INTEGRATION OF ECO-DESIGN IN SUPPLY CHAIN MANAGEMENT

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Due to the increasing population, increasing standard of living, and consequently, increasing human activities and production, environmental concerns are gaining more and more importance. It is becoming clear that our planet can no longer regenerate, and resources are being used in an unsustainable manner. Environmentally conscious and more sustainable practices provide organizations with a competitive advantage and the ability to operate in the long term. However, focusing on the environmental aspect within company walls, in just one part of the supply chain, is not sufficient for effective improvements. Environmental impacts occur throughout the entire supply chain, from resource extraction, material and component production, final product manufacturing, distribution, usage, to the end of the product's life cycle. Eco-design, as a tool for creating environmentally-friendly products, compels companies to consider various environmental impacts that occur beyond company walls and work towards preventing and minimizing them already within product/service planning and design phase.

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1 Introduction

Due to the rise in population number and living standards, and the subsequent growth in extensive human activities and production, environmental concerns are gaining in importance. It is becoming clear that our planet can no longer regenerate itself and that resources are being used in an unsustainable way (Obrecht & Knez, 2017). As human activities cause severe negative environmental impacts both locally and globally, our actions are increasingly focusing on environmental concerns. There is a belief that environmentally conscious and more sustainable practices can provide organizations with a competitive advantage, especially in the long term (Albino et al., 2009; Dangelico et al., 2017; Plouffe et al., 2011; Wong, 2013).

An extensive body of data indicates that the current linear economy is unsustainable. Population growth and rising living standards demand an increasing extraction of materials, as well as greater consumption of food, water, and energy. As a result, the prices of these materials are rising, arable land and forest areas are disappearing, long-term access to clean water is becoming uncertain, biodiversity is rapidly changing, and so on (Alexandratos & Bruinsma, 2012; International Energy Agency, 2009, p. 2030; The 2030 Water Resource Group, 2009). Due to the projected trends, environmentally friendly types of economies - such as the circular economy, eco-design based on life cycle principles, and sustainable supply chains - will become not only a source of competitive advantage in achieving a differentiation strategy but also a potential response to the anticipated socio-economic challenges in the coming decades (Bešter, 2017), as well as a systematic solution for the sustainable existence of humanity (Širec et al., 2018).

However, focusing exclusively on the environmental aspect in just one part of the supply chain (SC) does not prove sufficient for achieving effective improvements, as environmental impacts occur throughout the entire SC–from raw material extraction, production of materials and components, manufacturing of the final product, its distribution, usage, to the end of its life cycle. A review of the literature suggests that environmental goals–such as the 20/20/20 targets set by the EU-cannot be achieved solely through inter-organizational activities and measures but rather through collaboration along the entire value chain, leveraging synergies between supply chain participants (Szegedi et al., 2017). Therefore, environmental management systems (e.g., ISO 14001 or EMAS) and the collaboration of various actors within the entire supply chain are also included. The interconnectedness of sustainable supply chains, the circular economy, and eco-design requires the involvement of different stakeholders at multiple levels, making a systematic approach essential. Business leaders must recognise that economic and environmental goals are not mutually exclusive, but can, in fact, be achieved simultaneously (Preston, 2012; Lieder & Rashid, 2016; Ghisellini et al., 2016).

The idea of supply chain management (SCM) with an environmentally conscious (green) approach began to emerge in the technical literature in the early 1970s. The integration of green practices and complex supply chains (including procurement, production, and logistics) came to the forefront in the 1990s, particularly in the automotive industry (Szegedi et al., 2017). Many organizations still have a very narrow perception of their environmental impact, which is mostly limited to on-site production activities (Ammenberg & Sundin, 2005). One of the main trends in sustainability programs in industrialized countries is so-called life cycle thinking, which expands the focus beyond the production site and includes various economic, environmental, and social aspects related to a product throughout its entire life cycle (UNEP, 2017). Life cycle thinking is based on the principles of pollution prevention, where environmental impacts are reduced at the source, and on closing the loop of materials and energy (European Commission, 2014). All products and services have some impact on the environment, which can occur at any or all stages of a product's life cycle–including raw material extraction, production, distribution, use, and waste disposal (Denac et al., 2018). Companies with a more developed traditional supply chain also tend to have a more advanced green supply chain management (GSCM) system (Szegedi et al., 2017).

Strong evidence has confirmed that commitment to eco-design and sustainable development within an organization is the most critical factor for achieving improvements, and environmental labels are a powerful tool for communicating with customers–especially those who are environmentally conscious. Business leaders are inherently interested in achieving business benefits alongside environmental improvements, and environmental labels serve as a powerful means to accomplish this goal. On the one hand, they enhance the company's image, attract new environmentally conscious consumers, enable participation in green public tenders, support differentiation in highly competitive markets, and reduce costs related to waste or the use of hazardous materials, among others. On the other hand, they also bring direct environmental benefits within the company itself–such as reduced use of materials or energy, less waste, increased efficiency, and lower water consumption.

The goal of this chapter is to provide a clearer insight into the greening of supply chains, emphasize the importance of life cycle thinking for supply chain managers, and examine and discuss the use of various methodologies, principles, and tools such as life cycle impact assessment, eco-design, and environmental labels within supply chain management. Therefore, case studies of best practices in life cycle assessment and eco-design are also presented to reinforce knowledge about environmental issues and its integration into supply chain management. A comprehensive collection of such tools, principles, and methods, along with examples of solving real-world problems, is essential for supply chain managers, as it allows them to better understand the importance of environmentally oriented business models and highlights the significance of sustainable development for companies as well.

2 Eco-design integration

2.1 Principles and ideas for eco-design

Although the main environmental impacts occur during the extraction of materials, production, use, or even after the product's life cycle ends, most of the environmental burden of a product is determined during the design phase. Therefore, this phase is a critical step in improving the environmental performance of a product (Obrecht & Knez, 2017; Prendeville & Bocken, 2015). When discussing sustainable supply chains, it is essential to consider all stages of the product's life cycle and, where possible, optimize them during the supply chain planning phase. If environmental aspects are addressed preventively in the early stages of product or supply chain development, it is more likely that the overall environmental impact of the product through the supply chain can be significantly reduced. One of the tools that enables a preventive approach is eco-design.

Eco-design is based on incorporating environmental aspects into the design and development of a product, with the aim of reducing negative environmental impacts throughout the entire product life cycle (Denac et al., 2018). A review of the literature revealed that eco-design relies on the principles of clean production, sustainable development, and life cycle thinking. The main goals of eco-design are to reduce the consumption of (particularly rare and primary) resources, use more renewable resources, reduce the consumption of hazardous materials, increase the use of recycled materials, optimize production and distribution, make production cleaner, extend the product's life cycle, and facilitate and improve the efficiency of product handling at the end of its life cycle, both environmentally and economically (Brezet et al., 1997). This means that the potential economic and environmental benefits of eco-design go beyond the manufacturer's boundaries and link product design to a broader network of supply chain members, including raw material procurement, production, transportation and distribution, use, and disposal.

However, implementing eco-design or developing environmentally friendly products is not easy (Albino et al., 2009), as it simultaneously requires life cycle thinking, sustainable development, and clean production (Brezet et al., 1997). This is especially true for small and medium-sized enterprises (SMEs) (van Hemel & Cramer, 2002). Although there are currently many methods and tools available for eco-design, there is a gap in their integration into the design process and into the daily practices of designers, particularly if the top management of the company is not committed to steering the company's supply chain in a green direction. Existing methodologies for eco-design are not always suitable for all organizations or business sectors (Andriankaja et al., 2015). Consequently, eco-design activities need to be carefully and systematically planned, especially in SMEs, where human and financial capital are often limited (Miedzinski et al., 2013; van Hemel & Cramer, 2002). This requires support from top management, including supply chain management (SCM), regardless of the company's size (Annunziata et al., 2016; Dekoninck et al., 2016).

2.2 Eco-design framework and tools

In eco-design, the first step is to assess the environmental impacts and burdens throughout the entire life cycle of a product or service. This can be done in various ways, such as using the life cycle assessment (LCA) method or with simplified measures, such as using a Life Cycle Impact Tool (LIT), as shown in Figure 1. It can even be done through specific eco-design questionnaires. LIT can help companies understand the impacts associated with the environmental aspects of their product or service (Denac et al., 2018; Maribor Development Agency & Enterprise Europe Network, 2013).

Some areas presented in Figure 1 and included in the Life Cycle Impact Tool (LIT) may not be relevant for every product/service. However, the core idea is to encourage product designers to start thinking about environmental impacts that occur outside the company's walls. For example, a very small amount of energy will be consumed for lighting the restroom during use, and water consumption in the distribution phase of the product may not be as important. However, supply chain managers must be aware of the broad reduction of environmental impacts and take this into account when planning a sustainable supply chain. The Life Cycle Impact Tool (LIT) enables companies to eliminate certain impacts and potentially even stages of the life cycle (parts of the supply chain) and highlights areas where the major impacts occur. The matrix is useful because, once completed, product designers and supply chain managers can easily see which issues in which life cycle stages need to be focused on for eco-design. They can easily identify key points (Maribor Development Agency & Enterprise Europe Network, 2013; Obrecht, 2010) when they begin to think about which impacts to reduce (if not all, due to limited resources and production capacities).

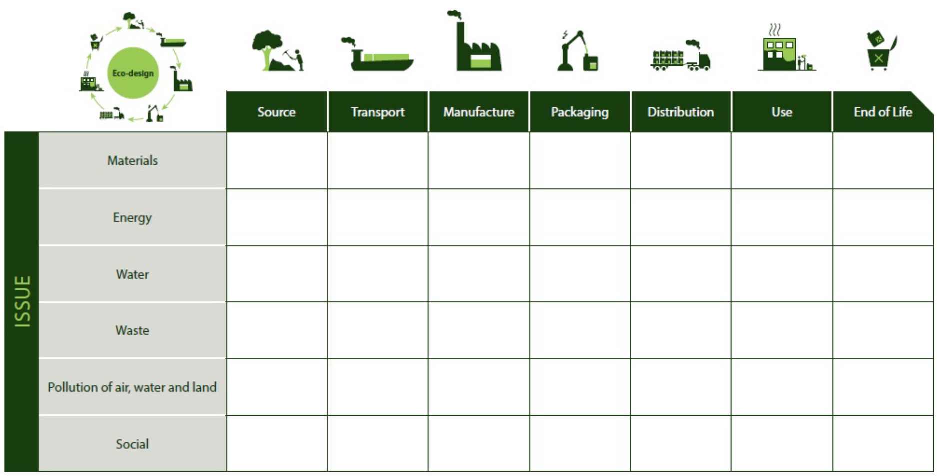

Figure 1: Tool affects life cycle (LIT)
Source: adapted from (Maribor Development Agency & Enterprise Europe Network, 2013; Obrecht, 2010)

After using the Life Cycle Impact Tool (LIT) to identify the most significant environmental impacts in the product's life cycle, product designers and managers (especially technical directors and supply chain managers) must focus on potential design improvements that offer the greatest opportunities for reducing these impacts. Table 3 presents an eco-design questionnaire with various design focus areas in line with eco-design strategies, which are, to some extent, applicable to all types of products or services. It should also be considered that, due to connections within the product supply chain and life cycle activities, organizations representing other supply chain members may face additional costs or benefits. Therefore, a comprehensive analysis is crucial to achieving the best outcome from a supply chain perspective.

Although many methods and tools for eco-design are currently available, there is a gap in their integration into the design process in the industry, as well as in the daily practices of designers. According to Andriankaja et al. (2015), existing eco-design methods are not always adapted to lightweight structures. Gerrard & Kandlikar (2007) predict that the most important change in transportation sectors is the design of new products, which involves changing the material composition: promoting the use of lightweight materials, extending product life (reuse and recycling), and improving environmental communication about products. Simplifications of these methodologies are crucial for a comprehensive impact assessment and reduction of environmental impacts, as their outputs are easier to obtain and cheaper for manufacturers.

Table 1: Eco-design questionnaire structure

Focused design areas	Key questions for designers	Environmental benefits	Business benefits
Material procurement design	When specifying materials and components, do you consider the environmental impact in terms of weight, volume, use of recycled materials, embodied energy and water, and impacts on biodiversity?	Reduced resource depletion. Reduced embodied energy/water. Reduced transport burden. Reduced carbon dioxide (CO_2) emissions. Reduced impact on biodiversity.	Reduced transportation costs. Improved image/access to markets.
Design for production	Have you considered changing your production processes to reduce energy and water consumption, waste and waste recycling?	Reduction of CO_2 emissions and depletion of water resources. Reduced resource depletion.	Reduced energy costs. Lower waste - reduced material costs.
Design for transportation and distribution	Have you considered the size, shape and volume of your products from a	Reduction of CO_2 emissions and depletion of water resources.	Reduced transportation costs.

	packaging and transportation perspective? Do you consider embodied energy and water, VOC or hazardous substance production when determining packaging?	Reduced air pollution. Reduced transport use – less emissions and wear and tear on infrastructure. Reduced potential for the spread of hazardous substances in the environment.	Reduced packaging costs.
Design for use (including installation and maintenance)	When designing your products, do you consider their energy and/or water consumption when they are used? Do you consider the amount of material consumed and any hazardous substances that may be released during use? Do you consider their longevity and ease of maintenance?	Reduced demand for new material resources. Reduced CO2 emissions. Reduced depletion of water resources. Reduced potential for the spread of hazardous substances in the environment.	Lower life cycle costs for the customer – higher profits due to higher prices. Reduced maintenance costs. Good product image.
End-of-life design	When you design your products, do you consider how easily they could be reused or disassembled and recycled? Do you think there are hazardous substances in the product that could be released during disassembly or recycling?	Reduced land use for landfill. Reduced demand for new material resources. Reduced CO2 emissions. Reduced depletion of water resources.	Regulation compliance. Reduced end-of-life costs.

Source: adapted from (Maribor Development Agency & Enterprise Europe Network, 2013; Obrecht, 2010)

2.1.1 Case Study 4 – A simplified eco-design approach to save carbon and resources in different forms of cargo containers[1]

Currently, a large quantity of freight containers is transported globally by sea and road, resulting in significant environmental impacts due to transportation and the manufacturing of containers; this involves the depletion of materials because of the large amounts of material used to produce approximately 18.6 million freight containers used globally. Another environmental impact is the carbon emissions released during the production and use of freight containers. One possible solution for more sustainable freight transport is the design of environmentally friendly freight containers, manufactured in accordance with eco-design principles. These

[1] adapted from (Obrecht & Knez, 2017)

containers are lighter, made with less material, and have a lower environmental impact throughout their entire life cycle. Our previous study focused on standard 20-foot ISO container models with a simplified life cycle assessment, specifically concentrating on greenhouse gas emissions. We found that the environmental impact of the freight container is highest in the first phase of its life cycle, i.e., during the raw material acquisition phase.

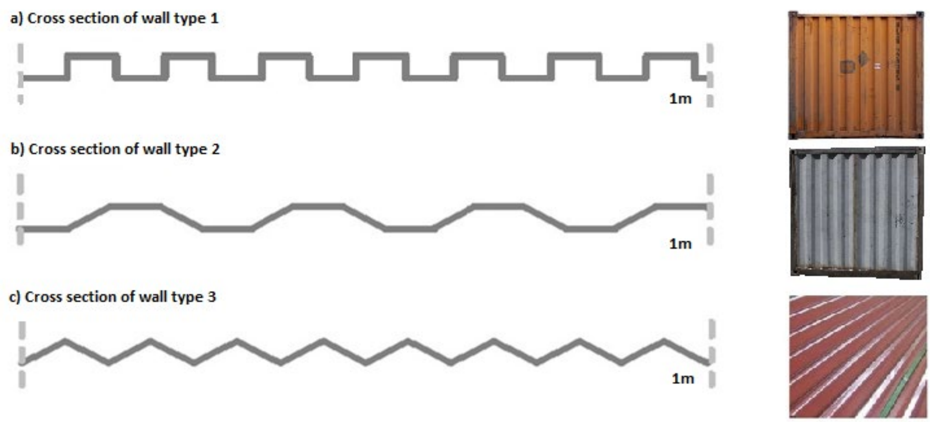

Figure 2: Cross-sections and images of the three types of container walls examined
Source: (Obrecht & Knez, 2017)

Due to the relatively high mass of standard 20-foot aluminum and steel freight containers (1,877 kg and 2,250 kg) and the nature of the material production phases (raw material processing, welding, assembly, etc.), this share accounts for 67% of all impacts. A solution for more environmentally friendly freight containers lies in the eco-design strategy of dematerialization, with a particular focus on material usage and the production phase, without compromising efficiency. From an environmental perspective, the effectiveness of three different wall designs for freight containers, shown in Figure 2, was assessed.

The comparative analysis showed a difference of approximately 15% (315 kg of primary material per container) in material consumption when comparing the types of freight container walls with the highest and lowest impacts, and significant differences were also observed in the environmental assessment, as shown in Figure 3.

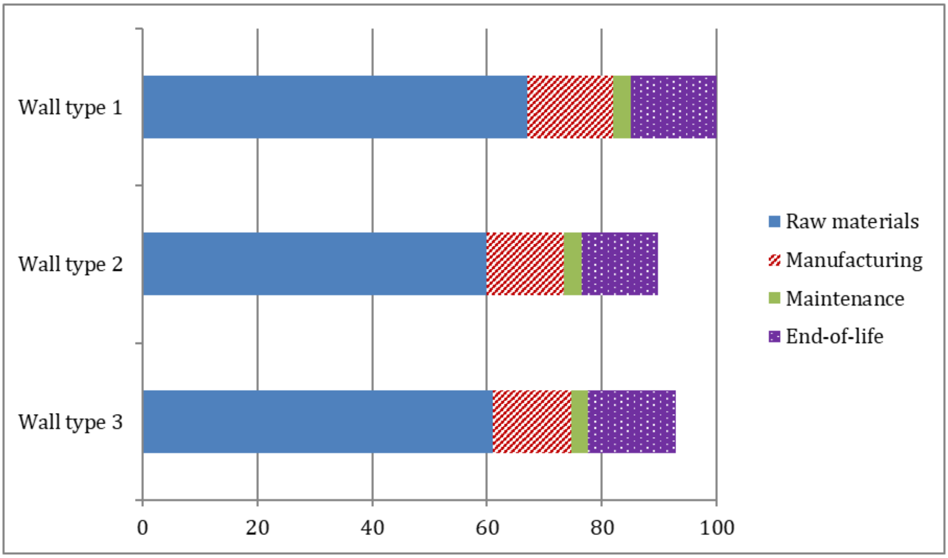

Figure 3: Comparison of the relative GWP of different studied container wall types
Source: (Obrecht & Knez, 2017)

The possibilities for reducing the material used for freight containers indicate that one side wall of a standard 20-foot container uses 20.97 square meters of aluminum or steel, with double the amount used for a standard 40-foot ISO container when the Type 1 Wall design is applied. A significant reduction can be achieved by replacing Type 1 Wall containers with Type 2 or Type 3 Wall containers. The amount of material used for one side wall of a standard 20-foot container can be reduced by 6.13 m² or 4.86 m² when implementing the Type 2 or Type 3 Wall design, respectively.

Additional environmental improvements and cost reductions are possible with mega container ships, which can load more than 18,000 twenty-foot equivalent units (TEU). This means that the loaded mass can be reduced by 4,734 tons when comparing aluminum containers and by 5,670 tons when comparing steel containers, simply by adjusting the container designs. Consequently, significant improvements in fuel efficiency on container ships can also be expected. Due to the large number of freight containers worldwide and container ships at sea, changing the types of walls could have a significant impact on reducing material consumption, improving fuel efficiency, and lowering greenhouse gas emissions in maritime transport.

The term "eco-friendly design" refers to measures taken to develop products in the most environmentally friendly way possible. In this way, the environmental impact of products is reduced throughout their entire lifecycle, without compromising other product characteristics such as functionality, price, and quality (Johansson, 2002). Sustainable product design stands for a philosophy and practice of design where products contribute to social and economic well-being while having a negligible impact on the environment, as they can be produced from a sustainable base of resources (Niinimäki, 2006; Verghese et al., 2012).

Companies that adopt measures to protect the environment across the entire supply chain (such as designing products to be more environmentally friendly) typically aim to gain financial benefits from such activities, which may require significant investments in the initial phase. Therefore, environmental improvements should be rewarded with various awards and labels that inform consumers about the environmental impact of products, in order to encourage sustainable production and consumption. The next section will focus on environmental labels and certifications.

Due to the complexity of the field, tools have been developed for the simplified implementation of eco-design. One such tool is the so-called "eco-design questionnaires" through which organizations gain a clear insight into how well they are performing in specific areas, where improvements are possible, where the greatest potential for improvement lies, and what the environmental and business benefits of specific improvements are. The tables with questions are presented below.

With the second set of questions, shown in Table 3, we can define the current state and potential for individual improvements even more precisely.

In Table 3, we enter numerical scores for each area representing the current state of affairs, and at the same time, we assess the potential for future improvements. For example, if the organization is already implementing 4 out of 10 possible measures, this is rated as a 2 on a scale from 1 to 5. Similarly, for the potential, we calculate the proportion–that is, how many of the total possible measures can still be implemented and to what extent we believe they can be improved.

Table 2: Table of key areas for planning the implementation of eco-design – for assessing the situation

Key planning areas	Key questions for planners/designers	Environmental benefits	Business benefits	Current status (descriptive + assessment)
Planning for material acquisition	Planning for material acquisition: When specifying materials and components, do you consider their environmental impact in relation to weight, volume, use of recycled materials, energy and water consumption, and impact on biodiversity?	– Less resource depletion. – Lower energy/water consumption. – Lower transport load. – Lower CO2 emissions.	– Lower transportation costs. – Improved company image.	
Planning for production	Have you considered changing your production processes to reduce energy and water consumption, reduce waste and recycle it?	– Lower CO2 emissions and reduced use of water resources. – Less resource depletion.	– Lower energy costs. – Less waste. – Lower material costs.	
Planning for transportation and distribution	Do you consider the size, shape and volume of your products from a packaging and transport perspective? Do you consider energy and water consumption and the generation of volatile organic compounds or hazardous substances when choosing packaging?	– Lower CO2 emissions and less depletion of water resources. – Less air pollution. – Less transport – lower emissions and less infrastructure wear and tear. – Reduced possibility of releasing hazardous substances into the environment.	– Lower transportation costs. – Lower packaging costs.	
Planning for use (including installation and maintenance)	When designing your products, do you consider their energy and/or water consumption during use? Do you consider the amount of consumables and hazardous materials released? Do you consider the lifespan and ease of maintenance of your products?	– Less need for new resources-materials. – Lower CO2 emissions. – Less depletion of water resources. – Reduced possibility of releasing hazardous substances into the environment.	– Lower lifecycle costs for customers. – Increased profits due to higher prices. – Lower maintenance costs.	

Key planning areas	Key questions for planners/designers	Environmental benefits	Business benefits	Current status (descriptive + assessment)
			– Good product image.	
Waste management planning	When designing your products, do you consider their reuse, disposal or recycling? Do you consider hazardous substances in products that may be released during decomposition or recycling?	– Fewer landfills. – Lower demand for new sources of materials. – Lower CO_2 emissions. – Less depletion of water resources.	– Compliance with regulations. – Lower end-of-life costs.	

Source: own

Table 3: Checklist (attachment to the eco-design questionnaire) for assessing the current state and potential

Area of plans.	Planning improvement options	a) already implemented (e.g. 0-5)	b) potential (e.g. 0-5)
Planning for material acquisition	Reduce the weight and volume of the product.		
	Increase the use of recycled material to replace new material.		
	Increase the use of renewable/sustainable materials (e.g. FSC for wood).		
	Increase the incorporation of used components.		
	Reduce the use of rare materials – copper is becoming a rare material.		
	Eliminate hazardous substances - substances identified as substances of very high concern (SVHC) in the REACH regulation 1907/2006.		
	Choose materials derived from plants or animals that were raised with little or no artificial fertilizers.		
	Identify materials that are produced using processes that do not release or release low concentrations of volatile organic compounds.		
	Use materials with lower energy/water consumption.		
Planning for production	Reduce energy consumption.		
	Reduce water consumption.		
	Reduce the amount of waste generated during production.		
	Use internally recovered or recycled materials that are generated from production waste.		
	Reduce emissions to air, water and soil during production.		
	Reduce the number of parts.		
Planning for transportation and distribution	Reduce the size and weight of the product.		
	Optimize shape and volume to maximize packing density.		
	Optimize transport/distribution in terms of fuel consumption and emissions.		

Area of plans.	Planning improvement options	a) already implemented (e.g. 0-5)	b) potential (e.g. 0-5)
	Optimize packaging according to regulations.		
	Reduce the weight and size of packaging.		
	Reduce energy and water used for packaging.		
	Use packaging that releases low concentrations of volatile organic compounds during production.		
	Increase the use of recycled packaging materials.		
	Eliminate hazardous substances in packaging.		
Planning for use (including installation and maintenance)	Reduce the energy required for use.		
	Reduce water consumption during use.		
	Optimize the quantity and properties of consumables.		
	Extend product life by designing for durability and reliability.		
	Extend the life of your product by designing for easier maintenance.		
	Reduce emissions to air, water and soil during use.		
	Eliminate potentially hazardous substances that may be released during use.		
Waste management planning	Restrict the use of substances classified as hazardous (RoHS Directive 2011/65/EU) – for electrical products only.		
	Increase ease of reuse, disassembly, and recycling.		
	Avoid designs that negatively impact reuse or recycling, such as a mix of materials.		
	Reduce the amount of final waste.		
	Reduce energy consumption during disassembly and recycling.		
	Reduce water consumption during dismantling and recycling.		

Source: own

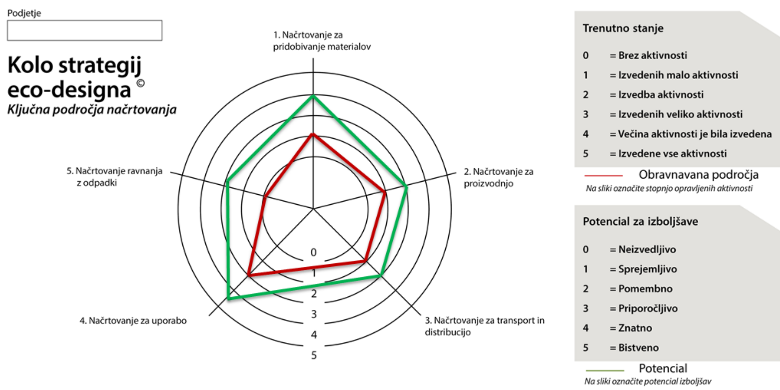

Figure 4: Graphical representation of key strategies for planning improvements

Source: (Maribor Development Agency & Enterprise Europe Network, 2013; Obrecht, 2010)

With the help of a graphical representation (e.g., a spider chart), we can then assess which areas are key for planning improvements–specifically, where the gap between the current state and the potential is the largest.

4 Conclusion

The described concept of eco-design enables systematic "green" approaches in the supply chain, as well as in products, where actual business cases show that a "green" supply chain is not necessarily complex if it is well planned and organized. It is simply about extracting more economic and at the same time environmental benefits from current operations. Supply chain management today faces new challenges such as just-in-time production, increased product variations, production of lot sizes of one, shortened product and service life cycles, rapidly changing environments, and increased environmental pressure. Recently, this has become a priority among supply chain managers, and innovative ways to green the supply chain are being studied. Eco-design is a tool for environmentally friendly product and service design, enabling an environmentally friendly supply chain right from the product design and supply chain planning stages. Environmental labeling programs, which incorporate lifecycle thinking as a potential tool for improving environmental performance in the supply chain and for communication with customers, are also relevant here. Due to limited natural resources and the awareness that the future well-being of society and businesses is linked to environmental protection and performance, these ideas have become more relevant than ever before. All these principles support the idea that economic growth and environmental sustainability are not opposing but complementary concepts, linking an increasing number of stakeholders within the supply chain.

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