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CO2 HOTSPOTS IDENTIFICATION IN SUPPLY CHAINS OF DIFFERENT PRODUCTS

Summary: The article presents an analysis of supply chains of different products based on case study research from the three European countries with the use of Supply Chain Environmental Analysis Tool (SCEnAT). The comparative analysis of gathered data allowed to recognize the CO2 hotspots in researched supply chains. The research implications of the paper lead to identification of processes/supply chains' parts with the highest environmental aspects. The practical implications of the paper are the possibilities of influencing recognized carbon dioxide hotspots with best practice recommendations. The article is based on the findings from an international project PrESS.

Keywords: CO2 hotspots, sustainability, supply chain management.

JEL Classification: M14, Q56, Q01.

Introduction

One of the most important challenges for current supply chains is environmental protection. The scarcity of natural resources, declining biodiversity or air, soil and water pollution, push corporations to include environmental issues to their business goals. The precautionary principle [World Charter for Nature, 1982] and the pollution prevention approach [Pollution Prevention Act, 1990] show main direction of acting for business organisations. The precautionary principle says about the need to protect environment in any case to anticipate the possible risk and avoid harmful consequences. In broader sense, it could be used in decision making process of planning business activities without additional environmental risks. Pollution prevention is more than working in line with minimum environmental requirements. It assumes environmental friendly choices that minimise the negative effects on environment such as: waste reduction, energy efficient operations, water saving, etc. The challenge for current enterprises seems to be the shift from theoretical consideration about the environment to practical realisation and implementation into strategy.

Last years showed the rising problem of CO2 emission as a global challenge that has to be addressed by all sectors including business. The debate about possible solutions focuses on supply chains as the path of life cycle of products that generate enormous emissions. From this perspective supply chain environmental management is needed. Environmental consideration in the whole supply chain is crucial for the sustainability of the global economy. It is also the demanding issue for corporations that are going to make effort to lowering the amount of CO2 in their processes and products. There are different approaches to CO2 measurement related to the whole supply chain. Knowledge about what causes the emission should be regarded as the starting point for further green improvements of logistics processes in supply chains. In the article, a possible scenario of CO2 management, its hotspots identification and possible improvements will be presented.

1. Environmental aspects of supply chain management

Environmental issues, next to social, are noneconomic aspects of business activities, that continuously gain the relevance as a focal point of sustainable development. Any business process may be the source of environmental aspects. In the table below the exemplary environmental issues are presented.

Table 1. General environmental issues of supply chain management

Business Process	Possible Environmental Issues
1	*2*
Extraction	emissions including CO2 depletion of non-renewable resources water and energy consumption degradation of the landscape reduce biodiversity pollution of the water, air and soil (including chemical pollution) eutrophication

Table 1 cont.

1	*2*
Transportation/Warehousing/ Distribution	emissions including CO_2 noise vibration leaks natural resources depletion
Production	dangerous materials and resources emissions including CO_2 sewage noise vibration water and energy usage non-recyclable materials insufficient waste management heat emissions
Consumption	over consumption extra emission due to improper consumption waste production insufficient waste management soil, water and ground pollution exposure to dangerous materials and substances
End-of use processes	soil air and water pollution emissions

Source: Based on environmental, sustainability and social reports of companies.

The scale and scope of environmental impact will differ due to the type and size of the company and the complexity of its supply chain. The environmental consideration is the result of tightening law regulations and other motivations identified by business like e.g. expected benefits [Diabat and Govindan, 2011].

Much attention is put on international and national level to improve the living conditions and assure decent environmental quality nowadays, without compromising the needs of future generations to meet their needs under the conditions of sustainable development [Agenda 21, 1993]. It is equally seen in environmental policies and projects set by individual entities and in whole supply chains [e.g. Carter and Rogers, 2008; Kleindorfer et al., 2005; Seuring and Muller, 2008a; Seuring and Muller, 2008b]. "A focus on supply chains is a step towards the broader adoption and development of sustainability, since the supply chain considers the product from initial processing of raw materials to delivery to the customer. However, sustainability also must integrate issues and flows that extend beyond the core of supply chain management: product design, manufacturing by-products, by-products produced during product use, product life extension, product end-of-life, and recovery processes at end-of-life" [Linton, Klassen and Jayaraman, 2007, p. 1078]. The problem of environmental issues in supply chain is confronted with the concept of green supply chain [Sarkis, 2014] or sustainable supply chain oriented to ecological aspects like greener partners selection [Wu and Barnes 2016], eco-efficiency [Michelsen, Magerholm Fet and Dahlsrud 2006; Verfaillie and Bidwell, 2000] or environmental performance [Gualandris and Kalchschmidt, 2016]. The current supply chain management practices are expected to take into consideration environmental impacts and the ways to increase efficiency while reducing negative externalities [Diabat and Al-Salem, 2015]. The environmental principles used at the stage of design of supply chain cover such areas as: product design, packaging, collection and transportation, recycling and disposal, greening the internal and external business environment [Tsoulfas and Pappis, 2006]. Mentioned elements are crucial for better understanding and managing all aspects of business operations of CO2 emission.

2. CO2 emission management as a current challenge for supply chains

CO2 emission is one of the crucial environmental issues nowadays. It is estimated that it cause half of man-made greenhouse effect [Jaber, Glock and El Saadany, 2013]. The effective reduction of CO2 is the important issue for both policy makers and practitioners who are responsible for the implementation of given laws and regulations. This is supported by numerous initiatives and documents, whose role is to work out a common compromise and performance standards like e.g. New Sustainable Goals of UN Programme, COP 21 and climate Agreement or Polish Climate Policy till 2020 and Strategy of Sustainable Development of Poland till 2025 [Strategia Zrównoważonego Rozwoju Polski do roku 2025, 1999]. The CO2 emission should be linked to the life cycle because of interconnected processes and flow of materials, resources and information. Emissions reduction can be only achieved by mutual, close cooperation of all organisations in the supply chain, from upstream to downstream. It needs the accountability for both direct and indirect CO2 emissions of the value stream of products including raw materials extraction [Oshita, 2012, p. 1041]. Furthermore all stakeholders, including customers, have to be included [Plambeck, 2012, p. 564]. The knowledge about the structure of supply chains is the basis for further improvement in life cycle to sufficient CO2 reduction [Wiedmann, 2009].

The proactive approach to greenhouse gases reduction can bring many benefits for the company and the whole supply chain, e.g. reduced costs, higher revenues, better knowledge and control on the supply chain (emissions measurement in the supply chain), improved public relations, scrutinised and rationalised supply chains, improved understanding and motivation among employers, better collaboration with policy makers, improved motivation among suppliers to reduce emissions [Plambeck, 2012, pp. 564-568]. To make it possible the set of tools and methods, that help to count total emissions and recognise the hotspots in value chains, need to be introduced. It is worth mentioning such procedures and initiatives like: Greenhouse Gas Protocol, Carbon Disclosure Project, Carbon Trust or IPCC Guidelines. The focal idea of mentioned initiatives and methodologies is carbon footprint defined as "[…] a measure of the exclusive total amount of carbon dioxide emissions that is directly and indirectly caused by an activity or is accumulated over the life stages of a product" [Wiedmann and Minx, 2008, p. 4]. State-of-art managerial process of carbon footprint includes: CO2 emission in value chain identification, hotspot recognition, possible improvement scenarios analysis, strategy of further emission reduction. The possible scenarios of emissions reduction may relate to changes in: production technology, product design, transportation and distribution system design. A procedure of the above mentioned calculations will be further presented, using an example of Supply Chain Environmental Analysis Tool (SCEnAT).

3. Methodology of the CO2 hotspots identification

In order to determine the impact of companies on the environment a Supply Chain Environmental Analysis Tool (SCEnAT) was used in this article. The tool supports decision-making for green supply chain development. This advanced analytical model was developed by Koh and others [2012]. The methodology adopts different methods and techniques such as supply chain mapping, carbon measuring and supply chain performance evaluation using economic, social and environmental key performance indicators (KPIs). However, the key methodology is a traditional or process Life Cycle Assessment and Environmental Input-Output LCA [Bochtis et al., 2015].

SCEnAT analysis is based on the product supply chain map. It is designed using inputs and processes. Its visibility allows companies to identify carbon emission and CO2 hotspots (places of the highest CO2 emission in the supply chain, critical emission points). This information assists managers during designing low carbon supply chains and building transparent B2B relationships.

SCEnAT also provides many benefits for its users [Koh et al., 2011, p. 12]. Primarily, it raises awareness of all CO2 hotspots across supply chain. It also provides potential low carbon intervention solutions. What is important, the tool promotes green thinking in supply chain. Finally, it helps to understand the interventions impact on a set of supply chain three bottom line KPIs.

All case studies presented in the paper were prepared using SCEnAT methodology. The following steps of using SCEnAT can be distinguished [Koh et al., 2015]: (1) Developing a supply chain map using inputs and processes; (2) Supply chain carbon map calculation using the Hybrid LCA methodology; (3) Low carbon interventions. Choosing the best change that leads to a reduction in CO2; (4) Supply chain performance evaluation. The adequate KPIs identification and performance measurement system creation. This paper will primarily focus on the first and second step.

In conclusion, SCEnAT is a practical tool that supports building green supply chains in a transparent and comprehensive way. It bases on a wide data system, that ensures credible assessment results and effective decision making process.

4. Methodology of research and presentation of results

The research was conducted within an EU funded project – Press – Promoting environmentally sustainable SMEs. The aim of PrESS project was to develop an online decision support system (DSS) that will allow European companies monitor and assess their current strategies in relation to environmental concerns, adopt low carbon decision-making patterns, and develop a long-term plan for environmental sustainability of their supply chains. The research was divided into two parts. Quantitative survey (performed in Poland, United Kingdom and Italy) was followed by an in-depth qualitative research. The questionnaires used, were based on Zhu and Sarkis et al. [Zhu, Sarkis and Geng, 2005; Zhu, Sarkis and Lai, 2007, 2012], approach as it have been widely adopted in an international environment, thus appropriate in this case. The study was conducted from April 2014 to September 2015. A total number of 183 valid responses were obtained. The results of the quantitative study have been presented in other papers published by the authors [e.g. Kalinowski, Rudnicka and Wieteska, 2016]. Further on, companies willing to further participate in the study, were chosen to collect data for case studies. The analysed companies represented different business sectors, however for the purpose of this study only production companies have been selected (the research sample for case studies counts 11 companies).

Table 2. Characteristics of the research sample

Company – country code	Detailed description of operations	Analysed product
1 – PL	Automotive textiles manufacturer	Textile tape
2 – PL	Furniture manufacturer	Set of sliding doors
3 – PL	Printing	Book
4 – PL	Manufacturer of materials for roads construction	Mineral asphalt
5 – UK	Steel stock holder and die forgings manufacturer	Rings/flanges for pipework systems)
6 – UK	Manufacturer of solid wall insulation	INNO-THERM (recycled cotton / denim) insulation
7 – UK	Manufacturer of energy saving solutions (e.g., voltage optimisation systems)	Powerstar voltage optimisation system
8 – IT	Sheet metal processing and manufacturer	Linear pipe
9 – IT	Confectionery manufacturer	Sugar-covered toasted almond candies
10 – IT	Cold automatic printed metal sheets manufacturer	Counter frame for blinding doors
11 – IT	Packaged dried fruit manufacturer	Shelled walnuts

Source: Based on the research results.

The below three tables demonstrate results of the performed analysis for every case study.

Table 3. Data for Polish case studies

Company – country code	Analysed product (unit of analysis)	Input type	Input	Quantity	Unit	GHG Intensity [kg CO2eq/unit]	Total emissions	Proportion of emissions
1 – PL	Textile tape (1 km)	Direct Materials	Polyester	600,0	kg	7,469	4481,4	99,64%
			Paper for packaging	0,6	kg	0,8486	0,50916	0,01%
			Cardboard for boxes and spools	9,0	kg	0,84859	7,63731	0,17%
		Utilities	Electricity	14,64	kWh	0,53143	7,78013	0,17%
		Logistics	In road transport	1,56	tkm	0,13364	0,20847	0,00%
2 – PL	One set of sliding doors /1 unit (set)	Direct Materials	Chipboard	1,69	kg	0,15	0,2535	5,92%
			Mirror	1,5	kg	0,02314	0,03471	0,81%
			Metal frame	4,5	kg	0,62936	2,83212	66,18%
		Utilities	Electricity	0,0265	kWh	0,53143	0,01413	0,33%
		Logistics	Road transport chipboard	0,0169	tkm	0,13364	0,00225	0,05%
			Road transport mirror	2,25	tkm	0,13364	0,30069	7,03%
			Road transport metal frame	6,3	tkm	0,13364	0,84193	19,67%
3 – PL	Book /1 piece	Direct Materials	Paper	0,615	kg	0,84761	0,52128	73,16%
			Ink	0,0015	kg	1,8087	0,00271	0,38%
			Polyester corespun thread	0,0001	kg	7,469	0,00074	0,10%
			Fount solution	0,0003	kg	0,89921	0,00026	0,04%
			Acetones / Solvents	0,0002	kg	2,2308	0,00044	0,06%
		Utilities	Water	0,0002	m3	0,00016	0,000000 037	0,00%
			Electricity	0,2128	kWh	0,53143	0,11308	15,87%
		Logistics	Road transport – paper	0,5535	tkm	0,13364	0,07396	10,38%
			Road transport – ink / polyester corespun thread / fount solution / acetones / solvents	0,0004	tkm	0,13364	0,00005	0,01%
4 – PL	Mineral-asphalt /1 tonne	Direct Materials	Aggregates	900	kg	0,00434	3,91086	0,06%
			Asphalts	47	kg	0,2081	9,7807	0,15%
			Lime powder	50	kg	0,00214	0,10718	0,00%
		Utilities	Electricity	26890	kWh	0,21225	5707,40	87,19%
			Oil	7540	kg	0,09245	697,088	10,65%
		Logistics	In road transport	760	tkm	0,16796	127,649	1,95%

Source: Based on the research results.

Table 4. Data for English case studies

Company – country code	Analysed product (unit of analysis)	Input type	Input	Quantity	Unit	GHG Intensity [kg CO2eq/unit]	Total emissions	Proportion of emissions
5 – UK	Finished forged product (rings/flanges for pipework systems) / 1 piece	Direct Materials	Unprocessed Steel	1,0766	kg	1,8899	2,03467	44,40%
			Steel Extraction	1	kg	1,7	1,70000	37,10%
		Utilities	Electricity	0,7511	kWh	0,5846	0,43909	9,58%
			Gas	18,969	MJ	0,0140	0,26557	5,80%
			Water	0,0010	M3	0,0003	0,00000	0,00%
		Processing	Heat Treamtent, Hot Impact Extrusion	1	kg	0,0169	0,01690	0,37%
		Recycling	Steel Recycling	1	kg	0,0576	0,05760	1,26%
			Diesel Burned in Building Machine	1	kg	0,0576	0,05760	1,26%
		Logistics	HGV (Diesel)	0,0092	vkm	0,25783	0,00237	0,05%
			Non-HGV (Diesel)	0,0151	vkm	0,28699	0,00433	0,09%
			Diesel Consump-tion for Forklift Trucks	0,0066	kg	0,0044	0,00433	0,09%
6 – UK	INNO-THERM insulation material (recycled cotton / denim insulation) / 1 kg	Direct Materials	Polyester	0,2	kg	3,0	0,60000	51,16%
			Wool	0,4	kg	0,2	0,08000	6,82%
			Cotton	0,4	kg	0,2	0,08000	6,82%
		Utilities	Electricity	0,412	kWh	0,5314	0,21894	18,67%
			Gas	0,0139	MJ	0,0045	0,00006	0,01%
		Logistics	Road Transportation	0,12	tkm	0,2578	0,03094	2,64%
			Rail Transportation	0,1	tkm	0,0292	0,00292	0,25%
		Consum-ables	Anti-Bacterial Fungicide Treatment	0,4	l	0,4	0,16000	13,64%
7 – UK	Powerstar voltage optimisation system /1 piece	Direct Materials	Polycarbonate	0,5106	kg	7,7876	3,97635	47,62%
			Injection Moulding	0,1403	kg	1,3342	0,18719	2,24%
			Epoxy Resin	0,3703	kg	6,7304	2,49227	29,85%
			Ferrite	0,5006	kg	1,5127	0,75726	9,07%
		Utilities	Electricity	0,5856	kWh	0,58459	0,34234	4,10%
			Gas	0,0943	MJ	0,01399	0,00132	0,02%
			Water	0,0019	M3	0,00031	0,00000	0,00%
		Logistics	Van Transportation (3.5-16t)	0,1963	vkm	0,28699	0,05634	0,67%
			Rail Transportation	0,6727	tkm	0,039603	0,02664	0,32%
		Metals Processing	Copper Refinery	0,1051	kg	3,1532	0,33140	3,97%
			Steel (low-alloyed)	0,0050	kg	1,7555	0,00878	0,11%
			Copper wire	0,1101	kg	0,48169	0,05303	0,64%
		Waste Dispoal	Disposal of Plastics	0,0501	kg	2,3483	0,11765	1,41%

Source: Based on the research results.

Table 5. Data for Italian case studies

Company – country code	Analysed product (unit of analysis)	Input type	Input	Quantity	Unit	GHG Intensity [kg CO2eq/unit]	Total emissions	Proportion of emissions
1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*
8 – IT	Linear pipe /1 piece	Direct Materials	Steel Inox	2,51	kg	0,55767	1,39975	18,80%
			Copper	4,24	kg	0,35404	1,50113	20,16%
			Rockwool	1,95	kg	1,3331	2,59955	34,91%
		Utilities	Electricity	0,547	kWh	0,64168	0,35100	4,71%
		Packaging	Pluriball	0,0675	kg	2,7004	0,18228	2,45%
			Boxboard	0,45	kg	0,9404	0,42318	5,68%
		Logistics	Steel Inox Transp.	0,0893	tkm	0,25783	0,02304	0,31%
			Copper Transp.	3,2139	tkm	0,25783	0,82864	11,13%
			Rockwool Transp.	0,0606	tkm	0,25783	0,01564	0,21%
			Pluriball Transp.	0,0047	tkm	0,25783	0,00122	0,02%
			Boxboard Transp.	0,0085	tkm	0,25783	0,00220	0,03%
			Item Transportation	0,461	tkm	0,25783	0,11886	1,60%
9 – IT	Pack of sugar-covered toasted almond candies / 1 unit (pack)	Direct Materials	Genuine almonds	0,18	kg	0,88	0,15840	4,27%
			Dark liquid chocolate	0,15	kg	2,10	0,31500	8,49%
			White liquid chocolate	0,45	kg	4,10	1,84500	49,73%
			Sugar	0,20	kg	0,51	0,10200	2,75%
		Utilities	Electricity	0,4633	kWh	0,64168	0,29733	8,01%
		Packaging	Small Package	0,05	kg	0,9404	0,04702	1,27%
			Boxboard	0,70	kg	0,9404	0,65828	17,74%
		Logistics	Genuine almonds	0,29772	tkm	0,25783	0,07676	2,07%
			Toasted almonds	0,0234	tkm	0,25783	0,00603	0,16%
			Liquid chocolate (dark and white)	0,2022	tkm	0,25783	0,05213	1,41%
			Sugar	0,1208	tkm	0,25783	0,03115	0,84%
			Small package	0,0011	tkm	0,25783	0,00030	0,01%
			Boxboard	0,0073	tkm	0,25783	0,00190	0,05%
			Genuine almonds	0,0234	tkm	0,25783	0,00603	0,16%
			Final product transportation	0,438	tkm	0,25783	0,11293	3,04%
10 – IT	Counter frame for blinding doors /1 piece	Direct Materials	Coils	5,55	kg	1,7555	9,74303	12,60%
			Wire net	2,4	kg	1,8044	4,33056	5,60%
			Side wall	18,25	kg	1,7555	32,0378	41,45%
			Screw	0,105	kg	1,8044	0,18946	0,25%
		Zinc coating	Zinc coating coils	0,0673	m2	4,4485	0,29938	0,39%
			Zinc coating pieces	3,80	m2	6,2079	23,5900	30,52%
		Utilities	Electricity	3,62	kWh	0,64168	2,32288	3,01%
		Packaging	Wodden rod	0,0048	m3	58,48	0,28304	0,37%
			Boxboard	1,15	kg	0,9404	1,08146	1,40%

Table 5 cont.

1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*
		Logistics	Zinc coating sheet Transp.	10,62	tkm	0,25783	2,73815	3,54%
			Wire netting Transp.	0,0192	tkm	0,25783	0,00495	0,01%
			Screws Transp.	0,0019	tkm	0,25783	0,00051	0,00%
			Wooden rod Transp.	0,59	tkm	0,25783	0,15212	0,20%
			Boxboard Transp.	0,029	tkm	0,25783	0,00748	0,01%
			Final product	2,003	tkm	0,25783	0,51643	0,67%
11 – IT	Pack of Shelled Walnuts /1 unit (pack)	Direct Materials	Walnuts	0,350	kg	0,9000	0,31500	52,42%
			Plastic for packaging	0,0089	kg	1,8145	0,01615	2,69%
			Cardboard	0,0194	kg	0,94977	0,01843	3,07%
			Sodium hypochlorite	0,0087	kg	0,92159	0,00806	1,34%
			Cellophane	0,0003	kg	0,36934	0,00013	0,02%
			Water	0,49	lt	0,00031753	0,00016	0,03%
			Pallet	0,036	kg	6,1708	0,22215	36,97%
		Utilities	Electricity	0,0061	kWh	0,71481	0,00438	0,73%
		Logistics	Walnuts Transp	0,0084	tkm	0,33165	0,00279	0,46%
			Plastic Transp	0,0006	tkm	0,33165	0,00021	0,04%
			Cardboard Transp	0,0003	tkm	0,33165	0,00012	0,02%
			Sodium hyp.Transp	0,000197	tkm	0,33165	0,00007	0,01%
			Cellophane Transp	0,0000191	tkm	0,33165	0,00001	0,00%
			Pallet Transp	0,0004	tkm	0,33165	0,00014	0,02%
			Item Transportation	0,0397	tkm	0,33165	0,01319	2,19%

Source: Based on the research results.

Discussion of results and conclusions

Polish companies represented a variety of industries, including production of: automotive textiles, furniture, publishing materials (incl. books) and products for roads construction. The analysis showed that in most of the cases the main source of the identified emissions were the direct materials used in the production process (such as: polyester, metal frame, paper, etc.). In case of two manufacturers a significant source of emission was noted with regard to logistics, especially if the transportation resulted from the weight of transported material or the distance of delivery. In two cases (mineral asphalt producer and publisher), the highest emission were observed with relation to utilities – electricity and oil in case of mineral asphalt producer and electricity in case of publisher, due to a high energy consumption of the technologies used in the manufacturing process.

In the United Kingdom in case of all analysed companies the highest shares of emissions could be observed within direct inputs. This was due to the fact, that analysed products required highly processed direct materials (e.g., polyester, polycarbonate, epoxy resin) or were intensively processed in-house (e.g., steel). However, some significant emissions could also be observed with relation to utilities and consumables.

In case of Italy, again in all analysed companies, direct materials, were the most substantial CO2 hotspots. This scenario was similar regardless the scope of production, both for companies manufacturing industry related products and food.

The following conclusions can be raised form the case studies. First of all, the highest emissions were related mostly with direct inputs, especially those that have been highly processed within the in-bound supply chain or require extensive processing. Secondly, the next significant CO2 hotspots are observed with regard to logistics, especially when it requires long distance deliveries or the weight of the used material is substantial. The road transport is the source of the highest CO2 emission in case of logistics inputs. Finally, some manufacturers noted substantial emissions as a result of the use of utilities (e.g. electricity or fuel). The reason for this was either high energy demanding production processes or old infrastructure, failing to meet current energy consumption standards.

Regarding the solutions to the identified hotspots, the following directions of improvement can be recognised. Primarily, companies should look for substitutes. Referring to the example of Italian company (number 8 in Table 1), where rockwool used for insulation in the manufactured product have been replaced with a material made from recycled fibres. The benefit for the company, apart from minimising the environmental aspect, was significant reduction of production costs, as the new material was much more economical. It has to be noted, however, that in some cases finding a substitute may be difficult. For example in case of Polish company No. 1, a producer of automotive textile tapes, an opportunity to replace the used polyester, thus high emissions, with other type of plastic fabric was identified. However, an obstacle to implement this solution was the customers' requirements, who claimed, the polyester tape has to be used, in order to follow the industry specifications.

Another way of reducing CO2 emission is to look for local suppliers. Local sourcing can positively influence the CO2 emissions reducing the length of routes. However, this can encourage companies to decrease the level of inventories what can increase the frequency of supplies.

Eventually, enterprises should improve energy efficiency of performed processes through investing in more energy efficient infrastructure (if the current one is not), performing joint actions leading to energy efficient operations in supply chain, e.g., involving suppliers in the product design, conducting supplier development programs, leading open innovations – both product and process (developing new solutions with e.g. logistics providers, clients), implementing ISO 50001 management system covering energy efficiency.

References

Agenda 21 (1993), *Globalny program działań*, Warszawa.

Bochtis D., Lakovou E., Vlachos D., Aidonis D. (2015), *Supply Chain Management for Sustainable Food Networks*, John Wiley & Sons, New York.

Carter C.R., Rogers D.S. (2008), *A Framework of Sustainable Supply Chain Management: Moving toward New Theory*, "International Journal of Physical Distribution & Logistics Management", Vol. 38, No. 5, pp. 360-387.

Diabat A., Al-Salem M. (2015), *An Integrated Supply Chain Problem with Environmental Considerations*, "International Journal of Engineering Production", Vol. 164, pp. 330-338.

Diabat A., Govindan K. (2011), *An Analysis of the Drivers Affecting the Implementation of Green Supply Chain Management*, "Resources, Conservation and Recycling", Vol. 55, pp. 659-667.

Gualandris J., Kalchschmidt M. (2016), *Developing Environmental and Social Performance: The Role of Suppliers' Sustainability and Buyer-Supplier Trust*, "International Journal of Production Research", Vol. 54, No. 8, pp. 2470-2486.

Jaber M.Y., Glock Ch.H., El Saadany A.M.A. (2013), *Supply Chain Coordination with Emissions Reduction Incentives*, "International Journal of Production Research", Vol. 51, Iss. 1, pp. 69-82.

Kalinowski T.B., Rudnicka A., Wieteska G. (2016), *Praktyki prośrodowiskowe wspierające rozwój zrównoważony w łańcuchu dostaw w wybranych krajach europejskich*, „Gospodarka Materiałowa i Logistyka", nr 4, pp. 2-12.

Kleindorfer P.A., Singhal K., Wassenhove L.N. van (2005), *Sustainable Operations Management*, "Production and Operations Management", Vol. 14(4), pp. 482-492.

Koh S.C.L. et al. (2011), *Supply Chain Environmental Analysis, a New System for Delivering a Low Carbon Supply Chain*, The Center for Low Carbon Futures, University of Birmingham, Birmingham.

Koh S.C.L., Genovese A., Acquaye A.A., Barratt P., Rana N., Kuylenstierna J., Gibbs D. (2012), *Decarbonizing Product Supply Chains: Design and Development of an Integrated Evidence-Based Decision Support System − the Supply Chain Environmental Analysis Tool (SCEnAT)*, "International Journal of Production Research", Vol. 51, pp. 2092-2109.

Koh S.C.L., Genovese A., Wieteska G., Rudnicka-Reichel A., Kalinowski T.B. (2015), *Supply Chain Environmental Analysis Tool, Enhanced Version (SCEnAT+)*, User Manual, PrESS project internal documentation, pp. 1-23.

Linton J.D., Klassen R., Jayaraman V. (2007), *Sustainable Supply Chains: An Introduction*, "Journal of Operations Management", Vol. 25, No. 6, pp. 1075-1082.

Michelsen O., Magerholm Fet A., Dahlsrud A. (2006), *Eco-Efficiency in Extended Supply Chains: A Case Study of Furniture Production*, "Journal of Environmental Management", Vol. 79, pp. 255-262.

Oshita Y. (2012), *Identifying Critical Supply Chain Paths that Drive Changes in CO2 Emissions*, "Energy Economics", Vol. 34, pp. 1041-1050.

Plambeck E.L. (2012), *Reducing Greenhouse Gas Emissions through Operations and Supply Chain Management*, "Energy Economics", Vol. 34, pp. 64-74.

Pollution Prevention Act, 1990.

Sarkis J. (2014), *Green Supply Chain Management*, Series: Technologies for Sustainable Life, Momentum Press, eBook, New York.

Seuring S., Müller M. (2008a), *From a Literature Review to a Conceptual Framework for Sustainable Supply Chain Management*, "Journal of Cleaner Production", Vol. 16, No. 15, pp. 1699-1710.

Seuring S., Müller M. (2008b), *Core Issues in Sustainable Supply Chain Management – a Delphi Study*, "Business Strategy and the Environment", Vol. 17, No. 8, pp. 455-466.

Strategia Zrównoważonego Rozwoju Polski do roku 2025 (1999), *Wytyczne dla resortów opracowujących strategie sektorowe*, Ministerstwo Środowiska, http://snep.edu.pl/sms/materialy/strategia%20zrownowazonego%20rozwoju%20polski%20do%20roku%202025.pdf (accessed: 25.04.2016).

Tsoulfas G.T., Pappis C.P. (2006), *Environmental Principles Applicable to Supply Chains Design and Operation*, "Journal of Cleaner Production", Vol. 14, pp. 1593-1602.

Verfaillie H.A., Bidwell R. (2000), *Measuring Eco-Efficiency − A Guide to Reporting Company Performance*, Report, World Business Council for Sustainable Development, Geneva.

Wiedmann T., Minx J. (2008), *A Definition of 'Carbon Footprint'* [in:] C.C. Pertsova (ed.), *Ecological Economics Research Trends*, Chapter 1, Nova Science Publishers, Hauppauge, NY, pp. 1-11, https://www.novapublishers.com/catalog/product_info.php?products_id=5999 (accessed: 25.04.2016).

Wiedmann T. (2009), *Carbon Footprint and Input–Output Analysis − An Introduction*, "Economic System Research", Vol. 21, No. 3, pp. 19-42.

World Charter for Nature (1982), United Nations General Assembly, 28 October, New York.

Wu Ch., Barnes D. (2016), *An Integrated Model for Green Partner Selection and Supply Chain Construction*, "Journal of Cleaner Production", Vol. 112, pp. 2114-2132.

Zhu Q., Sarkis J., Geng Y. (2005), *Green Supply Chain Management in China: Pressures, Practices and Performance*, "International Journal of Operations & Production Management", Vol. 25, No. 5, pp. 233-245.

Zhu Q., Sarkis J., Lai K.-H. (2007), *Green Supply Chain Management: Pressures, Practices and Performance within the Chinese Automobile Industry*, "Journal of Cleaner Production", Vol. 15, No. 11/12, pp. 1041-1052.

Zhu Q., Sarkis J., Lai K.-H. (2012), *Examining the Effects of Green Supply Chain Management Practices and Their Mediations on Performance Improvements*, "International Journal of Production Research", Vol. 50, No. 5, pp. 1377-1394.

IDENTYFIKACJA KRYTYCZNYCH PUNKTÓW EMISJI CO2 W ŁAŃCUCHACH DOSTAW WYBRANYCH PRODUKTÓW

Streszczenie: Artykuł prezentuje analizę łańcuchów dostaw różnych produktów, która przeprowadzona została z wykorzystaniem narzędzia *Supply Chain Environmental Analysis Tool* (SCEnAT). Analiza porównawcza zebranych danych pozwoliła na określenie krytycznych punktów emisji CO2 w badanych łańcuchach dostaw. Tym samym zidentyfikowano procesy i odcinki łańcuchów dostaw o kluczowym negatywnym wpływie na środowisko. Tego typu rozpoznanie umożliwia wdrożenie adekwatnych praktyk oraz jednocześnie skuteczną redukcję emisji dwutlenku węgla. Artykuł bazuje na wynikach międzynarodowego projektu PrESS.

Słowa kluczowe: krytyczny punkt emisji CO2, zrównoważony rozwój, zarządzanie łańcuchem dostaw.