm’s activities varies in relation to changing national primary energy mix.

Computation of direct emissions – emissions produced by energy consumption – its secondary objective of this paper, as well as change in tariff charged for energy consumption in relation to primary energy mix.

The very first step was review of existing literature - the search, organization and selection of papers published in well-known databases, such as Web of Science and Scopus. Search in databases was realized with main keywords and their mutual combination: life-cycle assessment (and its variations), carbon footprint, solar system.

Methods used in this paper: The LCA is a relative method that is structured by the functional unit, according to the requirements of EN ISO 14040 and EN ISO 14044. The functional unit used in this paper is 1 kWh net energy provided to the grid, respectively the electricity power obtained through solar system in case study. Auxiliary power is factored into the efficiency and hence subtracted ahead of time. Because all environmental consequences are represented in terms of kWh, they may be compared to other research. Beside LCA is in this paper also used observation, analysis, synthesis, and benchmarking.

After defining the assumptions regarding the median values for individual primary energy sources, the LCA coefficient was calculated, similarly as in study of Mekkonen et al. (2016):

$$LCA_{coef,total} = \sum_{s} (E \times EM[s] \times LCA\,[s]$$

where E stands for the electricity production (kWh), EM[s] the relative contribution of energy source s in the primary energy mix in Slovak Republic (%), and LCA [s] is the median value of emissions per source used in life cycle of electricity produced from energy source s (kg/kWh). LCA is related to the three major stages of the supply chain: fuel supply, construction, and operation and therefore it provides useful information how CF varies in "the whole picture".

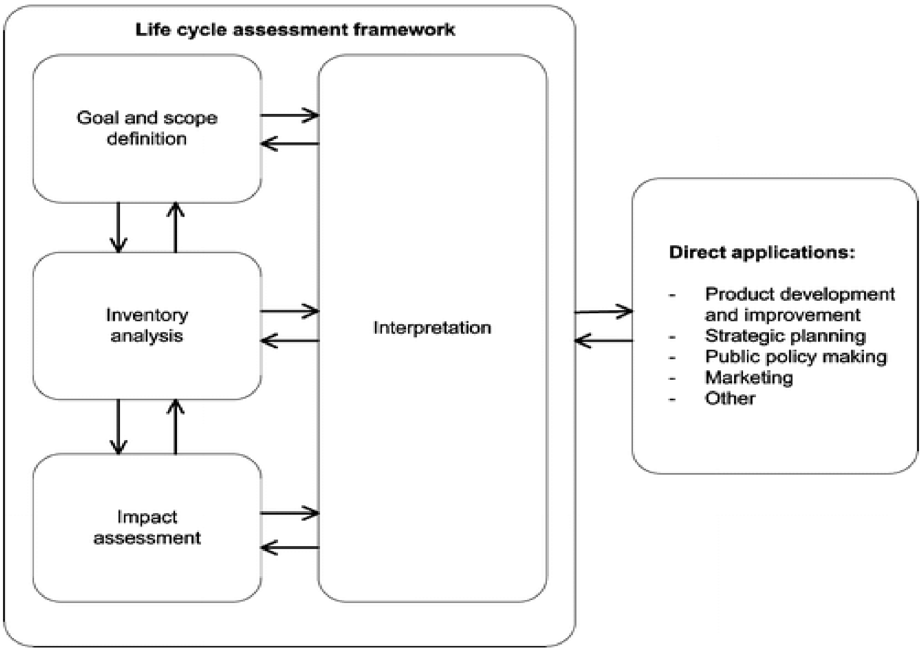

Fig. 5 General methodological framework of LCA. (EN ISO 14040, 2006)

LCA method could be carried out in different ways: attributional, consequential, and hybrid. (Guinée et al., 2018) This paper approach is based on hybrid model of LCA, however it deals with attributes of emissions depending of set factors and consequences in form of CF.

To approximate benchmark level to compare CF in case study using solar system while fixed energy consumption, study uses data of Slovak Powerplants from years 2017 and 2020. Year 2017 was chosen as starting point in analysis. Year 2020 as the most recent according to reachable data, to benchmark CF in relation with changes in primary energy mix. Year 2027 is containing targeted values by Slovak Republic and EU.

Data mining for this research was done from various sources:

- case study of small firm operating own solar system provides useful information about the capacity of energy that firm is able to produce by itself;

- websites of Slovak National Powerplants, Statistical Office of Slovak Republic, Recovery plan of Slovak Republic: used for the comparison of primary energy mix in time series and planned change in an energetic infrastructure;
- publication of European Central Bank (ECB) for predicted inflation in energetic sector: ECB staff macroeconomic projections for the euro area. (ECB, 2021)
- existing literature used to compute: LCA, CF difference, and median values of emissions produced per energy source. (Hunt, 2001; Ármannsson, 2003; Parliamentary Office of Science and Technology, 2006)

As stated in several methodological chapters of studies, LCA practitioner or researcher needs to find reasonable assumptions to carry out LCA analysis. (Suski et al., 2020; Guinée et al., 2018)

Pre-defined assumptions this study considered:

- for computing emissions is used composition of primary energy mix for year 2017 as a starting point and data for year 2020 as the most recent. For year 2027 is used relative share of energy resources according to mentioned official National documents to meet target of NextGenerationEU;
- as there is no specification which renewable resources will be targeted primary, the share will be divided proportionally among renewable resources according to actual values;
- consumption of kWh contained in this paper will arise from case study data of year 2019. Year 2019 is better to illustrate energy heftiness and requirements, as in years 2020 and 2021 were data strongly influenced by COVID-19 restrictions and closed facility due to lockdowns;
- to simplify analysis, study assumes all factors ceteris paribus and deals with changes in primary energy mix of Slovak Republic.

4 Results

In this part of paper is continually described how analysis of LCA of selected case study was approached. According to case study data it is possible to illustrate how much energy was self-produced. Self-efficiency is expressed as a difference between energy production and consumption is illustrated in figure 2 below. Green line represents the amount of kWh the firm was able to produce, and orange columns shows actual energy consumption for given month, marked from 1 to 12, as 1 stands for January, etc. Obviously in months with more sun light there is bigger production. It is observable that in given geographical location there is sharper decline in production of energy in autumn period in September in contrast to August than is continual growth from March until June.

Table 1 illustrates aggregate data from case study. Beside total production and consumption in given years there is also average value of tariff firm was charged. Vale of tariff is given as average per calendar year, as there are discrepancies in tariffs during the year according to season. Values from year 2019 of case study are used as fixed for all computations because of reasons mentioned in pre-defined assumptions. For year 2021 data are incomplete, covering only half of a year.

Table 22 Aggregate data from case study. Source: Authors processing.

	2017	2018	**2019**	2020	2021*
consumption (kWh)	41305	41826	**40925**	12220	7850
production (kWh)	6837	10515	**10592**	4170	3985
difference (kWh)	34468	31311	**30333**	8050	3865
tariff per unit – average (€)	0,0710	0,0790	**0,0808**	0,0988	0,0930

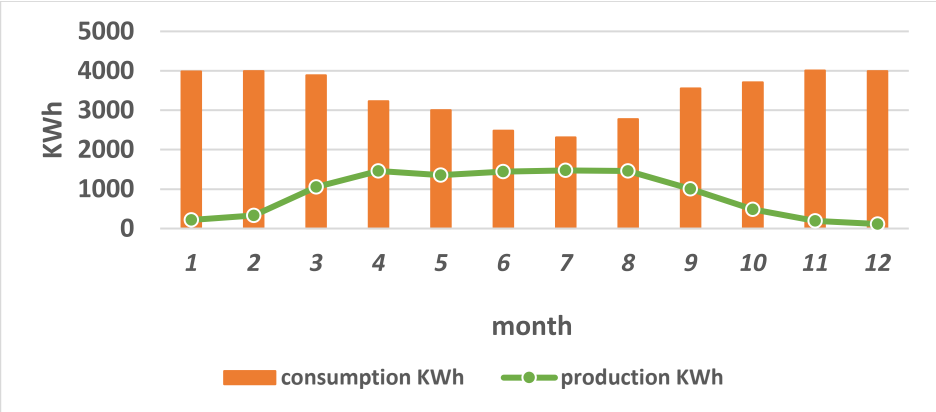

Fig. 6 Energy self-efficiency of case study after solar system installation. Source: Authors processing.

Table 2 contains data about quantity of CO2 emissions according to source used for energy consumption. There is also stated the median value of emissions which varies depending on primary energy source of power plant. Table 2 shows how primary energy mix (PEM) of Slovak Republic has changed in the observed time period. According to data of Slovak Powerplants and Statistics Office of Slovak Republic, in 2020 powerplants generated 18,773 GWh of electricity in total. Net electricity delivery of Slovak Powerplants in 2020 in total was at 16,994 GWh. As much as 95 % of electricity delivered was generated without direct carbon dioxide emissions – combining nuclear, hydroelectric, photovoltaic and biomass.

In comparison with year 2017 resources has changed according to powerplants annual records as described in table 2. There was decrease in share of coal in PEM, what leads to decreasing CF caused by energy production, as the coal is the most burdening fuel for energy production in the whole life-cycle point of view. As seen in table 2, the nuclear powerplants increased their share in PEM from approximately 52% to 83,5%. As mentioned earlier, nuclear energy is the purest one from the ways humanity obtains energy, but there are still many different opinions when discussion come to liquidation of nuclear waste.

Table 23 CO2 emissions per energy source, median value of CO2 in life cycle, relative share of energy sources in PEM of Slovak Republic. Source: Authors processing according to (Ármannsson, 2003; Hunt, 2001, Parliamentary Office of Science and Technology, 2006; Slovak powerplants, 2021; Statistics Office of Slovak Republic, 2021; Recovery Plan, 2021)

	g CO2 per kWh – source	kg CO2 per kWh – median of life cycle	share in PEM of SR 2017	share in PEM of SR 2020	targeted share in PEM of SR 2027
gas	0,5	622	0,07	-	-
oil	0,65	NA	-	-	-
coal	0,9	1041	0,12	0,05	-
nuclear	0,005	17	0,52	0,835	0,85
solar	0,058	39	0,007	0,001	0,005
biomass	0,0	46	0,05	0,01	0,025
water - pumped	0,02	18	0,13	0,09	0,1
water	0,005	18	0,04	0,02	0,02
wind	0,005	14	-	-	-

Values in table 2 show the amount of CO2 emissions and CF according to used energy resource, during to whole life cycle – from extracting to generating power. Values were used to identify, if there is not large deviation from median values, same as referred in EN ISO 14044: Environmental management - Life cycle assessment - Requirements and guidelines. Table 3 contains values of computed LCA coefficient according to case study data and data in previous tables 1 and 2. In table 4 is stated how differs CF of case study.

Table 24 Values of LCA determined by energetic mix in Slovak Republic and its relative share

Source of energy	Relative share	LCA coefficient
	2017	
gas	0,07	622
biomass	0,05	46
nuclear	0,52	17
water	0,17	18
coal	0,12	1041
solar	0,007	39
	2019	
biomass	0,01	46

nuclear	0,835	17
water	0,11	18
coal	0,05	1041
solar	0,001	39
	2027*	
biomass	0,025	46
nuclear	0,85	17
water	0,12	18
solar	0,005	39

Table 25 Production of CO2 by firms' activities with fixed consumption and production of solar energy by firms' solar system

Year	Production CO2 with solar system	Production CO2 without solar system	difference
2017	6036 tons	7587 tons	1551 tons
2019	2508 tons	2826 tons	318 tons
2027 (predicted)	958 tons	735 tons	-223 tons

As seen in table 3, LCA coefficient is changing as is changing PEM of Slovak Republic. Assumed on results, CF in case study has decreased. Thus, it is possible to conclude, that investment in solar system has also met the conditions of environmental aspects, beside the economical. Only two years after investment in solar system, the investment in solar system is losing its environmental advantage as it is possible to see in table 4.

Significant difference of case study is seen between years 2017 and 2019, as illustrated in table 4. For the same amount of energy was the whole LCA decreased from 7587 tons to 2826 tons in total. In relative deliverance, in 2017 Slovak Republic emitted 0,18 tons of CO2 per kWh during life cycle, while in 2019 it was only 0,07 tons of CO2 per kWh.

5 Conclusions

As a result of this paper, it is possible to state, that investing in solar system in this case study can bring the desired results if we look at the problem through LCA analysis - the carbon footprint has been reduced, the burden on the environment has decreased when expressed through the amount of CO2 emissions. Case study showed that change in structure of PEM of Slovak Republic has changed the environmental advantage of solar system. Mentioned result is consequence of gradual withdrawal from the use of coal as the primary energy source in the PEM, and its replacing with nuclear energy and renewable resources. In the other words, solutions that bring benefits 2 years ago are starting to lose their advantage in very short time.

This particular case study showed that transition to renewable resources is bringing along a question of increasing energetics tariffs and payments. Investing in new infrastructure, technologies, and ways of producing power might lead to increase of price.

As this paper was following pred-defined assumptions: fixed energy production of firm solar system, as well as the fixed energy consumption as in the default year 2019; all the covenants intervening from European Union (European Commission), National authorities will be fulfilled according to Recovery plan of Slovak Republic and NextGenerationEU to obtain financial resources; then from the environmental aspect the carbon footprint of this case study might be significantly higher just ten years after investment, nevertheless solar panels should be one of renewable resources that help to reduce environmental load of human activities.

If all the assumptions of this paper are fulfilled, then there might be situation, that environmental solution might after few years come to state, when it will not be serving its purpose, by contraries it may lead to bigger environmental and ecological burden.

From presented paper it may be obvious, that biggest change in PEM was mainly by increasing the share of nuclear power. Question for future research might be in place if humanity has sustainable plan to operate with nuclear waste.

Presented case should be helpful warning for public discussion with policy makers, as well as the politicians, as not every solution at first glance, an ecological solution can meet the parameters even in the time horizon of five or ten years. The basis not only for National Authorities or European Union, but for whole world should be the environmental approach, but also its sustainability. The reason is that the current problem does not move half a generation later, when resources, whether material, financial or human, may not be available.

References

1. Ármannsson, H. 2003. CO2 emission from Geothermal Plants. In International Geothermal Conference, Reykjavík, Sept. 2003. Session 12. p. 56 – 62.
2. Beccali, M., Cellura, M., Longo, S., Mugnier, D. 2016. A simplified LCA tool for solar heating and cooling systems. International Conference on Solar Heating and Cooling for Buildings and Industry. Energy Proceedia 91 (2016) 317 – 324.
3. Bieser, J., Hilty, L., 2018. Assessing indirect environmental effects of information and
4. communication technology (ICT): a systematic literature review. Sustainability 10, 2662.
5. British Petroleum company website. 2020. Sustainability report 2020. Reengineering energy.(http://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/sustainability/group-reports/bp-sustainability-report-2020.pdf
6. Campoy, A. 2009. Hot Job: Computing pollution. In Wall Street Journal. (http://www.wsj.com/articles/SB125176415696374409)
7. Chang, Z., Wu, H., Pan, K., et al., 2017. Clean production pathways for regional power-generation system under emission constraints: a case study of Shanghai, China. J. Clean. Prod. 143, 989-1000.

8. Chen, S., Liu, Y.-Y., Lin, J., Shi, X., Jiang, K., Zhao, G. 2020. Coordinated reduction of CO2 emissions and environmental impacts with integrated city-level LEAP and LCA method a case study of Jinan, China. Advances in Climate Change Research – article in press.
9. Delre, A., ten Hoeve, M., Scheutz, C., 2019. Site-specific carbon footprints of Scandinavian wastewater treatment plants, using the life cycle assessment approach. J. Clean. Prod. 211, 1001–1014.
10. EN ISO 14400: Environmental management - Life cycle assessment - Principles and framework.
11. EN ISO 14044: Environmental management - Life cycle assessment - Requirements and guidelines.
12. European Central Bank. 2021. ECB staff macroeconomic projections for the euro area. https://www.ecb.europa.eu/pub/pdf/other/ecb.projections202109_ecbstaff~1f59a501e2.en.pdf
13. European Commission. The European green deal. 2019. https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_fr.
14. European Commission, 2015. Better Regulation Toolbox. (http://publications.jrc.ec.europa.eu/repository/bitstream/JRC105145/)
15. European Commission. 2021. The EU's 2021-2027 long-term Budget and NextGenerationEU. Facts and Figures. Luxembourg: Publications Office of the European Union, 2021. ISBN 978-92-76-30627-6
16. Guinée, J.B., Cucurachi, S., Henriksson, P.J.G., Heijungs, R., 2018. Digesting the alphabet soup of LCA. Int. J. Life Cycle Assess. 23, 1507 e15 11.
17. Huang, K., Eckelman, M.J., 2020. Appending material flows to the National Energy Modeling System (NEMS) for projecting the physical economy of the United States. J. Ind. Ecol. 1e15.
18. Hunt, T.M. 2001. Five lectures on environmenta effects of geothermal utiliztion. United Nations University. Geothermal Training Programme 2000 – Report No. 1, p. 9-22. Reykjavik, 2001. ISBN - 9979-68-070-9.
19. Joint Research Center. 2021. JRC science for policy report. Technical assessment of nuclear energy with respect to the no significant harm' criteria of Regulation (EU). European Commission. Petten: European Commission, 2021. (http://ec.europa.eu/info/sites/default/files/business_economy_euro/banking_and_finance/documents/210329-jrc-report-nuclear-energy-assessment_en.pdf)
20. Lombardi, M., Laiola, E., Tricase, R., Rana, R. 2017. Assessing the urban carbon footprint: an overview, Env. Impact Assess. Rev. 66 (2017) 43–52.
21. Maktabifard, M., Zaborowska, E., Makinia, J. 2020. Energy neutrality versus carbon footprint minimization in municipal wastewater treatment plants. Bioresource Technology 300 (2020) 122647
22. Mekonnen, M., Gerbens-Lens, P.W., Hoekstra, A. 2016. Future electricity: The challenge of reducing both carbon and water footprint. Science of the Total Environment 569–570 (2016) 1282–1288.
23. Ødegaard, H., 2016. A roadmap for energy-neutral wastewater treatment plants of the future based on compact technologies (including MBBR). Front. Environ. Sci. Eng. 10, 2095 2201.
24. Parliamentary Office of Science and Technology. 2006. Carbon footprint of electricity generation. (http://www.parliament.uk/documents/post/postpn268.pdf)
25. Pohl, J., Suski, P., Haucke, F., Piontek, F.M., Jager, M., 2019. Beyond production the relevance of user decision and behaviour in LCA. In: Teuteberg, F., Hempel, M., Schebek,

L. (Eds.), Progress in Life Cycle Assessment 2018. Springer International Publishing, Cham, pp. 3e19.

26. Recovery Plan of Slovak Republic (Plán Obnovy). 2021. Published by Ministry of Finance of Slovak Republic. May 2021. (http://www.mfsr.sk/files/archiv/1/Plan_obnovy_a_odolnosti.pdf)
27. Slovak Ministry of Economy (Ministerstvo hospodárstva). 2019. National integrated energetic and climate plan for years 2021 – 2030 (Integrovaný národný energetický a klimatický plán na roky 2021 – 2027). Bratislava, December 2019. (http://www.economy.gov.sk/uploads/files/IjkPMQAc.pdf)
28. Slovak Powerplants. 2020. Key information (http://www.seas.sk/key-information)
29. Suski, P., Speck, M., Liedtke, Ch. 2020. Promoting sustainable consumption with LCA e A social practice based perspective. In Journal of Cleaner Production 283 (2021) 125234.
30. Tuel, A., Eltahir, E.A.B., 2020. Why is the Mediterranean a climate change hot spot? In Journal of Climate vol. 33., issue 14, p. 5829–5843. 2020. ISSN: 0894-8755
31. Xiao-Ming, H., Jie-Ru, M., Ying, J., Ming, C., Yun-Qi, K. 2021. Inferring future warming in the Arctic from the observed global warming trend and CMIP6 simulations. In Advances in Climate Change Research. (Article in press). ISSN: 1674-9278
32. Xu, J., Li, Y., Wang, H., Wu, J., Wang, X., Li, F., 2017. Exploring the feasibility of energy self-sufficient wastewater treatment plants: a case study in eastern China. Energy Proc. 142, 3055–3061.
33. Xu, L., Wang, A., Yu, W., Yang, S. 2021. Hot spots of extreme precipitation change under 1.5 and 2 C global warming scenarios. In Weather and Climate Extremes 33 (2021) 100357. ISSN: 2212-0947
34. Zink, T., Geyer, R. 2016. There Is No Such Thing as a Green Product. In Stanford Social Innovation Review, Spring 2016, p. 26 -31. ISSN: 1542-7099.