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ENERGY INDICATORS AND TOPICS IN FOOD SUPPLY CHAINS' LIFE CYCLE ASSESSMENT

ENERGETSKI KAZALCI IN VSEBINE V CELOSTNEM VREDNOTENU OKOLJSKIH VPLIVOV PREHRAMBENIH OSKRBOVALNIH VERIG

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Keywords: energy, food supply chain, life cycle assessment, Leximancer

Abstract

Food supply chains have a significant impact on the environment, using large amounts of fossil energy resources and other non-renewable resources. Energy is directly and indirectly needed in all the steps along the food supply chain. This paper explores energy-related indicators in food supply chains and life cycle assessment within sixty-six research papers, gathered from the Web of Science database. Furthermore, a quantitative content analysis was carried out to assess the research trends and future opportunities regarding energy-related topics. The results revealed that a holistic perspective is needed, as energy-related indicators should be included in the use and end-of-life stages, not only in the production processes, and that the inclusion should follow the life cycle assessment methodology. The current research topics are energy issues related to production processes and environmental impacts. Improvements are possible in extending research areas to renewable resources, whole life-cycle perspectives, and socio-economic consequences.

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Povzetek

Prehrambene oskrbovalne verige pomembno vplivajo na okolje, saj v procesih uporabljajo veliko količino fosilnih goriv in drugih neobnovljivih virov. Energija je neposredno in posredno potrebna v vseh korakih prehrambene oskrbovalne verige. Članek obravnava energetske kazalnike v celostni oceni življenjskega cikla prehrambenih oskrbovalnih verig, in sicer v šestinšestdesetih raziskovalnih člankih, zbranih iz podatkovne baze Web of Science. Poleg tega smo izvedli kvantitativno vsebinsko analizo, da bi ocenili trende raziskav in priložnosti v prihodnosti. Rezultati so pokazali, da je potreben celovit pogled, saj bi morali biti energetski kazalniki vključeni v fazo uporabe in ob koncu življenjske dobe, ne le v proizvodnih procesih. Vključitev kazalcev za izračun kategorij vpliva bi morala slediti metodologiji celovitega ocenjevanja življenjskega cikla. Trenutne raziskovalne teme povezujejo energetske vsebine s proizvodnimi procesi in posledično vplivi na okolje. Izboljšave so možne pri razširitvi raziskovalnih področij na obnovljive vire, celotni življenjski cikel in družbeno-ekonomske vsebine.

1 INTRODUCTION

Food supply chains have huge impacts on the local and global environments, as they heavily depend on fossil fuel energy supply and other non-renewable resources, *[1]*. Energy is needed in all steps along the food supply chain: in the production of crops, fish, livestock and forestry products; in post-harvest operations; in food storage and processing; in food transport and distribution; and in food preparation. The direct and indirect energy used in the food supply chain is represented in Figure 1. Direct energy includes electricity, mechanical power, as well as solid, liquid, and gaseous fuels. Indirect energy refers to the energy required for manufacturing inputs such as machinery, farm equipment, fertilizers and pesticides, *[2].* The Food and Agricultural Organization of the United Nations (FAO), *[2]*, further argues that the energy type used in the food chain and the way it is used in large determine whether food systems can meet future food security goals and support broader development objectives in an environmentally sustainable manner, *[2].*

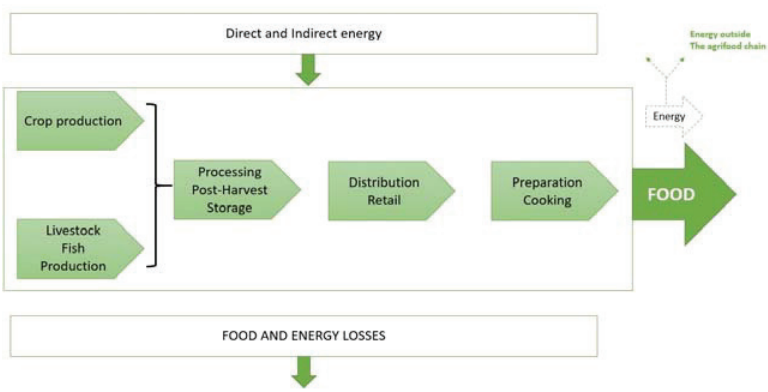

***Figure 1**: Direct and indirect energy use in food supply chains (adapted from [2])*

As reported by the European Commission, the food sector contributes to 23 per cent global resource use and 31 per cent acidifying emissions, *[3].* Also, Noya et al., *[4]*, reported that a large amount of resources is required for food production and a great deal of food waste is formed in food supply chains throughout the life cycle. Consequently, the food sector is responsible for around 20 per cent of greenhouse gas emissions, which are expected to expand in a correlation with the global food demand, *[5].* FAO, *[2]*, projections indicate that by 2050 a 70 per cent increase in food production over 2005-2007 levels will be necessary to meet the expanding demand for food. Therefore, the need for a transition from fossil to sustainable resource usage for a global food supply chain exists, *[6].* To approach the transition, an understanding of energy demand and resources usage related to the environmental impacts is a prerequisite, *[7].*

Life cycle assessment (LCA) is an approach that evaluates all the stages of a product's life. During this evaluation environmental impacts from each stage are considered, from raw material acquisition, processing to distribution and use, and finally disposal, recycling, etc. This methodology considers not only the material flows but also the outputs and their environmental impacts, *[8].* The LCA methodology was standardized with ISO 14040, *[9]*, and ISO 14044, *[10]*, and consists of the following main steps: goal and scope definition, inventory analysis, life cycle impact assessment and interpretation. As claimed by McAuliffe et al., *[11]*, LCA is considered to be one of the most informative tools to quantitatively compare environmental performances of multiple food consumption strategies. Arvidsson and Svanström, *[12]*, argue that many different energy indicators are used in LCA studies to account for energy issues in various ways, where their application and choices are poorly described.

The goal of this paper is two-fold. First, to obtain an in-depth view of the energy-related indicators in food supply chain LCA studies to assess their current state-of-the-art, usage, transparency and consistency. Second, to identify research areas and topics related to energy issues and LCA, by using quantitative content analysis to assess trends and opportunities in future research. Thus, sixty-six LCA food supply chain scientific papers, published from 2009 to 2019 were systematically reviewed and elaborated.

2 METHODS

Our research is based on scientific papers found in the Web of Science only, as it represents the most comprehensive scientific databased of publications with impact factors. For the search purposes keywords “LCA” and “food supply chain” were used. The review was carried out at the beginning of 2019. Conference papers, proceedings, and monographs were not considered, as our interest was identifying purely scientific publications with impact factors, which went through the strict and in-depth review process, assuring their novelty and added value to the scientific community. Two-hundred and forty-four such papers were identified. Reading titles, abstracts, and keywords revealed that not all are suitable to be included in our study as they included unrelated topics, for example, water supply, food packaging, and did not include LCA as such. Thus, we have ended up with sixty-six suitable papers, with which we have focused on energy indicators and quantitative content analysis.

When researching energy indicators in the existing LCA studies to identify the state-of-the-art, the illustration of the energy indicator generated by Arvidsson and Svanström, *[12]*, was considered as a framework. See Figure 2.

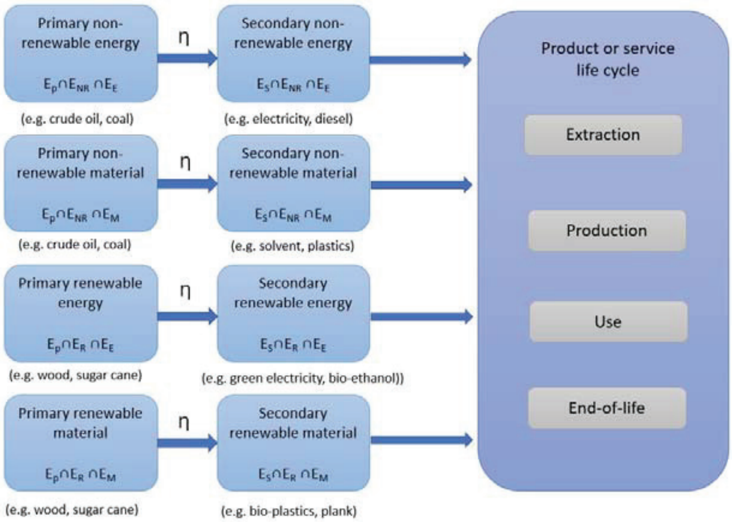

Figure 2: *A graphical illustration of the suggested framework for energy indicators in LCA, [12]*

The quantitative content analysis, including both thematic and semantic analyses, was carried out using Leximancer software, version 4.5, which can identify core concepts and their correlations. Leximancer uses statistical algorithms, integrating nonlinear dynamics and machine learning, enabling a quantitative content analysis by determining concepts' presence in textual documents, so manageable categories and relationships can be formed, *[13].* Consequently, a result is a concepts list with relationships visualized via a concept map, *[14].* The themes importance is expressed by the circles colour, where the "hottest" or most important theme appears in red, and the next "hottest" in orange, etc., according to the colour wheel. Concepts within the themes (coloured circles) are strongly related to the theme in which the concept is located. Another sign of importance is the circles' size (the size indicates how many concepts have been clustered together). The distance between concepts shows concepts relations, *[15]*, in which semantically less related concepts are mapped apart, while close concepts even overlap, *[16].* Baldauf and Kaplan, *[17]*, argued that the software is appropriate for exploratory research as it produces high concept extractions and thematic clustering reliability and reproducibility.

3 RESULTS

The results section represents the papers' analyses, including energy-related indicators and Leximancer's thematic and semantic results. Energy-related indicators were evaluated according to the framework Arvidsson and Svanström, *[12]*, which we have modified, see Table 1.

Table 1*: Fraction (in %) of energy indicators and energy data used in LCA food supply chain*

Life cycle	Primary non-renewable energy	Secondary non-renewable energy	Primary renewable energy	Secondary renewable energy
Extraction	0	12	2	2
Production	0	100	4	19
Use	0	8	0	2
End-of-life	0	10	0	0

In the energy indicators and data search, we have identified fifty-two papers (out of sixty-six). Table 1 indicates that within the fifty-two papers, all contained the energy secondary non-renewable energy indicator, mostly calculated as electricity or diesel fuel used; 12% of the fifty-two papers considered secondary non-renewable energy, mostly in the cultivation of plants processes within the extraction phase. Jez et al., *[18]*, considered primary and secondary renewable energy by exploring oil production from micro-algae and terrestrial oilseed crops. Freon et al., *[19]*, compared the use of natural gas and fuel within fishmeal plants, while Miah et al., *[20]*, compared direct natural gas energy and indirect electricity energy. However, the authors did not consider primary non-renewable energy, and only 2% of the papers considered primary renewable energy indicators/data. Within the reviewed papers, the authors only briefly mention the energy considered in their calculations and do not specifically determine, which kind of energy data or indicators are included in the results. As indicated in Table 1, energy-related indicators or data mostly focused on the production processes.

Regarding the methodology and indicators, it is important to mention the third LCA step (i.e., LCIA), in which 20% of studies “energy impact category” emerged, e.g., primary energy demand, cumulative energy demand indicator (CED), non-renewable energy demand, etc., which is later discussed.

Sixty-six reviewed papers were examined using Leximancer software to determine the main concepts related to energy within the LCA food supply chain studies. Non-relevant words, such as “year”, “study”, “using”, “figure”, “table”, etc., were excluded. The concepts were then collected into themes (see Figure 3).

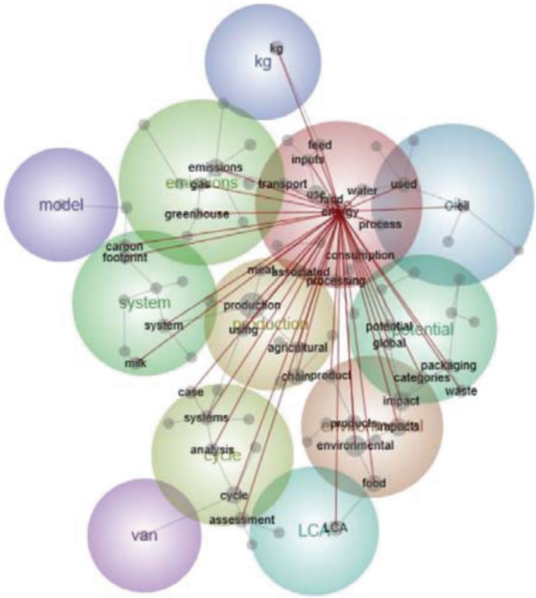

Figure 3: *Energy-related concepts*

The content analysis results indicated that *use*, *environment* and *production* are the most dominant themes, and the most dominant concept clusters within them (within individual circles) are "energy", "production", and "environmental impacts". Thus, the "energy" concept cluster covers "use", "consumption", "processes", "water", "inputs", "feed", and "transport", showing a close interlinkage between these concepts. Our main research topic was the energy-related issues in LCA of food supply chains; thus, a focus was given to the "energy" concept, see Figure 3 and its relations to other concepts. The "energy" concept is closely related to concepts of "production" and "environmental impacts".

Related Word-Like	Count	Likelihood
demand	1005	60%
inputs	617	25%
water	991	24%
consumption	1027	24%
efficiency	298	23%
materials	455	23%
use	1787	21%
gas	612	18%
greenhouse	364	17%
primary	262	17%
increase	241	17%
process	457	16%
land	393	16%
local	243	16%
associated	406	15%
reduce	231	15%
distribution	302	14%

Figure 4: *The "energy" concept ranking table*

To get a more in-depth view, we ran another analysis, the concept ranking table (see Figure 4), to explore and indicate the relevance of the concept (in %) and their likelihood. This represents a measure: a relative strength indicator of a concept's occurrence frequency. As shown in Figure 4, 60% of the text containing the concept "energy" also contains the concept "demand", and express a conditional probability if the data discuss "energy" then "demand" will also be mentioned, followed by concepts "inputs", "water", "consumption", and "use".

4 DISCUSSION AND CONCLUSIONS

In fifty-two papers out of sixty-six, we have identified energy-related indicators and data. The studies mostly cover production processes, identifying environmental impacts from electricity or diesel use (secondary non-renewable energy). Eight per cent of papers covered all the life cycle phases (extraction, production, use, and end-of-life), while primary non-renewable resources (crude oil, coal) were not considered. This shows that the system boundary for the studies was narrowed down and the cut-off criteria were employed. However, such narrowing processes might be uncertain in terms of comprehensiveness and transparency, as the FAO, *[2]*, claims that supply chains are highly dependent on fossil fuels, and could have a high impact on the obtained results. It is also interesting that authors did not consider renewable sources at the end-of-life-stage as materials, because other resources can be re-used, re-cycled, especially when considering principles of the circular economy.

Furthermore, twenty per cent of studies used energy-related indicators in the stage of LCIA as impact categories, which might also be arbitrary, from the LCA methodological perspective, as they are indicators, not the impact categories. Turconi, *[21]*, argued that impact categories should not be confused with lifecycle energy indicators such as CED (normally expressed as energy input per unit of product, i.e., kWh electricity), which is often used with power generation technologies to assess their performance. Also, Huijbregts et al., [22], states that CED can serve as a screening indicator for environmental performance, but its usefulness as a stand-alone indicator for environmental impact is very limited. Product environmental performance guides, *[23]*, further suggest that the identification of the most relevant impact categories shall be based on the normalized and weighted results, and at least three relevant impact categories (e.g., global warming, acidification, eutrophication, etc.) shall be considered; the results shall not be represented via one impact category or even one indicator.

Considering a quantitative content analysis, the energy theme emerged as significant within the LCA supply chain studies, which is expected as the food supply chain processes heavily depend on energy sources, directly and indirectly linked to all the life cycle stages; thus, energy demand emerged as most significant. The quantitative content analysis also revealed the main research areas: energy, production, and environmental impacts, which are also related, as LCA studies of the food supply chain evaluated production processes and their environmental impacts. However, the concept perspective of energy theme within the studies is limited by processes, consumption and transport. This opens up a need for an extension of research contents within the LCA, especially the importance of renewable resources, and end-of-life options (such as the circular economy) or various products' usage at the end-of-life. This will also assure a comprehensiveness of the LCA, not focusing only on the production stage. However, energy-related issues did not reveal any role of economic or societal related topics, the integration of which would be interesting.

To summarize, our study argues that including energy-related indicators is of utmost importance to obtain a holistic perspective. However, they should be more comprehensive, comprising (besides extraction and production stages) use and end-of-life, the data acquisition of which might be very demanding. Furthermore, indicators' inclusion should follow the LCA methodological rules, as suggested. We have identified that room for improvement exists within energy-related issues in the LCA food supply chain studies, embracing renewable resources, whole life-cycle perspective, and socio-economic topics.

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APPENDIX

A list of papers included in our study.

Paper No.	Paper
1.	Arnal, Á., Royo, P., Pataro, G., Ferrari, G., Ferreira, V., López-Sabirón, A., & Ferreira, G. (2018). Implementation of PEF Treatment at Real-Scale Tomatoes Processing Considering LCA Methodology as an Innovation Strategy in the Agri-Food Sector. *Sustainability*, *10*(4), 979.
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