MASTERING SUSTAINABILITY IN SUPPLY CHAINS

EDITOR
Matevž **Obrecht**

University of Maribor Press

University of Maribor

Faculty of Logistics

Mastering Sustainability in Supply Chains

Editor
Matevž Obrecht

January 2026

Title **Mastering Sustainability in Supply Chains**

Editor Matevž Obrecht
(University of Maribor, Faculty of Logistics)

Review Tina Cvahte Ojsteršek
(University of Maribor, Faculty of Logistics)

Marijana Pecarević
(University of Dubrovnik)

Translation Mirjana Lazarević
(University of Maribor, Faculty of Logistics)

Language editing Kirsten Hempkin
(University of Maribor, Faculty of Arts)

Technical editor Jan Perša
(University of Maribor, University of Maribor Press)

Cover designer Jan Perša
(University of Maribor, University of Maribor Press)

Cover graphic Logistics web, author: Gerd Altmann, pixabay.com, 2023

Graphic material Sources are own unless otherwise noted.
The authors and Obrecht (editor), 2026

Published by *Založnik* **University of Maribor**
University of Maribor Press
Slomškov trg 15, 2000 Maribor, Slovenia
https://press.um.si, zalozba@um.si

Issued by *Izdajatelj* **University of Maribor**
Faculty of Logistics
Mariborska cesta 7, 3000 Celje, Slovenia
https://www.fl.um.si, info.fl@um.si

Edition First edition. Translation of the original work from the Slovenian language Obrecht, M. (ur.). (2025). *Upravljanje trajnostnosti v oskrbovalnih verigah.* Univerza v Mariboru, Univerzitetna založba. doi: 10.18690/um.fl.4.2025

Publication type E-book

Available at http://press.um.si/index.php/ump/catalog/book/1093

Published at Maribor, Slovenia, January 2026

Project name Vzpostavitev okolja za izobraževanje zelene in digitalne logistike ter oskrbovalnih verig

Project financier The project is co-financed by the Republic of Slovenia, the Ministry of Higher Education, Science and Innovation, and the European Union - NextGenerationEU. The project is implemented in accordance with the plan within the development area Smart, Sustainable and Inclusive Growth, component Strengthening Competences, in particular Digital and those required by New Professions and the Green Transition (C3 KS), for the investment measure F. Implementation of pilot projects, the results of which will be the basis for preparing the starting points for the reform of higher education for a green and resilient transition in the S.O Company: project Pilot projects for the renovation of higher education for a green and resilient transition. The project is part of the NOO scheme (Recovery and Resilience Plan)

THE RECOVERY AND RESILIENCE PLAN University of Maribor REPUBLIC OF SLOVENIA MINISTRY OF HIGHER EDUCATION, SCIENCE AND INNOVATION Funded by the European Union NextGenerationEU

CIP - Kataložni zapis o publikaciji
Univerzitetna knjižnica Maribor

658.7:502.131(0.034.2)

MASTERING sustainability in supply chains [Elektronski vir] / editor Matevž Obrecht ; [translation Mirjana Lazarević]. - 1st ed. - E-knjiga. - Maribor : University of Maribor, University of Maribor Press, 2026

Način dostopa (URL): https://press.um.si/index.php/ump/catalog/book/1093. - Prevod dela: Upravljanje trajnostnosti v oskrbovalnih verigah

ISBN 978-961-299-100-5
doi: 10.18690/um.fl.4.2026
COBISS.SI-ID 264692227

ISBN 978-961-299-100-5 (pdf)

DOI https://doi.org/10.18690/um.fl.4.2026

Price Free copy

For publisher Prof. Dr. Zdravko Kačič,
Rector of University of Maribor

Attribution Obrecht, M. (ed.). (2026). *Mastering Sustainability in Supply Chains.* University of Maribor, University of Maribor Press. doi: 10.18690/um.fl.4.2026

Table of Contents

1 **Climate Change and Post-carbon Alternatives in Transport** 1
Maja Vrčon

2 **Sustainable Organizational Transformation** 27
Matjaž Knez

3 **Environmental Assessment: Integration of Carbon Footprint** 53
Matevž Obrecht

4 **Environmental Impact Assessment with LCA** 67
Matjaž Denac

5 **Circular Economy and Value Chains (Life Cycle Analysis)** 97
Rebeka Kovačič Lukman, Kristijan Brglez

6 **Integration of Eco Design in Supply Chain Management** 117
Matevž Obrecht

7 **Sustainable Energy Self-sufficiency** 133
Matevž Obrecht, Martin Fale

Climate Change and Post-carbon Alternatives in Transport

Maja Vrčon
Gorizia, Italy
maja.vrcon@gmail.com

DOI
https://doi.org/10.18690/um.fl.4.2026.1

ISBN
978-961-299-100-5

Since the first IPCC report was published in 1990, policy makers have been confronted with the major issue of climate change and its socio-economic impacts. The impact of climate change and its consequences is a complex process that raises several questions. The current shift toward a sustainable future has made various sectors, including transport, the focus of the current urgency to address climate change. Despite this, this matter remains sensitive because it directly affects the daily decisions of countless citizens. While there is no single solution to transforming the transport sector, solutions like clean energy vehicles and fairer public transport can perhaps help us achieve the ambitious goals set by the IPCC. A post-carbon future is also possible by looking back, utilizing wind in sails for transport and riding cargo bikes around the city. Various social innovations and initiatives, such as community transportation and car sharing, together with lively debates about the fair distribution of public space between different traffic users, are already changing the modes of mobility in many metropolises.

Keywords:
climate change,
climate policy,
planetary boundaries,
post-carbon transport,
sustainable transport

University of Maribor Press

1 Introduction

Climate change is no longer just a problem of the future–we are already witnessing its effects today. Some parts of our planet have been visibly affected for decades, and with each passing year, we are seeing more catastrophic consequences in our own region as well. The changes in the Earth's climate, driven by increased human emissions of greenhouse gases, are having a profound impact on the environment. Glaciers and ice sheets are shrinking, ice on rivers and lakes is melting earlier, natural habitats of plants and animals are shifting and changing, and plants are blooming earlier than before … Some changes–such as droughts, forest fires, and other extreme weather events–are occurring even faster than scientists had predicted. In the summer of 2022, we witnessed an almost unstoppable wildfire that devastated the Karst region. We also experienced one of the driest years in Slovenia. According to the Slovenian Environment Agency (ARSO), based on preliminary (and not yet fully verified) data, 2022 was the warmest year on record nationwide, with below-average precipitation and high levels of sunshine. We also witnessed two more severe weather events in 2023: a major hailstorm and one of the largest floods in Slovenia in this century.

Since the release of the first report by the Intergovernmental Panel on Climate Change (IPCC) in 1990, climate change and its socio-economic impacts have become a central topic for policymakers. Climate change and its consequences are highly complex processes that raise a wide range of questions. From an ethical perspective, some of the most pressing issues relate to the balance between mitigation and adaptation efforts, as well as assigning responsibility for past and present greenhouse gas emissions. The fact that climate change is an intergenerational issue is something we can no longer afford to ignore. The well-being and survival of future generations depend now more than ever on the decisions we make today. Thanks to, and because of, the growing pressure for action - both from the top down (such as climate policies at international, national, and regional levels) and from grassroots initiatives - positive changes are happening at the micro level. We are witnessing numerous strategies being implemented that contribute to the transition toward a low-carbon society, the mitigation of climate change, as well as a fairer society and a higher quality of life.
In the following part of this contribution, I would like to shed light on some fundamental concepts related to the climate crisis, such as the Anthropocene, Planetary Boundaries, the IPCC, climate policies, and - most importantly - highlight

some existing solutions in the field of transport that could mark the beginning of the so-called post-carbon society.

2 From humans to climate change

2.1 Anthropocene era

The Anthropocene is the proposed - though not yet officially recognized - geological epoch in which we are currently living. It is considered part of the Quaternary period (from 2.6 million BCE to the present) and is characterized primarily by significant alterations to the Earth's surface, atmosphere, oceans, and nutrient cycles as a result of human activity. An increasing number of scientists argue that the Anthropocene should follow the Holocene epoch (from 11,700 BCE to the present) and that it began around the year 1950. The formalization of the Anthropocene depends on whether the impacts of human activity on planet Earth are - or will become - significant enough to be detectable in the geological strata. Most scientists agree that humanity's collective impact was considerably smaller prior to the Industrial Revolution, that is, before the mid-18th century. After that point, technological advancements enabled humans to initiate large-scale, systematic changes affecting multiple aspects of the Earth's system. Some scientists have proposed that the Anthropocene should begin in the year 1784, when Scottish inventor James Watt significantly improved his steam engine (originally patented in 1781), which coincided with the onset of the Industrial Revolution and the widespread use of fossil fuels (Issberner & Léna, 2018).

The term defining the most recent geological epoch - one in which human activities are believed to have triggered biophysical changes on a planetary scale - was coined in 1980 by American biologist Eugene F. Stoermer. However, it gained widespread popularity in the early 21st century, thanks to Dutch atmospheric scientist and Nobel Prize laureate in Chemistry (1995), Paul Crutzen. The word Anthropocene comes from Ancient Greek: ἄνθρωπος (anthropos), meaning "human," and καινός (kainos), meaning "new." The term is used across a variety of cultural and scientific contexts. It is employed by researchers, poets, philosophers, politicians, and activists - often with different interpretations. While some associate humanity's impact on the planet solely with climate change (such as the warming of the atmosphere, air, and oceans due to the use of fossil fuels), human influence on the transformation of the Earth extends far beyond climate change alone. Just consider the accumulation of waste, the construction of cities, roads, and other infrastructure.

As noted by Issberner and Léna (2018), from 1987 to 2015, a large-scale multidisciplinary research initiative - the International Geosphere-Biosphere Programme (IGBP) - was conducted, during which an extensive amount of data on anthropogenic changes to the Earth's system was collected. Another research effort, which began as early as the 1950s, involved sampling ancient ice in Antarctica and analyzing the current composition of the atmosphere. This study revealed the accelerated accumulation of greenhouse gases, particularly carbon dioxide. In 1988, the Intergovernmental Panel on Climate Change (IPCC) was established with the aim of examining the impact of these phenomena on the climate. In the last sixty years especially, human impact on the planet has reached unimaginable dimensions and speeds. As Rafferty (2023) notes, this period is also known as the "Great Acceleration." It refers to the post-war era, characterized by the rapid expansion and exponential growth of the population, massive consumption of fossil fuels and water, food production, global communication, and the use of vast agricultural lands. This period also marks the beginning of carbon dioxide emissions, global warming, ocean acidification, destruction of natural habitats, species extinction, and extensive exploitation of natural resources. These are clear signs that we have significantly altered our planet.

By combining all this data - first in 2009 and later in 2015 - environmental scientist Johan Rockström (Sweden) and his colleagues from the Stockholm Resilience Centre outlined nine Planetary Boundaries. Four of these nine boundaries have already been exceeded (according to data prior to 2023[1]). These include climate change, loss of biodiversity, species extinction and changes in land cover, as well as biogeochemical cycles - particularly those involving phosphorus and nitrogen (Issberner & Léna, 2018). The Planetary Boundaries framework was updated in September 2023.

It is now clear that our climate is no longer stable and is warming rapidly. Scientists now agree that the main driver of accelerated global warming is human activity. Agriculture, urbanization, deforestation, and pollution have caused dramatic changes to the Earth. However, geologists are still divided on whether humans will leave a

[1] Author's notes.

truly lasting and significant impact on the chemical composition of rocks and fossils beneath our feet. And that is precisely the kind of evidence needed to officially declare a new epoch - the Anthropocene. Humans have existed for such a brief moment in Earth's history that it may still be too early to determine whether our impact will truly be visible in the fossil record millions of years from now.

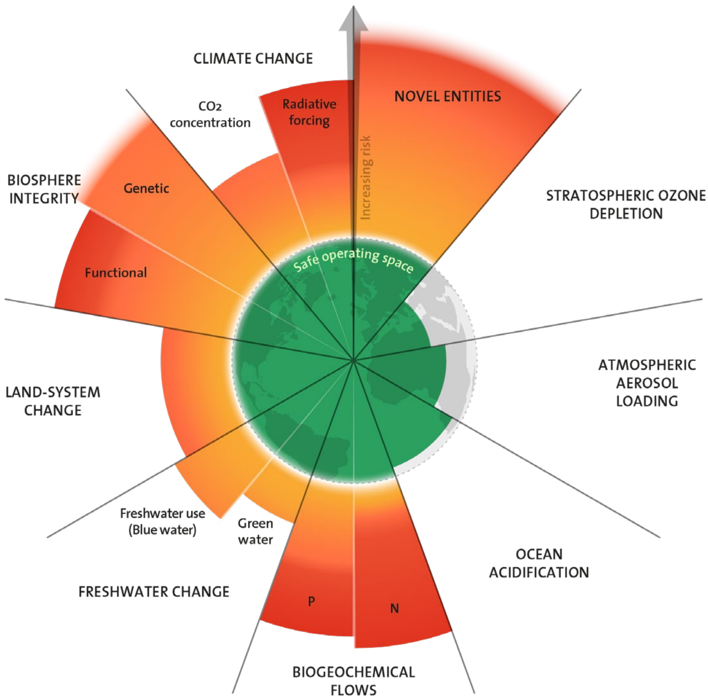


Figure 1.1: The 2023 update to the Planetary boundaries
Vir: Azote for Stockholm Resilience Centre, based on analysis in Richardson et al 2023

The most recent, third update of the Planetary Boundaries framework was conducted by 29 scientists from eight different countries. The researchers first identified processes in the Earth system that have been crucial for maintaining favorable conditions for humanity over the past 12,000 years. This period is known for its stable and warm conditions on planet Earth. The researchers then assessed the extent to which human activities have altered these processes and determined at what level human intervention increases the risks of potentially dramatic and irreversible changes in the overall conditions on Earth. They also used computer simulations in their research. As noted by the group of scientists in the study *Earth* *beyond six of nine planetary boundaries* (Richardson et al., 2023), the findings regarding the exceeded planetary boundaries are as follows:

- Carbon dioxide (CO2) in the atmosphere: The researchers set the planetary boundary for CO2 concentration in the atmosphere at 350 parts per million (ppm), but it has currently reached 417 ppm;
- Land-use change: This mainly refers to deforestation, logging, and the destruction of large forest areas. The current level has surpassed the safe boundary;
- Biosphere integrity: The boundary set for species extinction was to limit it to fewer than 10 extinctions per million species-years (10 E/MSY). However, the extinction rate has exceeded 100 extinctions per million species-years. This boundary has already been surpassed. It is currently estimated that around one million of the 8 million plant and animal species are at risk of extinction. Over the past 150 years, more than 10 percent of genetic diversity, both in plants and animals, may have been lost. Another aspect of biosphere integrity is the energy available to ecosystems, or net primary production (NPP). This represents the difference between the amount of carbon produced through photosynthesis and the energy used for respiration. Humans have appropriated about 30 percent of the energy that supported biodiversity before the Industrial Revolution;
- Freshwater resources: This includes blue water (surface water and groundwater, including drinking water) and green water (the water available to plants). Human impact on blue and green water has been calculated at 18.2% and 15.8%, respectively, exceeding the boundary of 10.2% and 11.1%. Analyses showed that the boundaries for blue and green water were surpassed in 1905 and 1929, respectively;
- Nutrient cycling (biogeochemical flows): Biogeochemical flows already reflect anthropogenic disruptions in the cycles of elements. Currently, the framework focuses on nitrogen (N) and phosphorus (P), as these two elements are fundamental building blocks of life, and their global cycles have been significantly altered by agriculture and industry. The boundary was set at 11 teragrams (Tg) for phosphorus and 62 Tg for nitrogen. The exceeded boundaries are now 22.6 Tg for phosphorus and 190 Tg for nitrogen;
- Creation of new entities: This boundary is now defined by truly novel anthropogenic inputs into the Earth's system. These include synthetic chemicals and substances (e.g., microplastics, endocrine disruptors, and organic

> pollutants); anthropogenically mobilized radioactive materials, including nuclear waste and nuclear weapons; as well as human-induced changes in evolution–genetically modified organisms and other direct human interventions in evolutionary processes. New entities serve as geological markers of the Anthropocene. The quantitatively defined planetary boundary for new entities should be maintained at zero. This means zero release of synthetic chemical compounds into the open environment, unless they are certified as harmless and are regularly monitored. This is the goal set by the Montreal Protocol.

Since 1988, humans have aggressively intervened in what was a relatively stable climate and terrestrial system of the planet (Richardson et al., 2023). Now, we are facing risks and are increasingly approaching irreversible system disturbances. The planetary boundaries are interconnected processes within the Earth's complex biophysical system. This means that simply focusing on climate change is not enough to achieve greater sustainability and resilience. Therefore, understanding the interplay of these boundaries, especially climate change and biodiversity loss, is crucial both in science and practice.

2.3 Climate change and IPCC

Humanity has already witnessed profound climate changes throughout its history, but these occurred more slowly, and the memory of them, in the absence of written records, has been preserved only in myths passed down orally through generations (for example, the myth of the Cosmic Flood) (Allan, 2017). The first known records of observations on changing weather patterns date back to Ancient Greece, while early systematic climate research and the development of modern understanding of climate processes date back to the 19th century. The influence of CO2 in the atmosphere and the related concept of the 'greenhouse effect' was proposed in 1825 by naturalist Jean-Baptiste Fourier. The first calculations on the impact of elevated CO2 concentrations on global temperatures and the associated idea of potential human influence on climate change were developed by Nobel laureate Svante Arrhenius at the turn of the 20th century (Flemming, 2014). With the development of technologies and methods for capturing and processing climate data, alongside the rapid increase in human impact on the environment, the presence of climate change has become increasingly evident and concerning. This, over time, contributed to the establishment of the Intergovernmental Panel on Climate Change (IPCC) in 1988. The IPCC (2018) was founded under the auspices of the World

Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP). The IPCC regularly reviews and assesses the various scientific bases related to climate change, its impacts, future risks, and the possibilities for adaptation and mitigation. The IPCC's role is to provide governments at all levels with scientific data that they can use to shape climate policies. It is important to emphasize that, although different governments or organizations may interpret climate change somewhat differently, the definition of climate change provided by the Intergovernmental Panel on Climate Change (IPCC) is widely recognized and accepted within the scientific community and by major international organizations.

In the IPCC Glossary (2018), we find a general definition of climate change, which reads:

"Climate change refers to a change in the state of the climate that can be identified (e.g., using statistical tests) through changes in the average and/or variability of its properties, and which lasts for an extended period, typically decades or more. Climate change may result from natural internal processes or external influences, such as solar cycle modulations, volcanic eruptions, and ongoing anthropogenic changes in the composition of the atmosphere or land use."

It is also worth noting that the United Nations Framework Convention on Climate Change (UNFCCC) defines climate change in Article 1 as:

"Climate change refers to a change in climate that is directly or indirectly attributed to human activity that alters the composition of the global atmosphere and that is observed in addition to natural climate variability over comparable time periods."

The UNFCCC thus distinguishes between climate change that can be attributed to human activities that alter the composition of the atmosphere and climate variability that can be attributed to natural causes (IPCC, 2018).

The Sixth Assessment Report (AR6) of the Intergovernmental Panel on Climate Change (IPCC) is the sixth in a series of reports that provide a comprehensive review of scientific, technical, and socio-economic information related to climate change. Three Working Groups (WG I, WG II, and WG III) contributed to the report, each focusing on a specific area: the physical science basis (WG I), impacts, adaptation, and vulnerability (WG II), and mitigation of climate change (WG III). The first study was released on August 9, 2021, while the contributions of the second and third working groups followed on February 28 and April 4, 2022. The final Synthesis Report was published on March 20, 2023.

The IPCC's Working Group I (IPCC, 2023), in its latest report, not only reconstructs past knowledge about climate change and examines current developments, but also explores various possible futures. The five new greenhouse gas emission scenarios used in the report represent potential climate trajectories throughout the 21st century, based on differing levels of greenhouse gas emissions and pathways of socio-economic development.

Five narratives were developed to describe the potential social, economic, political, and technological developments up to the end of the century. These five storylines were used to model different scenarios for the evolution of economic, energy, and land-use systems. Some of these scenarios are constrained by climate targets (referred to as "mitigation pathways"), while others are not ("baseline scenarios"). The results are presented as projected changes for the near future (2021–2040), mid-century (2041–2060), and end of the century (2081–2100), relative to the period 1850–1900, which serves as a reference for the pre-industrial era. As summarized in the Slovenian translation of the latest IPCC Summary for Policymakers (ARSO, 2021), the scenarios begin in 2015 and are as follows: two involve high and very high greenhouse gas emissions (SSP3-7.0 and SSP5-8.5), with CO_2 emissions approximately doubling by 2100 or 2050; one scenario involves intermediate emissions (SSP2-4.5), where CO_2 emissions remain around current levels until mid-century and then decline; and two scenarios involve very low and low emissions (SSP1-1.9 and SSP1-2.6), in which CO_2 emissions decline to net-zero around or after 2050, followed by net negative CO_2 emissions. Emission differences across these scenarios stem from varying socio-economic assumptions, levels of climate change mitigation, and air pollutant emissions. The narratives of these five scenarios are as follows:

– SSP1: Sustainability (Taking the Green Road) – In this scenario, the world gradually but decisively moves toward sustainable development. There would be improvements in education and healthcare systems, and economic growth would focus on lower material consumption and energy intensity.
– SSP2: Middle of the Road – The world follows a path where social, economic, and technological trends continue in a way that is broadly consistent with

historical patterns. Global and national institutions would make slow progress toward achieving sustainability goals, and income growth would occur unevenly across regions.

- SSP3: Regional Rivalry (A Rocky Road) – Rising nationalism, concerns about competitiveness and security, and regional conflicts would push countries to focus on local and regional issues at the expense of broader development. Economic growth would be slow, material consumption high, and inequality would persist or even worsen.
- SSP4: Inequality (A Road Divided) – In this scenario, significant inequality in investment in human capital, as well as disparities in economic development and political power, would lead to growing inequality both between and within countries. The gap between developed and developing nations would widen. Developed countries would experience rapid technological advancement, while developing countries would remain reliant on labor-intensive industries and low-tech solutions. The energy sector would see parallel investments in both carbon-intensive fuels (such as coal and oil) and low-carbon energy sources.
- SSP5: Fossil-Fuel Development (Taking the Highway) – In this scenario, the world would pursue sustainability through competitive markets, innovation, and cooperation between societies. Investments in health and education would be high; however, fossil fuels would continue to be heavily exploited. An energy- and resource-intensive lifestyle would become widespread globally. As a result, the global economy would experience rapid growth.

(Summarized from: ARSO – Slovenian Environment Agency: Office for Meteorology, Hydrology and Oceanography. (2021). *Climate Change 2021, Physical Science Basis and the Situation in Slovenia, IPCC Report 2021, Summary for Policymakers with an Added Description of the Situation in Slovenia.*)

The latest IPCC report is intended to serve as the basis for the United Nations Climate Change Conference - COP28, which was hosted by the United Arab Emirates in Dubai starting on November 30, 2023. At COP28, the progress of countries in reducing greenhouse gas emissions since the Paris Climate Agreement of 2015 was re-evaluated.

3 Major international climate policies

Research and findings from both the Planetary Boundaries framework and the IPCC reports are used as the basis for shaping various climate policies and international negotiations. Among the most significant international environmental and climate agreements are the Paris Agreement (which came into force in 2016) and the Kyoto Protocol (in force from 2005 to 2012 and extended for the period 2013–2020), both of which were adopted under the United Nations Framework Convention on Climate Change (UNFCCC). Since 1995, the member states of the Framework Convention have met annually at the Conference of the Parties (COP).

3.1 United Nations Framework Convention on Climate Change (UNFCCC)

The United Nations Framework Convention on Climate Change (UNFCCC) is one of three conventions adopted in 1992 at the Earth Summit in Rio de Janeiro, when the international community recognized the need for collective action to protect people and the environment and to limit greenhouse gas emissions. It has been ratified by almost all countries in the world. The UNFCCC came into force on March 21, 1994. Today, it has near-universal membership, with 198 countries that have ratified the convention and are parties to it. The UNFCCC states that its objectives are to "stabilize greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system" (UNFCCC, 2022). The UNFCCC is the first global treaty on climate change and an organized community of member states. The members meet annually to discuss progress and adopt various measures. The Kyoto Protocol and the more recent Paris Agreement are two landmark treaties that resulted from such annual meetings. Since 1995, the parties to the Framework Convention have gathered at annual conferences (Conference of the Parties – COP), where they assess progress in addressing climate change. These conferences also involve negotiations on the content of international climate agreements aimed at reducing greenhouse gas emissions. According to the agreements, industrialized countries were to be the first in line to reduce emissions. One of the agreements was also that the UNFCCC would provide financial support to developing countries to mitigate the impacts of climate change. In this context, it is worth mentioning that the Global Environment Facility (GEF) oversees the system of grants and loans to direct assistance to emerging economies. Industrialized countries are also required to regularly report on their climate change policies and provide annual inventories of greenhouse gas emissions from 1990 onwards. Developing countries are required to report on their actions to address climate change and their methods of adaptation. The UNFCCC recognizes, however, that the share of emissions from developing countries is likely to increase. Nevertheless, it strives to assist these countries in curbing emissions without undermining their economies. In the early years of the agreement, the UNFCCC emphasized climate change mitigation over adaptation in order to better understand the actual impacts of climate change with greater certainty. Recently, the UNFCCC has also started supporting and financing adaptation policies to the climate crisis. As stated by the UNFCCC (2022) on its official website, work on adaptation is currently taking place within the framework of various convention bodies. The Adaptation Committee, which the parties agreed to establish in accordance with the UNFCCC's Cancun Adaptation Framework, is an important step towards a cohesive approach to adaptation based on the convention.

3.2 Kyoto Protocol

The Kyoto Protocol was adopted on December 11, 1997. Due to the complex ratification process, it only came into force on February 16, 2005. The Kyoto Protocol was designed to operationalize the United Nations Framework Convention on Climate Change (UNFCCC) by binding industrialized countries and economies in transition to limit and reduce greenhouse gas (GHG) emissions in accordance with agreed individual targets. The convention required these countries to adopt policies and measures to mitigate climate change and to report regularly.

As stated by the UNFCCC (2019a) on its website, the Kyoto Protocol was based on the principles and provisions of the convention and followed a structure based on annexes. It only bound developed countries and imposed a heavier burden on them under the principle of "common but differentiated responsibilities and respective capabilities," acknowledging that they are largely responsible for the high levels of greenhouse gas emissions in the atmosphere. The Kyoto Protocol committed most signatories of Annex I (Annex I countries) to mandatory emission reduction targets, which varied according to the unique circumstances of each country. Other signatories of the UNFCCC and the Protocol, which are mostly developing countries, were not required to limit their emissions. The Protocol provided several options for countries to achieve their targets. One approach was the use of natural processes, known as carbon sinks, which absorb greenhouse gases from the atmosphere. One example of this was tree planting, which absorbs carbon dioxide from the air. Another approach was the international program called the Clean Development Mechanism (CDM), which encouraged developed countries to invest in technology and infrastructure in less developed countries. The Kyoto Protocol, in this way, unfortunately also opened the door to some unethical practices that were exploited by certain corporations and governments for their own benefit (such as land grabbing from indigenous peoples, deforestation, and the planting of monoculture tree plantations, etc.).

At the 18th Conference of the Parties (COP18) held in 2012 in Doha, Qatar, delegates agreed to extend the Kyoto Protocol until 2020 (UNFCCC, 2019a). Although the Kyoto Protocol represented an important diplomatic achievement, its success was far from being realized. Even if the targets were met, some critics argue that the final environmental benefit would not have been significant, as China, the world's largest emitter of greenhouse gases, and the United States, the second-largest emitter, were not bound by the protocol (China due to its status as a developing country and the United States because it did not ratify the protocol).

3.3 Paris agreement

The Paris Agreement is a legally binding international treaty on climate change and serves as an action plan to limit global warming. With the Paris Agreement, countries reaffirmed their commitment to climate action and agreed on new goals to accelerate efforts to limit global warming. It was adopted by 196 parties at the United Nations Climate Change Conference (COP21) in Paris on December 12, 2015. The Paris Agreement entered into force on November 4, 2016, after the condition was met that at least 55 countries, accounting for at least 55% of global greenhouse gas emissions, ratified it. All EU member states have ratified the agreement.

As stated by the UNFCCC (2023) on its website, the long-term goal of the Paris Agreement and the agreement of governments is to limit the average global temperature increase to well below 2°C compared to pre-industrial levels and to strive to limit the increase to no more than 1.5°C. In recent years, world leaders have emphasized the need to limit global warming to 1.5°C by the end of this century. This is also because the IPCC states that exceeding the 1.5°C threshold poses a risk of much more severe and more impactful consequences of climate change, including more frequent and intense droughts, heatwaves, and precipitation. To limit global warming to 1.5°C, greenhouse gas emissions must peak no later than 2025 and then be reduced by at least 43% by 2030 (UNFCCC, 2023).

The Paris Agreement is an important political achievement that has defined ambitious yet necessary goals to prevent dangerous climate change. For the first time in history, the Paris Agreement united all nations in the effort to combat climate change and adapt to its impacts, with enhanced support for assisting developing countries.

The IPCC, in its Summary for Policymakers (IPCC, 2023), states that the UNFCCC, the Kyoto Protocol, and the Paris Agreement support increasing levels of ambition by countries. The Paris Agreement, adopted under the UNFCCC with nearly universal participation, has led to the development of policies and the setting of targets at national and subnational levels, particularly regarding climate change mitigation and enhanced transparency of actions and support mechanisms. Numerous regulatory and economic instruments are already successfully in use. In many countries, these policies have improved energy efficiency, reduced deforestation rates, and accelerated the adoption of new technologies. In some cases, this has led to the prevention and reduction, or even the elimination, of emissions. At least 18 UNFCCC member countries have been maintaining reductions in greenhouse gas emissions from production and consumption for over 10 years. Unfortunately, this reduction has only partially offset and slowed global emissions growth (IPCC, 2023).

For a better understanding and a detailed review of climate policies (including policies at the European level and in Slovenia), we recommend reading the publication *Politično-zakonodajno ozadje blaženja podnebnih sprememb* (Political-Legal Background of Climate Change Mitigation), published in 2022 by the Slovenian organization Umanotera.

4 Post-carbon transport - examples of alternatives

One of the goals of the UNFCCC and, of course, the EU, is to reduce the negative impacts of transport on the environment. In December 2020, the European Commission published the *Sustainable and Smart Mobility Strategy – Guiding the European Transport System Towards a Green Future*, presenting a vision to ensure that the EU's transport system achieves a green transformation. This strategy outlines various milestones for achieving the goals of sustainable, smart, and resilient mobility, in relation to the scope and composition of passenger transport and traffic. The UNFCCC, within the framework of the Marrakech Partnership for Global Climate Action, has also set a vision for transportation in a post-carbon society by 2050. According to UNFCCC (2021), by 2050, both passenger and freight transport are expected to be fully decarbonized through the transition to more sustainable and resilient vehicle technologies. While individual countries will need to define their own pathways to decarbonize the transport sector based on existing or potential regulations, challenges, and policy priorities, these shifts will be made gradually and through a series of milestones. Here, low- or fully zero-emission transportation modes (such as trains, public transport, walking, and cycling) and vehicles (e.g., electric, hydrogen, hybrid, biofuel, or ammonia-powered ships and airplanes) are envisioned. This is expected to lead to the complete decarbonization of all transportation modes by 2050.

Many shipping companies are already exploring alternative fuel sources, such as hydrogen, ammonia, or methanol, but the current costs associated with producing "green" fuels are too high to compete with fossil fuels. Wind is a well-known renewable energy source that could be harnessed by shipping companies–after all, it once powered global maritime trade: "Simply put, in order to meet climate and broader environmental goals, vessels must minimize fuel consumption by using slower and more efficient ships that utilize sails and other renewable technologies on board, with any remaining fuel they need being new zero-emission fuels," said John Maggs, Senior Policy Advisor at the organization Seas At Risk, to UNFCCC (2021a).

4.1 Climate-friendly maritime transport

According to the International Maritime Organization (IMO), international shipping accounts for about 2.2 % of global greenhouse gas emissions. To put it into perspective, if international shipping were a country, it would be the sixth-largest emitter, releasing more CO2 annually than Germany. As Willner (2021) notes, these annual carbon emissions from container ships not only significantly contribute to accelerating climate change (one of the nine scientifically defined planetary boundaries we risk exceeding), but also to ocean acidification (another planetary boundary), which greatly affects biodiversity (the third planetary boundary). All of this must also be considered in light of chemical pollution (the fourth planetary boundary) coming from ship exhausts.

Today's freight industries are not only plagued by environmental issues but also by complex logistical and economic problems, as highlighted by Willner (2021). Cargo ships that use fossil fuels are generally massive in size, with enormous carrying capacities. However, it is precisely due to these excessive capacities that these ships are unable to adapt to sudden and unexpected changes in the global market. Today, the needs of international cargo ports and specialized markets would be much better served by smaller cargo ships with efficient and fuel-saving consumption, writes Willner (2021). Willner (2021) also emphasizes that the current system of maritime freight transport is becoming increasingly vulnerable due to unpredictable fuel prices, the scarcity of fossil fuels, geopolitical conflicts, wars, instability in the Middle East, Venezuela, and other regions.

When faced with these numerous challenges in the cargo shipping industry, one may wonder: what’s next? What should the transition to a new era of shipping, one that is not dependent on fossil fuels, look like, while still preventing significant economic harm? The good news is that change is already underway. Ships powered by wind, solar energy, and hydrogen are offering innovative low-carbon or carbon-free alternatives to fossil fuel-powered cargo vessels. Wind, as the primary source of propulsion, is soon expected to make a comeback in shipping, according to experts. New experimental sail designs include rigid sails, rotating vertical cylinders, and even wind kites.

4.1.1 Fairtransport

From the late 1970s to the early 21st century, the legendary captain Paul Wahlen captained the cargo schooner *Avontuur*. At that time, he was the last captain of a sailing cargo fleet in the Caribbean. In European waters, another sailing cargo operator, the North Sea clipper *Albatros* and its captain Ton Brouwer, were also well-known. These two companies were likely the last in the Northern Hemisphere to rely on wind for shipping. A few years later, everything changed, and sailing cargo vessels made a comeback. Sustainability became mainstream, and shipping by sail began to be promoted online as the ultimate adventure, fulfilling society's desire for a real, authentic experience.

Currently, more than 20 sailing cargo projects are underway, operating from Denmark to the Caribbean (EcoClipper, 2018). The concept has proven to be a successful model even in the 21st century. Two lobby groups have been established: the International Windship Association (IWSA) and the Sail Cargo Alliance (SCA). This can be seen as the emergence of a new economic sector within the domain of maritime freight transport.

In 2006, both *Avontuur* and *Albatros* ceased their cargo operations. Soon after, the newly refurbished sailing ship *Kwai* took over trade between Hawaii and the Cook Islands. Shortly thereafter, another sailing cargo company, *Fairtransport*, was established. Fairtransport operated the vessel *Tres Hombres*, which became widely recognized as the unofficial ambassador of sailing cargo ships. A few years later, the world's oldest cargo ship, *Nordlys*, joined *Tres Hombres* in the fleet. This was followed by the launch of the beautiful ship **Grayhound**, the return of the schooner *Avontuur*, and the conversion of *Luna II* and *Gallant* from passenger ships to cargo vessels. The transportation of goods by sailboats has experienced a resurgence.

As stated on their website (Fairtransport, 2022), the mission of Fairtransport, since its inception in 2027, has been to raise awareness about climate-friendly transport and reducing carbon footprints. With their fleet of sailboats, which operate without engines, they primarily focus on trading ecological and traditional artisan products. They transport goods in a completely sustainable manner, solely using wind energy. In this way, they demonstrate that transport with a nearly zero carbon footprint is possible and environmentally friendly.

In an interview with Sailors for Sustainability (2022), one of the co-founders of Fairtransport, Captain of the ship *Tres Hombres*, Andreas Lackner, states that Fairtransport is the world's largest sailing freight carrier. Their current fleet of seven cargo sailing vessels sails across the Atlantic and the North Sea. Without engines, they rely solely on wind power. Solar panels and wind generators provide energy for their communication and navigation equipment. For emergencies, they also have a generator that runs on recycled cooking oil. Their transoceanic schooner *Tres Hombres* measures 32 meters and has been sailing sustainably, without emissions, since December 2009. It is used for general cargo transport between Europe, the Atlantic and Caribbean islands, and the Americas. Its capacity exceeds 35 tons, and it can accommodate a crew of seven professionals and eight apprentices (training is essential at Fairtransport, as today's sailors need to be taught a combination of historical and modern sailing skills). In their fleet, they also have the *Nordlys*, a 25-meter ketch - a two-masted schooner, built on the Isle of Wight in 1873 as a fishing vessel. Now, it transports up to 30 tons of cargo between European ports. Additionally, they operate the *De Gallant*, *SV Zeehaen*, *SV Brigantes*, the previously mentioned *Avontuur*, and one of the more well-known vessels, *Hawila*. *Hawila* is not only used as a cargo ship but also serves as a cultural and educational platform to raise environmental awareness and encourage the global shipping industry to adopt a sustainable, zero-carbon transportation culture (Fairtransport Holding B.V., 2022).

Fairtransport not only transports goods in the most sustainable way, but also follows strict sustainability principles for the goods they carry. They know the producers of the goods they transport and are confident that their operations are fair, respecting both nature and their workers. *"Furthermore, we only transport luxury goods such as coffee, cocoa, and rum. In this way, we meet special needs without harming the environment. Other products are best produced locally, so transport is not necessary,"* explains Captain Andreas (Sailors for Sustainability, 2022).

Even in the late 1940s, enormous steel sailing ships transported cargo along some of the transoceanic routes. Now, cargo ships powered by fossil fuels will have to make way for high- and low-tech sailing vessels by 2030, which will reduce transportation costs and emissions.

4.2 Around the city: cargo bikes and electric car sharing

The vision framework for transportation set by the UNFCCC within the Marrakech Partnership for Global Climate Action (2020) also envisions nearly fully decarbonized cities. In this vision, cities prioritize walking, cycling, and other forms of active mobility - along with existing public transportation and mobility services utilizing apps - representing a significant portion of urban movement. These changes are expected to occur primarily due to significant shifts in demographics, economic activities, travel patterns, behavior, investments, and policies. Such transformations will be possible through the integration of land-use planning with transportation infrastructure planning, which will reduce the distance traveled per capita. The level of car ownership in urban areas will significantly decrease, thanks to a number of regulations such as tolls and parking fees, traffic restriction schemes in cities, investments in high-quality public transport, green public procurement, and other forms of shared mobility services. Urban transportation will be completely emission-free, with improved load factors and reduced unnecessary trips, as outlined in the UNFCCC vision (2020).

Some cities have already been implementing the vision of post-carbon mobility for quite some time, using solutions that have either emerged from community-driven initiatives or have been developed in response to specific urban needs. Alongside the rapid rise of digital technologies and increasing demand for better urban logistics, there is also growing pressure to improve the overall quality of urban life. As Vasiutina et al. (2021) point out, the bottom-up approach is gaining momentum due to increasing public awareness of the dangers of global warming - particularly the impact of transportation as one of the main contributors to climate change. Given the growing concern among citizens about the quality of life in their neighborhoods- and increasing calls for city authorities to take appropriate action-the question arises of how to introduce new, environmentally friendly business models and strategies. In response to such grassroots initiatives, many cities around the world have implemented urban transport policies aimed at reclaiming public space for pedestrians and non-motorized vehicles. These policies also seek to limit both the speed and access of heavy motor vehicles in city centers. In addition, city authorities have committed to encouraging residents to shift toward more sustainable modes of transportation. For example, incentives for purchasing electric cars and cargo bikes can include financial support as well as tax reductions. Cycling can be further encouraged through improvements in infrastructure and various community initiatives, as noted by Vasiutina et al. (2021).

4.2.1 Cargo bikes

Urban supply chain management is receiving increasing attention. In recent years, new urban mobility initiatives have been developed to enable more efficient delivery of goods, reducing both delivery costs and negative environmental impacts. Cargo bikes have proven to be a highly effective solution for last-mile delivery in urban centers. This delivery method has low investment costs (making it economical), and the vehicles are versatile, able to navigate densely populated areas and narrow streets with ease, while having near-zero environmental impact (making them ecological). By using cargo bikes, it would be possible to halve the volume of freight transported by polluting vehicles in urban centers, thereby reducing emissions and delivery costs.

As noted by Sesana (2023) in his article for the Italian monthly *Altreconomia*, Vienna introduced a cargo bike sharing project as early as 2017. *Grätzlrad*-a German term that can be translated as "neighborhood bike" is the name chosen by the City of Vienna for this innovative bike-sharing initiative aimed at promoting the use and sharing of cargo bikes in urban environments. The operating model and incentives for sharing these bikes are simple: the municipality co-finances the purchase of the bike for a local business, pub, café, or neighborhood association. They then make the cargo bike available for free rental for a minimum period of two years, in addition to using it for their own needs (deliveries, errands). Local residents can borrow the bike for a day or even just a few hours, depending on their needs. Booking a bike is easy and can be arranged in just a few steps via a dedicated online platform. However, Vienna is not the only city to have promoted the expansion and shared use of cargo bikes in recent years, as Sesana (2023) emphasizes. The European Cyclists' Federation (ECF) has mapped the use of cargo bikes in 125 European cities–from Rotterdam to Copenhagen, and from Salzburg to Brussels–and has compiled the findings on a dedicated website called *"Cargo-bike friendly cities."* On this interactive platform, users can explore data for each city based on seven different indicators, including purchase incentives, sharing system models, urban context, and bike manufacturers (Sesana, 2023).

A cargo bike is a bicycle designed specifically for transporting various types of loads, such as goods or passengers, and was originally developed for this purpose almost a century ago. The first cargo bikes were commonly used for delivering mail, bread, and milk. As noted by Vasiutina et al. (2021), cargo bikes are named based on their design, number of wheels, or intended use. They may be called cargo bikes, transport or "box" bikes, carrier bikes, tricycles and quadricycles, cycle trucks, long johns, and others. Modern cargo bikes are usually equipped with electric assistance. The models vary widely – from simple two-wheel bikes with boxes mounted in the front or back, to more advanced *longtails* and extended bikes capable of carrying weights between 50 and 100 kg. The most advanced multi-wheel bikes or light electric vehicles can even transport loads ranging from 500 to 700 kg.

Recent studies confirm the enormous potential of cargo bikes as a sustainable alternative to traditional delivery vehicles, according to Vasiutina et al. (2021). At the same time, people's willingness to shift to more environmentally friendly means of transportation–especially for last-mile delivery–can be observed in just over 60% of the studies reviewed. Nearly 50% of scientific sources advocate for the adoption of cargo bikes. According to the findings of the *CycleLogistics* project, almost half of all urban freight transport in the EU could be carried out using cargo bikes (Vasiutina et al., 2021). Of course, financial incentives and other initiatives to promote the use of cargo bikes in cities are not enough on their own. There also needs to be sufficiently wide bike lanes–between two to four meters in each direction–so that those riding cargo bikes can do so safely and without obstructing other road users, says Anna-Karina Reibold from the European Cyclists' Federation (Sesana, 2023).

"Cargo bikes have great potential to transform our cities by reducing motor vehicle traffic, congestion, noise, and air pollution. Local authorities can help unlock this potential by providing policies and infrastructure, incentives, services, and other forms of support," said Jill Warren, Executive Director of ECF, to Altereconomia newspaper (Sesana, 2023).

4.2.2 Electric car sharing in cities and SPARK

The challenges related to mobility and transportation in urban areas have become one of the priority areas for policies aimed at improving the quality of life for citizens. Inefficient traffic system organization and distorted mobility development reveal a scenario that is becoming increasingly critical day by day. We are witnessing numerous traffic jams, air pollution, noise pollution, high energy consumption, traffic accidents, overcrowding of public spaces with cars, uneven distribution, and rising costs (fuel, parking fees), etc. All of this contributes to the fact that our cities no longer offer a high quality of living. One of the alternative methods that is undoubtedly interesting and already in use is carsharing. *Carsharing* complements public transportation and often involves walking or cycling as well. It is one of the most prominent examples of the sharing economy and a modern, sustainable form of mobility. Significant progress in sustainable development policies and the shift towards electromobility has led to increased interest in the use of electric vehicles among carsharing providers.

As Turoń and others (2019) mention in their study on electric vehicles in carsharing systems, the basic idea of carsharing is to limit the number of vehicles in cities and reduce people's need for car ownership. Carsharing systems include services based on the principle of short-term vehicle rental. Initially, carsharing systems were based on the option of renting a vehicle and returning it to the same location (the return system). Later, the possibility of returning the cars at different locations designated by the service provider was introduced. Finally, the possibility of so-called free-floating rentals was implemented, allowing users to pick up and drop off cars anywhere within the operational area of a specific carsharing provider. Currently, the most commonly used carsharing model is this type of rental system. Users can take a car from where it is parked (anywhere) and park it anywhere in the city at their final destination. The first carsharing system was established in the market in 1948. However, the main development of carsharing systems began after 2006. In 2008, European automotive giants like Daimler and BMW created carsharing services. Due to the growing demand for these systems, by 2009, there were already 14 operators offering carsharing services (Turoń et al., 2019).

One such operator is the company and platform SPARK, which is an example of good practice in the carsharing of electric vehicles in the cities of Vilnius (Lithuania) and Sofia (Bulgaria). This system provides affordable, environmentally friendly mobility solutions through the use of free-floating carsharing models. The use of cars is tied to a mobile app, through which users can find and reserve a car they wish to use. With the app, users can view the route to the selected vehicle, reserve it, unlock and lock the car, and also receive a bill for use. Each ride is charged by the minute or per day, with costs including insurance, technical maintenance, and charging. Charging is free at one of SPARK's charging stations, or users can charge the vehicle at home (a cable is provided). Parking is also free in any paid parking zones in Vilnius and Sofia. SPARK has a network of 85 charging stations in Vilnius and a total of 88 electric vehicles in Vilnius and 63 in Sofia. To date, the SPARK service has been used approximately 225,000 times in both Vilnius and Sofia, covering 2,000,000 kilometers, which has helped save 400 tons of CO2 emissions, according to Kaveckis (2018).

Kaveckis (2018) also emphasizes that car-sharing of electric vehicles reduces traffic congestion, lack of parking spaces, pollution, and noise levels in urban areas, which are major issues for any modern city. This contributes to sustainable mobility plans in cities and should encourage municipalities to develop networks of charging stations. Additionally, it highlights the importance of promoting the greater use of electric vehicles, which represent the future of the automotive industry.

5 Conclusion

A large part of human history has been dedicated to improving ways and abilities to move, with inventions followed by improvements and new innovations. Testing and innovating versions of bicycles, sails, and engines has led to significant progress in transportation. However, to rapidly adapt transportation systems to the upcoming energy challenges, more than just adjusting existing systems will be needed. New revolutions in transportation will be necessary to make the use of fossil fuels irrelevant. Part of this is figuring out how we can change things like current cars and trucks, which significantly contribute to atmospheric warming and, consequently, climate change. To achieve resilience to the already evident impacts of climate change and prevent the worsening of negative effects, we must radically reduce emissions across the entire global economy and protect and restore the natural ability to absorb emissions that are already in the atmosphere. For a successful post-carbon green transition, we will need a new revolution in transportation, as well as an understanding of the dynamics of this revolution, or the fundamental change in transport and mobility in general. This fundamental change in the given situation would mean a significant reduction (or increase) in traffic activity, and a new mode of transportation would become so widespread that at least one-tenth of the population would use it. The changes will need to be far-reaching and bold enough to break established organizational structures and user expectations.

Although humans are responsible for the climate crisis, it's important to remember that human ingenuity can also be a source of positive change, which is a source of optimism. Furthermore, we already have many tools and innovations at our disposal to build a better and brighter future–from the potential creation of alternatives to air travel and greater investments in public transportation, to the transition to electric vehicles and cleaner modes of long-distance travel. However, as the latest IPCC report clearly states, we no longer have time–now is the moment to act.

References

Allan, S. (2017). The Jishi Outburst Flood of 1920 BCE and the Great Flood Legend in Ancient China: Preliminary Reflections. *Journal of Chinese Humanities*, *3*(1), 23–34. https://doi.org/10.1163/23521341-12340041

ARSO - Agencija Republike Slovenije za okolje: Urad za meteorologijo, hidrologijo in oceanografijo. (2021). *Podnebne spremembe 2021, Fizikalne osnove in stanje v Sloveniji, Poročilo IPCC 2021, Povzetek za odločevalce z dodanim opisom stanja v Sloveniji.* ARSO - Agencija Republike Slovenije za okolje.

Baines, D. (2021). Images that help us see time with new eyes [Spletno]. In *www.activehope.info*. https://www.activehope.info/images

EcoClipper. (2018). *Proof of concept*. EcoClipper ; EcoClipper Cooperative. https://ecoclipper.org/proof-of-concept/

Edenhofer, O., & Seyboth, K. (2013). Intergovernmental Panel on Climate Change (IPCC). *Encyclopedia of Energy, Natural Resource, and Environmental Economics*, *1*(1), 48–56. https://doi.org/10.1016/b978-0-12-375067-9.00128-5

European Environment Agency. (2021). *Dejstva in številke: Evropsko okoljsko poročilo o pomorskem prometu*. European Environment Agency. https://www.emsa.europa.eu/publications/download/6756/4515/23.html

Fairtransport Holding B.V. (2022). *Fairtransport - Cargo Under Sail*. Fairtransport; Fairtransport Holding B.V. https://fairtransport.eu/en/

Fleming, J. R. (2014). Climate, Change, History. *Environment and History*, *20*(4), 577–586. https://doi.org/10.3197/096734014x14091313617442

IPCC, 2018: Annex I: Glossary [Matthews, J.B.R. (ed.)]. In: *Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty* [Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 541-562, doi:10.1017/9781009157940.008.

IPCC, 2023: Summary for Policymakers. In: Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, H. Lee and J. Romero (eds.)]. IPCC, Geneva, Switzerland, pp. 1-34, doi: 10.59327/IPCC/AR6-9789291691647.001

Issberner , L.-R., & Léna, P. (2018). Anthropocene: the vital challenges of a scientific debate. *UNESCO Courier*, *2018-2*. https://en.unesco.org/courier/2018-2/anthropocene-vital-challenges-scientific-debate

Kaveckis, G. (2018). SPARK - Electric Car Sharing | Interreg Europe - Sharing solutions for better policy. In *www.interregeurope.eu*. Interreg Europe. https://www.interregeurope.eu/good-practices/spark-electric-car-sharing

Lade, S. J., Steffen, W., de Vries, W., Carpenter, S. R., Donges, J. F., Gerten, D., Hoff, H., Newbold, T., Richardson, K., & Rockström, J. (2019). Human impacts on planetary boundaries amplified by Earth system interactions. *Nature Sustainability*, *3*(2), 119–128. https://doi.org/10.1038/s41893-019-0454-4

Pavid, K. (2019). *What is the Anthropocene and why does it matter?* Nhm.ac.uk; Natural History Museum. https://www.nhm.ac.uk/discover/what-is-the-anthropocene.html

Rafferty, J. P. (2023). Anthropocene Epoch. Encyclopedia Britannica. In *Encyclopædia Britannica*. https://www.britannica.com/science/Anthropocene-Epoch

Richardson, K., Steffen, W., Lucht, W., Bendtsen, J., Cornell, S., Donges, J. F., Drüke, M., Fetzer, I., Bala, G., Werner von Bloh, Feulner, G., Fiedler, S., Gerten, D., Gleeson, T., Hofmann, M., Willem Huiskamp, Matti Kummu, Mohan, C., Bravo, D., & Petri, S. (2023). Earth beyond six of nine planetary boundaries. *Science Advances*, *9*(37). https://doi.org/10.1126/sciadv.adh2458

Rockström, J. (2009). A safe operating space for humanity. *Nature*, *461*(7263), 472–475. https://doi.org/10.1038/461472a

Sailors for Sustainability. (2022). *Emission-Free Shipping over Sea (PRT)*. Sailors for Sustainability. https://sailorsforsustainability.nl/portfolio/emission-free-shipping-sea-prt/

Sesana, I. (2023, March 10). *Le città che scommettono sulle cargo-bike secondo l'European cyclists' federation*. Altreconomia. https://altreconomia.it/le-citta-che-scommettono-sulle-cargo-bike-secondo-leuropean-cyclists-federation/

Steffen, W., Richardson, K., Rockstrom, J., Cornell, S. E., Fetzer, I., Bennett, E. M., Biggs, R., Carpenter, S. R., de Vries, W., de Wit, C. A., Folke, C., Gerten, D., Heinke, J., Mace, G. M., Persson, L. M., Ramanathan, V., Reyers, B., & Sorlin, S. (2015). Planetary boundaries:

Guiding human development on a changing planet. *Science*, *347*(6223). https://doi.org/10.1126/science.1259855

Stockholm Resilience Centre. (2023). *Planetary boundaries - Stockholm Resilience Centre*. Stockholmresilience.org; Stockholm Resilience Centre . https://www.stockholmresilience.org/research/planetary-boundaries.html

Turoń, K., Kubik, A., & Chen, F. (2019). Operational Aspects of Electric Vehicles from Car-Sharing Systems. *Energies*, *12*(24), 4614. https://doi.org/10.3390/en12244614

UNFCCC. (2019a). *What is the Kyoto Protocol?* UNFCCC; UNFCCC secretariat (UN Climate Change). https://unfccc.int/kyoto_protocol

UNFCCC. (2019b, June 12). *Conference of the Parties (COP) | UNFCCC*. Unfccc.int; UNFCCC secretariat (UN Climate Change). https://unfccc.int/process/bodies/supreme-bodies/conference-of-the-parties-cop

UNFCCC. (2020). *Climate Action Pathway: Transport. Executive Summary*. Global Climate Action - UN Climate Change. https://unfccc.int/sites/default/files/resource/ExecSumm_Transport_1.pdf

UNFCCC. (2021a). All At Sea. *Unfccc.int*. https://unfccc.int/blog/all-at-sea

UNFCCC. (2021b, May 5). Transport - Climate Action Pathway. *Unfccc.int*. https://unfccc.int/climate-action/marrakech-partnership/reporting-tracking/pathways/transport-climate-action-pathway

UNFCCC. (2022). *What is the United Nations Framework Convention on Climate Change?* Unfccc.int; United Nations Climate Change. https://unfccc.int/process-and-meetings/what-is-the-united-nations-framework-convention-on-climate-change

UNFCCC. (2023). *The Paris Agreement*. UNFCCC ; UNFCCC secretariat (UN Climate Change). https://unfccc.int/process-and-meetings/the-paris-agreement

Vasiutina, H., Szarata, A., & Rybicki, S. (2021). Evaluating the Environmental Impact of Using Cargo Bikes in Cities: A Comprehensive Review of Existing Approaches. *Energies*, *14*(20), 6462. https://doi.org/10.3390/en14206462

Willner, A. (2021, March 15). *New age of sail looks to slash massive maritime carbon emissions*. Mongabay Series; Mongabay. https://news.mongabay.com/2021/03/new-age-of-sail-looks-to-slash-massive-maritime-carbon-emissions/

SUSTAINABLE ORGANIZATIONAL TRANSFORMATION

MATJAŽ KNEZ
University of Maribor, Faculty of Logistics, Celje, Slovenia
matjaz.knez@um.si

Sustainability has become an essential part of business strategies around the world, as companies discover how green approaches strengthen their financial and market positions. Implementing sustainable practices leads to greater profitability by ensuring efficiency and innovation, which reduce costs and create new opportunities. Companies that comply with environmental standards and legislation often go beyond minimum requirements, which brings advantages in reducing risks and building a brand that reflects social responsibility and ethics. Effective planning for sustainable transformation requires a careful assessment of the current situation, setting SMART goals, and developing a strategy that leads to truly sustainable operations. In the following text, we will explore how companies move through the different stages of sustainable transformation, from committing to action to fully integrating sustainability into the core of the business model.

DOI
https://doi.org/10.18690/um.fl.4.2026.2

ISBN
978-961-299-100-5

Keywords:
sustainable development, sustainable goals, phases of sustainable transformation, sustainability strategy, SMART goals

University of Maribor Press

1 The importance of sustainability in today's business environment

Sustainability has become a crucial factor in today's business environment, as companies and organizations around the world recognize its increasing value and importance. Sustainability is not just a passing trend but a necessity for the long-term success of businesses.

Companies that focus on the sustainability of their operations influence several key areas (see Figure 1):

1. **Profitability**: Sustainable practices can have a positive impact on a company's profitability (Elkington, 1997). Numerous studies have shown that companies investing in sustainability tend to achieve better business performance. This includes resource savings, lower waste management costs, and improved risk management.
2. **Competitive advantage**: Sustainability can provide a competitive advantage (Porter et al., 2011). Companies that are sustainability-oriented are often perceived as more attractive to consumers and investors. This can result in increased market share and access to new capital for continued growth.
3. **Faster adaptation to legislation**: An increasing number of countries are introducing legislation and regulations that promote sustainable practices. This requires companies to comply with environmental standards and shift toward renewable energy sources, which can affect their long-term viability (Hopkins, 2012).
4. **Brand development and strengthening**: Sustainability can contribute to the positive development of a company's brand. Companies committed to sustainability build a reputation as responsible and ethical businesses, which attracts loyal customers and business partners.

Sustainability has thus become an indispensable part of modern business, impacting not only profitability but also the long-term survival and reputation of organizations. The development of sustainable strategies and practices has become a necessary step for successfully navigating today's business environment.

Figure 1: The impact of an organization's sustainability orientation
Source: own

1.1 How to start with sustainable corporate transformation?

How should one actually approach and implement the sustainable transformation of a company or organization? Figure 2 presents the essential steps:

Figure 2: How to tackle sustainable organizational transformation
Source: own

1.1.1 Step 1: the importance of an initial assessment of organizational sustainability

An initial organizational sustainability assessment is a crucial step for companies and organizations seeking to achieve their sustainability goals. This process allows organizations to assess their current sustainability status, identify areas for improvement, and develop strategies for sustainable development.

An initial assessment of organizational sustainability helps companies understand where they stand in terms of adopting sustainable practices (Epstein & Roy, 2001). This involves analyzing the current:

- environmental,
- social, and
- economic impacts of their activities.

Awareness of the starting point is key to further developing sustainable strategies.

Based on an initial assessment of the organization, companies can set **clear and achievable goals for sustainable development** (Schaltegger & Wagner, 2011). These goals may include:

- reducing the carbon footprint;
- increasing energy efficiency, or
- improving the working conditions of employees.

An initial assessment of organizational sustainability contributes to building awareness of sustainability issues among employees and management, which enables better alignment and collaboration in implementing sustainable practices (Lozano & Huisingh, 2011).

An initial assessment of organizational sustainability is therefore a crucial first step on the path to sustainable business. It enables organizations to identify their strengths and weaknesses and opportunities for improvement, which is crucial for the long-term successful implementation of sustainability strategies and the achievement of sustainability goals.

1.1.2 Step 2: methods and tools for collecting data on the current state

Collecting data about the current state of the organization is an important step in planning sustainable changes i, and to successfully identify areas for improvement, it is necessary to have accurate and reliable information.

Data collection can be carried out using various tools:

a) **Surveys and questionnaires:** are commonly used tools to collect opinions and information from employees, customers, or other stakeholders in an organization (Dillman et al., 2014). The use of standardized questionnaires allows for easy comparison of responses and data analysis.

b) **By reviewing documentation**: reviewing documents such as internal reports, financial records, and company policies can provide insight into existing practices and outcomes (Yin, 2018). This may also include reviewing legislation and regulations that affect the organization.

c) **Through workshops and interviews**: an organization can conduct workshops or interviews with employees, management, or other stakeholders to gain more detailed information about the current state of the organization and potential challenges (Rubin, & Rubin, 2011). These methods allow for deeper insight and understanding.

d) **By analyzing performance data**: The use of quantitative measures, such as key performance indicators (KPIs), allows for a quantitative assessment of the status quo (Neely, 2005). For example, measuring energy consumption or waste levels can provide a concrete picture.

The use of the appropriate data collection method or tool depends on the specific goals and needs of the organization. A thorough analysis of the current situation is key to creating effective strategies for sustainable development and improvement.

Collecting data on the current state of the organization is therefore the foundation for planning sustainable changes within it. Accurate and reliable information is essential for identifying improvements. Organizations can gather data through surveys and questionnaires, document reviews, workshops, interviews, and analysis of key performance indicators (KPIs). Each method provides distinct insights that are crucial for developing successful sustainability strategies.

Effective data collection and analysis enable organizations to accurately assess their current capabilities and identify areas where sustainable improvements can be achieved, thereby strengthening their sustainable development.

1.1.3 Step 3: the process of creating an organization's sustainable vision

Formulating a sustainability vision is a crucial stage in steering an organization towards sustainable development. This vision defines clear goals, core values, and strategic approaches that will guide the organization towards more responsible and sustainable operations.

The process of capturing:

a) **Understanding the status quo:** the first step in developing a sustainability vision is a thorough understanding of the organization's current situation. This includes an analysis of existing practices, processes, environmental impacts, as well as the social and economic aspects of operations (Schaltegger & Burritt, 2018).

b) **Involving key stakeholders:** the development of a sustainability vision requires the active involvement of all relevant stakeholders, including management, employees, customers, suppliers, and the local community (Figge & Hahn, 2018). Dialogue and collaboration with different groups enable a better understanding of their expectations and needs.

c) **Setting goals:** based on the understanding of the current state of the organization and stakeholder feedback, specific sustainability goals are defined. These goals should be measurable, achievable, and time-bound (SMART goals) (Doran & Ryan, 2017).

d) **Developing a sustainability strategy:** the organization's sustainability vision serves as the foundation for developing a sustainability strategy. This strategy outlines concrete actions and approaches that will enable the achievement of the defined goals.

e) **Monitoring and improvements:** the process of developing a sustainability vision does not end with goal setting and strategy development. The organization must continuously monitor its progress, evaluate its achievements, and implement improvements where necessary (Epstein & Buhovac, 2014).

An organization's sustainability vision serves as a guide for the entire organization, directing it towards sustainable operations and a responsible attitude towards the environment and society. With an appropriately implemented process of creating a sustainability vision, an organization can set itself on the path of sustainable development, which brings benefits to both itself and the wider community.

Developing a sustainability vision is therefore essential for guiding an organization toward sustainable development. It involves understanding the status quo, engaging stakeholders, setting SMART goals, developing a sustainability strategy, and ensuring continuous monitoring and improvement. The sustainability vision serves as a foundation for steering organizations toward more responsible operations and a greater contribution to society. A company's sustainability vision is like a compass that guides its journey into the future. It influences not only internal decisions and processes, but also how the company communicates and operates within the broader community – which is vital for achieving sustainability goals and creating a positive impact on both the environment and society.

1.1.4 Step 4: setting SMART goals for sustainability

Setting SMART goals (Specific, Measurable, Attainable, Relevant, Time-bound) is crucial for successfully achieving sustainability efforts in companies. SMART goals provide clarity, focus, and measurability to sustainability efforts:

a) **Specific:** SMART goals must be specific and well-defined enough to allow employees, partners and stakeholders to understand exactly what the company wants to achieve in terms of sustainability. *An example of a specific goal would be: "Reduce carbon dioxide (CO2) emissions in our logistics network by 20% over the next three years."*

b) **Measurable:** measurability is key to assessing the progress and effectiveness of sustainability efforts. A logistics company could set a measurable goal, for example: *"Increase transportation asset utilization by 15% by the end of 2026."*

c) **Achievable:** SMART goals should be realistic and achievable, taking into account available resources, technology and capacity. *For example: "Install a more energy-efficient vehicle fleet within the next year."*

d) **Relevant:** objectives should be linked to the organization's strategy and important sustainability challenges. *An example of a relevant objective would be: "Reduce the amount of waste in our warehouses, which will reduce negative environmental impacts and lower waste management costs."*

e) **Time-bound:** goals should have a clear time frame that defines when they should be achieved. *For example: "Reduce energy consumption by 10% across all our distribution centers by the end of 2026."*

Setting SMART goals is the foundation for targeted and effective achievement of sustainable changes in the company. This process contributes to the development of a culture of responsibility and engagement among all employees. In addition, it should be stressed that SMART goals allow the company to not only measure its progress but also communicate with external stakeholders, which strengthens transparency and trust. It is important that these goals are dynamic and adaptable, so that the company can proactively react to changing environmental conditions and technological advances.

Examples of logistics companies:

a) **UPS (United Parcel Service):** UPS set a specific goal to reduce the carbon footprint of its fleet. Their goal was to reduce CO_2 emissions by 20% by 2020. The goal was measurable through precise measurements of emissions and kilometers driven. UPS achieved this goal by improving the efficiency of its fleet and using alternative fuel vehicles (UPS, 2020).

b) **DHL:** has set itself an ambitious goal–to become the most sustainable logistics company in the world. The goal is specific, as it focuses on sustainability, measurable - through the use of emission meters and data management. DHL has achieved this goal by switching to electric vehicles, optimizing routes and reducing energy consumption in warehouses (DHL, b.d.).

c) **Maersk Line:** Maersk, one of the world's largest shipping lines, set a goal to reduce CO_2 emissions per container kilometer transported by 60% by 2020. This goal was measurable and achievable by switching to more energy-efficient ships and using cleaner fuels (Maersk, 2020).

d) **Amazon:** has set a goal to become a carbon-neutral delivery company by 2040. This goal is specific, measurable and time-bound. To achieve this goal, Amazon has ordered a large number of electric delivery vehicles and has committed to reducing its carbon footprint (Amazon, n.d.).

These examples of logistics companies show how SMART goals lay the foundation for sustainable transformation. Goals are specific, measurable, achievable, relevant and time-bound, which allows for monitoring progress and directing efforts towards sustainable solutions.

2 Four phases of sustainable organizational transformation

Figure 3: Four phases of sustainable organizational transformation
Source: own

Sustainable organizational transformation can be a long-term process involving many steps, with the organization gradually adapting to sustainable practices. The speed and scope of the transformation also depends on the amount of financial resources the organization allocates for it.

Sustainable transformation can be divided into four main phases, which include greening employees, greening the plant, greening processes, and finally, riding the green wave (Figure 3).

2.1 Phase 1: greening employees

The first phase of a sustainable transformation begins with employee awareness and education. The organization focuses on educating its employees about sustainable values and practices and encouraging them to become sustainability ambassadors. It can also simply be a written policy or circular informing/encouraging employees on how to act/behave in the future to operate more sustainably. *Example: The company "XGreen" organized training for its employees on sustainability principles and encouraged employees to share their sustainable ideas for improving the work environment.*

Investment level: At this stage, the main costs are related to educating and raising employee awareness about sustainability. This includes training, communication and awareness costs. *Example: The company "GreenX" invested 50,000 euros in an employee training program on sustainable practices. The result was an increase in employee awareness of sustainability and a 15% reduction in electricity consumption in the first year.*

The employee greening phase therefore refers to the initial step in the process of a company's sustainable transformation, where the emphasis is on raising awareness and educating employees about the importance and practical aspects of sustainability. In this phase, the organization focuses on encouraging employees to understand sustainable values and how they can contribute to environmental responsibility and the sustainable development of the company through their actions. The goal is to encourage employees to become active participants and ambassadors of sustainable initiatives within the company.

2.2 Phase 2: greening of the plant

The next phase focuses on changes to the company's plant or facility. This may include reducing energy consumption, using resources more efficiently, and creating more sustainable infrastructure. *Example: A car manufacturer installed solar panels on the roof of its factory, reducing its dependence on fossil fuels.*

Investment level: In this phase, investments are focused on energy efficiency and renewable energy sources. This includes investments in solar panels, energy-efficient equipment, and environmentally friendly technologies. *Example: The manufacturer "EcoX" invested €500,000 in installing solar panels on the roof of their factory. This allowed them to reduce their dependence on fossil fuel electricity by 40% and save €100,000 per year.*

The greening phase of the facility is the second step in a company's sustainability transformation process, focusing on the physical environment and operational processes. In this phase, companies implement measures to reduce the environmental impact of their operations, such as lowering energy and water consumption, improving resource efficiency, and investing in green infrastructure like solar power plants or waste management systems. The goal is to reduce the company's carbon footprint and create a more sustainable working environment.

2.3 Phase 3: greening of processes

In this phase, the organization examines its business processes and looks for ways to reduce its environmental footprint. This includes optimizing production processes, reducing waste, and improving a sustainable supply chain. *Example: A distribution company switched to electronic documents, thereby reducing paper consumption and CO2 emissions.*

Investment level: this phase requires investments in optimizing production processes, recycling waste, and reducing emissions. This includes investments in more efficient machinery, recycling facilities, and waste treatment. *Example: Distribution company "XEcoL" invested 300,000 euros in switching to electronic documentation. This allowed them to reduce paper consumption by 70% and reduce CO2 emissions by 20%.*

The process greening phase represents a further step in the sustainability transformation, where companies analyze and redesign their business processes to reduce their environmental footprint and enhance social responsibility. This phase involves optimizing production, increasing efficiency, minimizing waste, and improving the overall sustainability performance of the supply chain. The goal is to develop greener and more efficient business processes that not only reduce environmental impact but also bring economic benefits to the company.

At this stage of the transformation, organizations often complement other methods–such as Lean Manufacturing, Six Sigma, Eco-design, Environmental Benchmarking, and Energy Audits–by employing Life Cycle Assessment (LCA). LCA is a methodology used to evaluate the environmental impacts of a product, process, or service throughout its entire life cycle: from raw material extraction, production, and use, to recycling and final disposal. This analysis enables companies to identify areas within their processes where improvements can be made to reduce environmental impact and enhance efficiency.

2.4 Phase 4: riding the green wave

The final stage involves sustainable management of the organization and the use of sustainability principles as a driving force for innovation and growth. It assumes the role of a leader in the industry, the role of the so-called "trend setter", thereby setting an example for others and motivating competitors to imitate.
Example: A large technology company has committed to becoming completely carbon neutral by 2030 and is encouraging others in the industry to do the same.

Investment level: in this phase, the organization commits to sustainable management and continuous improvement. This includes investing in research and development of sustainable products and promoting sustainable practices in all aspects of the business. *Example: Technology company "GreenX" invested €1 million in research into sustainable solutions. As a result, they developed a product that reduces energy consumption in smart devices, which brought them an additional €2 million in revenue in the first year.*

The final phase, "Riding the Green Wave," represents the concluding stage of a company's sustainability transformation process, where the organization not only implements sustainable practices but also actively promotes and integrates them into all aspects of its operations. This is the phase in which the company leverages the full benefits of sustainable business practices, becomes a role model in the industry, and influences its suppliers, partners, and customers to adopt sustainability practices as well. The goal is to create a "green wave" that transcends the company's boundaries and has broader positive effects on the entire industry and society.

Each phase represents a key step in the organization's journey toward sustainability transformation. By properly executing these phases, an organization can achieve better efficiency, reduce its environmental impact, and become sustainability-oriented, bringing long-term benefits to all stakeholders. The level of investment may vary depending on the size and industry of the organization, but sustainable investments are profitable in the long run due to cost reductions and improved organizational reputation.

2.5 A few more examples of introducing concrete measures to achieve sustainable goals in logistics

Implementing concrete actions to achieve sustainability goals in logistics is crucial for organizations seeking to reduce their environmental impact, improve social responsibility, and increase the efficiency of their operations. Here are some more key actions and approaches that organizations can use:

– **Green transport:** replacing existing vehicles with alternative fuel vehicles, such as electric or hydrogen vehicles, can significantly reduce CO_2 emissions.

– **Route optimization:** using advanced technologies to optimize transportation routes can reduce travel times, fuel consumption, and emissions.

– **Waste reduction:** implementing recycling and waste reduction programs in logistics operations can help reduce environmental impact.

– **Use of renewable energy sources:** such as solar or wind power plants to supply electricity to logistics facilities, contributes to reducing the carbon footprint (Sarkis et al., 2011).

- **Employee training:** educating employees on sustainable practices and raising awareness of the importance of sustainability can help increase their engagement and involvement in sustainable activities (Seuring & Müller, 2008).

Increasing safety and efficiency: the integration of advanced telematics systems and tracking technologies enables better safety and efficiency of transportation (Kleindorfer et al., 2005).

Implementing these measures requires holistic thinking and an organizational commitment to sustainability goals. With these measures, logistics companies can reduce their ecological footprint, increase efficiency, and create a positive impact on society.

3 The importance of continuous monitoring of sustainability indicators

In today's business environment, where sustainability and environmental and social responsibility are increasingly recognized as key success factors, continuous monitoring of sustainability indicators has become indispensable. This is crucial for organizations striving for the sustainable development of their operations.

Sustainability indicators are metrics that enable organizations to measure and monitor their progress toward sustainability goals. These indicators can include various quantitative and qualitative data, such as greenhouse gas emissions, energy consumption, waste management, social responsibility, and economic performance. Sustainability indicators are essential for assessing how effectively a company is implementing its sustainability strategies and for informing stakeholders about its sustainability performance (Global Reporting Initiative, 2016).

By constantly monitoring sustainability indicators, organizations gain insight into their activities, which in turn enables them to develop.

Assessing progress: by monitoring indicators, organizations can assess how well they are implementing their sustainability goals and strategies. Based on these assessments, they can adjust their actions and strategies and improve their sustainability impact (Eccles et al., 2011).

Transparency: continuous monitoring and publication of sustainability data increases the transparency of the organization. This is crucial for meeting the expectations of customers, investors and other stakeholders regarding sustainable business operations (Porter & Kramer, 2011).

Good-decision making: sustainability indicators provide a basis for better decisions. Based on the collected data, organizations can better understand which actions are most effective and where improvements are needed (Elkington, 1997).

Improving competitiveness: organizations that successfully track sustainability indicators are better prepared for future changes in the business environment. This gives them a competitive advantage (Hart, 1997).

Raising awareness: sustainability indicators raise awareness of sustainability issues both within the organization and among employees and stakeholders. This can contribute to greater engagement and motivation for sustainable action (Kiron et al., 2012).

Compliance with regulatory requirements: more and more countries and regions are implementing legislation requiring monitoring and reporting on sustainability indicators. Ongoing monitoring is key to meeting these requirements (Delmas & Montes-Sancho, 2011).

To successfully monitor sustainability indicators, it is important that organizations use appropriate methods and tools to collect, analyze, and report on sustainability data. In addition, it is necessary to take a consistent approach to integrating sustainability into all aspects of business.

4 Conducting evaluations and assessments for sustainable development

Evaluations and assessments are key steps in achieving sustainable development in an organization. They allow us to measure the effectiveness and efficiency of sustainable practices and identify areas for improvement.

The steps of evaluation and assessment are:

- **determination of measurement indicators:** the first step in the sustainability evaluation is to determine the measurement indicators that will be used to measure the sustainability achievements of the organization. This includes quantitative and qualitative indicators, such as carbon dioxide emissions, water consumption, social responsibility, innovation and other indicators (Luka Koper, 2020);

- **data collection and analysis:** the next step is to collect relevant data for each measurement indicator. This includes business data, sustainability reports, stakeholder surveys, and other sources of information. The data is then analyzed and compared with past results and set goals (Schaltegger & Burritt, 2018);

- **performance assessment:** based on data analysis, an assessment of the organization's performance against its sustainability goals is carried out. This includes assessing the effectiveness of practices and their impact on the environment, society and the economy (Eccles & Krzus, 2010);

- **identifying areas for improvement:** based on the evaluation findings, areas where sustainable practices can be improved are identified. This may include changes in the organization's processes, technologies, policies or strategies (Kurucz et al., 2017);

- **reporting and communication:** the results of evaluations and assessments must be appropriately reported and communicated internally and externally. Transparency and communication are key to meeting stakeholder expectations and building trust (CSR Europe, 2015);

- **upgrading the sustainability plan:** at the end, evaluations and assessments contribute to upgrading the organization's sustainability plan. This means setting new goals, improving practices, and continuously adapting and harmonizing sustainability approaches (Lozano, 2015).

Evaluations and assessments are a key factor in ensuring that an organization remains on a sustainable development path. By properly implementing these processes, an organization can improve its sustainable impact and contribute to better business, social and environmental outcomes.

5 The importance of communicating about sustainability achievements and efforts

Sustainability has become an essential part of the business world, making it crucial for organizations to effectively communicate their sustainability achievements and efforts. With proper communication, organizations can enhance their reputation, build stakeholder trust, and attract consumers who value sustainable practices.

Some key tips for effectively communicating about the sustainability aspects of your organization:

1. Define the message: before you start communicating, you need to clearly define what you want to communicate. Consider your sustainability goals, achievements and efforts and choose the messages that are most relevant to your target audience (Kotler et al., 2019).

2. Use different channels: use different communication channels such as: websites, social media, printed materials and media releases. The right choice of channels will allow you to reach different groups of stakeholders (Du et al., 2010).

3. Stakeholder stories: connect with your stakeholders and tell stories about your sustainability efforts. Using examples and real-life stories can help increase your organization's credibility and visibility (Whelan et al., 2017).

4. Use numbers and statistics: to support your claims about sustainability achievements. Clear data can add authority and persuasiveness to your messages (Hansen & Machin, 2019).

5. Be proactive: instead of waiting for questions or criticism, be proactive in communicating about sustainability issues. This will help you control the debate and shape public opinion (Lyon & Montgomery, 2015).

6. Involve employees: your employees can be a powerful resource for spreading sustainability messages. Involve them in communication activities and empower them to become sustainability ambassadors.

7. Maintain consistency: your sustainability message should be consistent with your organization's sustainability practices. Consistency will prevent confusion and doubt about your intentions.

Communicating sustainability achievements and efforts is key to building reputation and engaging stakeholders. With the right approach, an organization can become recognized as a leader in sustainability practices.

6 The importance of raising awareness of internal and external stakeholders about sustainability

In today's business world, raising awareness among internal and external stakeholders about sustainability has become crucial. Organizations must communicate their sustainable practices, goals, and achievements in order to build reputation, gain trust, and meet the expectations of stakeholders, including employees, customers, suppliers, and the general public (Bansal & Song, 2017).

6.1 Raising awareness of internal stakeholders

Employees: internal stakeholders, such as employees, are an important group that needs to be made aware of the organization's sustainable practices. This is achieved through continuous education, training, and by involving employees in sustainability activities. Example: the organization holds internal training sessions on the environmental impacts of its operations.

Leadership: the organization's leadership must set an example and actively participate in communicating sustainability goals and practices. Example: the CEO publishes a message about sustainability goals in the annual report.

6.2 Raising awareness of external stakeholders

Customers: companies must clearly present their sustainability approaches and products to their customers. This can include labeling sustainable products or services. Example: a food company labels its products with sustainable farming certifications.

Suppliers: communicating with suppliers about sustainability expectations and requirements is key to a sustainable supply chain. Example: A trading company conducts sustainability assessments for its suppliers.

Investitors: investors are increasingly interested in the sustainability aspects of companies. Organizations need to clearly present their sustainability achievements to investors. Example: a company prepares a special report on sustainable financial performance.

Public: organizations must regularly communicate with the general public through media, social networks, and other communication channels. Example: a campaign about the company's carbon footprint reduction.

Raising awareness among internal and external stakeholders is crucial for building trust, understanding, and support for the organization's sustainable practices. It is important that this communication is carried out transparently, consistently, and honestly, as it can lead to the organization's long-term success and sustainable growth (Dias-Sardinha et al., 2021).

7 The importance of recognizing greenwashing in communication.

Greenwashing refers to misleading marketing in which companies falsely present their products, services, or business practices as environmentally friendly, even though they are not. The goal is to create the impression of sustainability and responsibility, even when the actual environmental benefit is inadequate or negligible (Delmas et al., 2011). Below are some examples of what companies should watch out for and how consumers can avoid misleading marketing practices related to greenwashing.

7.1 What should companies be aware of?

Companies must ensure that their sustainability measures are genuine, verifiable, and comply with legislation and ethical standards. Key aspects include:

- **transparency:** clear and accurate communication about environmental efforts and results;
- **supported claims:** all environmental claims must be backed by evidence (e.g., certifications, studies, product life cycle analyses);
- **comprehensiveness of sustainability practices:** companies should not highlight only one sustainability aspect (e.g., recycled packaging) if other practices (e.g., carbon footprint of production) are not environmentally friendly;
- **avoiding vague terms:** terms like "eco-friendly," "green," or "sustainable" should only be used if supported by concrete data;
- **compliance with legislation:** adhering to regulations on misleading advertising and sustainability reporting (e.g., EU directive on non-financial reporting).

7.2 What should consumers be aware of?

Consumers should avoid misleading marketing practices and critically evaluate the green claims made by companies. They should pay attention to:

- **evidence and certifications:** checking if sustainability claims are supported by independent certifications (e.g., EU Ecolabel, Fair Trade, FSC);
- **company integrity:** determining whether the company implements sustainability practices throughout its operations or just for a specific product;
- **following the details:** paying attention to specific and measurable promises, not just general slogans;
- **pitfalls of symbols and colors:** green-colored packaging or logos with natural motifs do not necessarily mean the product is actually sustainable;
- **independent sources:** reviewing evaluations from independent organizations and the company's sustainability reports.

7.3 Bad practices of greenwashing

There are several forms of greenwashing, and some of the most common include:

- **misleading labels and certifications** – using proprietary, unofficial eco-labels without independent verification;
- **highlighting one green attribute while ignoring others** – e.g., a product with eco-friendly packaging but harmful ingredients
- **using vague or unsubstantiated claims** – terms like "100% natural" or "eco-friendly" without evidence;
- **hiding the real impact** – companies promoting one "green" product while the majority of their production significantly harms the environment;
- **incorrect imagery and symbols** – the use of leaves, trees, or green colors to create an impression of sustainability without actual environmental benefits;
- **incomplete information** – companies highlighting the environmental benefits of one aspect while not disclosing the full impact of the product (e.g., electric vehicles, where battery production causes significant environmental harm).

Greenwashing is an increasingly serious issue that undermines consumer trust and hinders genuine sustainable change. Companies should strive for honest and comprehensive sustainability policies, while consumers should remain critical and verify claims. Education, awareness, and regulation are key to preventing these practices and ensuring a truly more sustainable future.

8 Continuous growth and adaptation of the organization to sustainability challenges.

Sustainability, as we've noted several times and as is increasingly recognized by companies and organizations-has become a key focal point in the business world. Organizations understand that sustainability is not a one-time effort, but a continuously evolving process of adapting to sustainability challenges. This requires a sustainability-oriented mindset that develops over time through ongoing efforts for improvement.

Continuously adapting an organization to sustainability challenges involves several key aspects;

Sustainability culture: properly establishing a culture of sustainability within an organization requires persistence and ongoing employee awareness about the importance of sustainability. This is supported by continuous education and training focused on sustainable practices and values (Darnall et al., 2009).

Strategic planning: the organization must continuously review and update its sustainability strategy to respond to evolving environmental and social challenges. Adapting the strategy can help ensure that goals remain relevant and achievable (Hart, 1997).

Innovation: is crucial in addressing sustainability challenges. Organizations must promote innovations that contribute to reducing environmental and social impact. Over time, they must adapt to new technologies and approaches that enable more sustainable operations (Porter & van der Linde, 1995).

Monitoring and reporting: organizations must continuously monitor their sustainability progress and outcomes, and share this data with stakeholders. This ensures accountability and allows for the adjustment of goals and practices when necessary (Epstein & Roy, 2001).

Stakeholder engagement: engaging with various stakeholders, including customers, suppliers, investors, and local communities, is essential for the organization's ongoing adaptation. Considering their perspectives and needs contributes to more sustainable business operations (Freeman et al., 2010)

Organizations that continuously adapt to sustainability challenges will be better prepared for the future and better equipped to address environmental and social issues. Ongoing commitment to sustainability will contribute to the organization's long-term growth and success.

9 Does a company need an ISO standard for a sustainable transformation?

Companies do not need ISO standards, such as ISO 14001, to undertake a sustainable transformation, but these standards can significantly contribute to the effectiveness and credibility of the process. ISO standards provide recognized methods and procedures that are internationally accepted and can serve as a guideline for achieving sustainability goals. Using ISO standards can help companies structure their sustainability efforts, assist in measuring and reporting environmental performance, and improve risk management and legal compliance. Nevertheless, ISO standards are not mandatory, and companies can implement sustainable practices even without them.

ISO standards, such as ISO 14001, which focuses on environmental management, can offer several key benefits to companies aiming to undergo a sustainable transformation:

Framework for improvement: ISO standards provide a clear structure for establishing, implementing, monitoring, and improving environmental management systems.

International recognition: ISO standards are internationally recognized, which enhances credibility and can improve a company's image in the global market.

Legal compliance: they help ensure compliance with environmental laws and regulations, reduce risks, and can lower costs related to fines or legal actions.

Resource efficiency: they promote the efficient management and use of resources, as well as the reduction of waste.

Reduction of environmental footprint: the focus on minimizing negative environmental impacts supports greener business operations.

Competitive advantage: ISO standards can offer a competitive edge in the eyes of customers and partners who value sustainability.

Obtaining and maintaining ISO standards is certainly an advantage that supports a company's sustainability goals, ensures consistency and commitment to improvement, and strengthens its market position. However, as mentioned, it is not a requirement for a company to successfully carry out a sustainable transformation.

10 Conclusion

Sustainable organizational transformation is a long-term process that includes changes in the business model, company culture, processes, and attitude towards the environment and society.

Organizations that choose to undergo a thorough sustainable transformation–a process that typically takes time–often develop new, innovative sustainable business models and invest in green technologies such as electric vehicles, solar power systems, and smart logistics. These organizations also frequently invest in transforming their organizational culture and leadership. There are no quick fixes; however, in the pursuit of faster implementation, organizations may opt for quicker sustainability solutions, such as an immediate switch to electric vehicles for short-distance urban deliveries. Organizations focused on short-term sustainability goals often prioritize rapid actions, such as route optimization and waste reduction. In some cases, companies also collaborate with third-party providers to accelerate the implementation of sustainable solutions and reach their goals more efficiently.

In short, sustainable organizational transformation, one way or another, can always help organizations gain a sustainable competitive advantage and a positive impact on the environment.

Sustainable transformation of an organization is a complex and multidimensional process that goes beyond basic environmental measures and requires a fundamental overhaul of the business model, corporate culture, leadership, and operational processes. It involves a strategic focus on innovation and green technologies–such as renewable energy sources and electric vehicles–as well as the optimization of logistics operations to reduce waste. Organizations that embrace a sustainability mindset can strengthen their market position, gain a competitive advantage, and contribute to the health of the planet and the well-being of society. The ultimate goal of sustainable transformation is not merely to meet short-term targets, but to embed sustainability at the core of business operations–positioning organizations as drivers of innovation, growth, and social responsibility, both locally and, where possible, globally.

References

Amazon. (n.d.). Sustainability. Pridobljeno 12. septembra 2023 s https://sustainability.aboutamazon.com/reporting

Bansal, P., & Song, H. C. (2017). Similar but not the same: Differentiating corporate sustainability from corporate responsibility. Academy of Management Annals, 11(1), 105-149.

CSR Europe. (2015). A Guide to Communicating on Corporate Social Responsibility. CSR Europe.

Darnall, N., Jolley, G. J., & Handfield, R. (2009). Environmental management systems and green supply chain management: complements for sustainability? Business Strategy and the Environment, 18(1), 30-45.

Delmas, M. A., & Montes-Sancho, M. J. (2011). An institutional perspective on the diffusion of international management system standards: The case of the environmental management standard ISO 14001. Business Ethics Quarterly, 21(1), 103-132.

DHL. (n.d.). Sustainable Logistics. Pridobljeno 15. septembra 2023 s https://www.dhl.com/global-en/home/logistics-solutions.html

Dias-Sardinha, I., Oliveira, M. G., & Lourenço, I. C. (2021). The Corporate Sustainability Communication Model: Assessing the Causality Relationship with Stakeholder Satisfaction and Loyalty. Sustainability, 13(2), 1000.

Dillman, D. A., Smyth, J. D., & Christian, L. M. (2014). Internet, phone, mail, and mixed-mode surveys: The tailored design method. John Wiley & Sons.

Doran, R., & Ryan, M. (2017). Measuring SMART: Developing a practical tool for planning and monitoring KPIs. International Journal of Productivity and Performance Management, 66(2), 167-184.

Du, S., Bhattacharya, C. B., & Sen, S. (2010). Maximizing business returns to corporate social responsibility (CSR): The role of CSR communication. International Journal of Management Reviews, 12(1), 8-19.

Eccles, R. G., & Krzus, M. P. (2010). One Report: Integrated Reporting for a Sustainable Strategy. John Wiley & Sons.

Eccles, R. G., Ioannou, I., & Serafeim, G. (2011). The impact of corporate sustainability on organizational processes and performance. Management Science, 60(11), 2835-2857.

Elkington, J. (1997). Cannibals with Forks: The Triple Bottom Line of 21st Century Business. Capstone Publishing.

Epstein, M. J., & Buhovac, A. R. (2014). Making sustainability work: Best practices in managing and measuring corporate social, environmental, and economic impacts. Berrett-Koehler Publishers.

Epstein, M. J., & Roy, M. J. (2001). Sustainability in action: Identifying and measuring the key performance drivers. Long Range Planning, 34(5), 585-604.

Figge, F., & Hahn, T. (2018). Value Creation Through Sustainability: How Sustainability Can Affect the Quality of Business. Routledge.

Freeman, R. E., Harrison, J. S., Wicks, A. C., Parmar, B. L., & De Colle, S. (2010). Stakeholder theory: The state of the art. The Academy of Management Annals, 4(1), 403-445.

GRI (2016). GRI Standards 2016: Environmental and Social Topics. Global Reporting Initiative.

Hansen, J. M., & Machin, J. E. (2019). Green branding and consumers: Exploring the role of persuasion knowledge. Journal of Advertising, 48(2), 180-197.

Hart, S. L. (1997). Beyond greening: strategies for a sustainable world. Harvard Business Review, 75(1), 66-76.

Hopkins, M. (2012). The Planetary Bargain: Corporate Social Responsibility Comes of Age. Macmillan International Higher Education.

Kiron, D., Kruschwitz, N., Haanaes, K., Reeves, M., & Goh, E. (2012). Sustainability Nears a Tipping Point. MIT Sloan Management Review, 53(2), 69-74.

Kleindorfer, P. R., Singhal, K., & Van Wassenhove, L. N. (2005). Sustainable operations management. Production and operations management, 14(4), 482-492.

Kotler, P., Kartajaya, H., & Setiawan, I. (2019). Marketing 4.0: Moving from Traditional to Digital. John Wiley & Sons.

Kurucz, E. C., Colbert, B. A., & Wheeler, D. (2017). Business Ethics Quarterly, 27(2), 213-239.
Lozano, R. (2015). A holistic perspective on corporate sustainability drivers. Corporate Social Responsibility and Environmental Management, 22(1), 32-44.
Lozano, R., & Huisingh, D. (2011). Inter-linking issues and dimensions in sustainability reporting. Journal of Cleaner Production.
Luka Koper (2020). Trajnostno poročilo 2020. Pridobljeno 24. februarja 2025 s https://www.luka-kp.si/wp-content/uploads/2022/03/Trajnostno-porocilo-2020-SLO.pdf?utm_source=chatgpt.com .
Lyon, T. P., & Montgomery, A. W. (2015). The means and end of greenwashing. Organization & Environment, 28(2), 223-249.
Maersk. (2020). Sustainability Report. Pridobljeno 19. oktobra 2023 s https://www.maersk.com/sustainability
Neely, A. (2005). The evolution of performance measurement research: Developments in the last decade and a research agenda for the next. International journal of operations & production management.
Porter, M. E., & Kramer, M. R. (2011). The Big Idea: Creating shared value. Harvard Business Review, 89(1/2), 62-77.
Porter, M. E., & van der Linde, C. (1995). Toward a new conception of the environment-competitiveness relationship. The Journal of Economic Perspectives, 9(4), 97-118.
Rubin, H. J., & Rubin, I. S. (2011). Qualitative interviewing: The art of hearing data. Sage.
Sarkis, J., Zhu, Q., & Lai, K. H. (2011). An organizational theoretic review of green supply chain management literature. International Journal of Production Economics, 130(1), 1-15.
Schaltegger, S., & Burritt, R. (2018). Contemporary Environmental Accounting: Issues, Concepts and Practice. Routledge.
Schaltegger, S., & Wagner, M. (2011). Sustainable entrepreneurship and sustainability innovation: Categories and interactions. Business Strategy and the Environment.
Seuring, S., & Müller, M. (2008). From a literature review to a conceptual framework for sustainable supply chain management. Journal of cleaner production, 16(15), 1699-1710.
UPS. (2020). Global Impact Report. Pridobljeno 22. septembra 2023 s https://about.ups.com/us/en/our-impact/sustainability/climate/2020-ups-corporate-sustainability-report.html
Whelan, T., Fink, C., & Smith, N. C. (2017). The Business of Changing the World: How Billionaires, Tech Disrupters, and Social Entrepreneurs Are Transforming the Global Aid Industry. Oxford University Press.
Yin, R. K. (2018). Case study research and applications: Design and methods. Sage publications.

ENVIRONMENTAL ASSESSMENT: INTEGRATION OF CARBON FOOTPRINT

DOI
https://doi.org/10.18690/um.fl.4.2026.3

ISBN
978-961-299-100-5

MATEVŽ OBRECHT
University of Maribor, Faculty of Logistics, Celje, Slovenia
matevz.obrecht@um.si

Due to the rise in population numbers the standard of living and the subsequent growth in human activities and production, environmental concern is intensifying and the current linear economy is becoming unsustainable. The idea of an environmentally conscious (green) supply chain management first began in the early 1970s; however, a systematic approach is still lacking today. The focus of this chapter is therefore to gain a clearer insight into environmental assessment for efficient greening of supply chains, to raise importance of the life cycle thinking and decarbonisation and to study and discuss the use of methods for environmental impact assessment. Comprehensive assessment of environmental impacts is crucial for supply chain managers to enable them to better understand the importance of environmentally sound business models while also emphasising sustainable development for the resilient future of decarbonisation since human activities are a major contributor of carbon dioxide and other greenhouse gases. Carbon footprint identifies and measures the impact and enables systematic minimisation of emissions from company's processes and business.

Keywords:
carbon footprint,
LCA,
sustainable development,
resilient supply chains,
responsible production and consumption

Univerzitetna založba
Univerze v Mariboru

1 Introduction

Due to the growing population, rising living standards, and the consequent increase in human activities and production, environmental concerns are becoming increasingly important. It is becoming clear that our planet can no longer regenerate itself and that resources are not being used sustainably (Obrecht & Knez, 2017). Since individual activities seriously impact upon the environment both locally and globally, environmental considerations are being increasingly integrated into economic activities. There is a prevailing belief that environmentally conscious and more sustainability-oriented practices can provide organizations with a competitive advantage, especially in the long term (Plouffe et al., 2011; Albino et al., 2009; Dangelico et al., 2017; Gerstlberger et al., 2014).

An extensive body of data has demonstrated that the current linear economy is unsustainable. Population growth and rising living standards demand increasing extraction of materials and higher consumption of food, water, and energy. As a result, the prices of these materials are rising, arable land and forests are disappearing, the long-term availability of clean water is becoming uncertain, and biodiversity is rapidly changing (The 2030 Water Resource Group, 2009; Alexandratos & Bruinsma, 2012; International Energy Agency, 2017). Given the projected trends, environmentally friendly economic models–such as the circular economy, life cycle-based eco-design, and sustainable supply chains–are expected to become not only a source of comparative advantage in achieving competitive strategies but also a potential response to anticipated socio-economic challenges in the coming decades (Bešter, 2017), as well as a systemic solution for the sustainable survival of the human species (Širec et al., 2018).

However, focusing on the environmental aspect in only one part of the supply chain (SC) is not sufficient for achieving effective improvements. Environmental impacts occur throughout the entire supply chain–from raw material extraction, production of materials and components, manufacture of the final product, its distribution and use, all the way to the end of its life cycle. A review of the literature shows that environmental goals, such as the EU's 20/20/20 targets, cannot be achieved solely through inter-organizational activities and measures but require collaboration along the entire value chain by leveraging synergies among supply chain stakeholders (Szegedi et al., 2017). For this reason, environmental management schemes (e.g., ISO 14001 or EMAS) also include the participation of various stakeholders across the entire supply chain. The complexity of sustainable supply chains, the circular economy, and eco-design call for collaboration among diverse stakeholders at multiple levels–making a systemic approach essential. Business leaders must recognize that economic and environmental goals are not mutually exclusive but can be achieved simultaneously (Preston, 2012; Lieder & Rashid, 2016; Ghisellini et al., 2016).

The concept of environmentally conscious (green) supply chain management (SCM) first appeared in academic literature in the early 1970s. The integration of the disciplines of green business practices and complex supply chains–including procurement, production, and logistics–gained prominence in the 1990s, particularly in the automotive industry (Szegedi et al., 2017). Many organizations still perceive their environmental impact very narrowly, typically limiting it to production activities at individual manufacturing sites (Ammenberg & Sundin, 2005). In contrast, one of the key trends in sustainability programs in industrialized countries is so-called life cycle thinking, which shifts the focus from the production site to various environmental and social factors associated with a product throughout its entire life cycle (UNEP, 2006). Life cycle thinking is based on the principle of pollution prevention, which aims to reduce environmental impacts at the source and to close the loop of materials and energy (European Commission, 2014). All products and services have a certain environmental impact, 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 more developed traditional supply chains also tend to have more advanced green supply chain management (GSCM) systems (Szegedi et al., 2017).

It is also clear that commitment to eco-design and sustainable development within an organization is a key factor for driving improvements, while environmental labels serve as a powerful tool for communicating with consumers–particularly those with a green orientation. Since business leaders are inherently interested in achieving business benefits alongside environmental improvements, environmental labels are a persuasive means of achieving both. On the one hand, they help enhance the company's image, attract environmentally conscious consumers, compete in green public procurement, differentiate in highly competitive markets, and reduce fees for waste or the use of hazardous substances. On the other hand, they also deliver direct environmental benefits–such as lower material and energy consumption, reduced waste generation, improved efficiency, and decreased water usage.

The aim of this chapter is to provide a better understanding of the greening of supply chains, to emphasize the importance of the life cycle principle for supply chain managers, and explore and discuss the use of various methods, principles, and tools such as carbon footprint, eco-design, and environmental labels in supply chain management. Therefore, case studies of best practices in life cycle assessment and eco-design related to carbon footprint are presented in order to enhance our knowledge of environmental issues and incorporate it into supply chain management. A comprehensive collection of such tools, principles, methods, and real-world problem-solving examples is crucial for supply chain managers, as it enables them to better understand and appreciate environmentally friendly business models and underscores the importance of sustainable development for businesses as well.

2 Integration of the life cycle concept into supply chain management

Organizations are increasingly aware of their environmental impacts and are taking measures to reduce these impacts by incorporating cleaner production within the organization, improving energy efficiency to reduce energy consumption among end consumers, optimizing transportation and distribution, or dematerializing production to reduce costs. Due to the growing energy shortages, particularly in the EU, Cerovac et al. (2014) point out that it is not only the amount of energy used in production that matters, but also the mix of energy sources used within the supply chain. However, all of these measures are partial and do not cover all the environmental impacts associated with a company's supply chain. Rising material costs, linked to resource depletion, stricter environmental regulations–especially in the EU–and increasing consumer environmental awareness are driving companies to adopt more comprehensive measures. When discussing sustainable supply chains, supply chain managers must consider all stages of the product life cycle, which include not only individual links in the supply chain but the entire supply chain. If only production, logistics, or the use of a particular product are considered, only partial environmental burdens can be identified. Such analyses can be misleading and may not address the most significant environmental impacts, making it impossible to implement the most appropriate environmental improvements. This idea is the core principle of life cycle thinking, which means that environmental impacts should be considered at all stages of the life cycle, including raw material sourcing, production, distribution, use, and the end-of-life phase, which in supply chain management (SCM) is often linked to reverse logistics. The emphasis is on incorporating comprehensive environmental burdens and addressing them according to their significance throughout the entire supply chain. The challenge here is that life cycle thinking requires collaboration from all stakeholders/members of the supply chain and can be particularly problematic for small and medium-sized enterprises (SMEs) that do not have enough bargaining power with larger and stronger suppliers. Nevertheless, it must be clear that sustainable production and consumption can be achieved through both bottom-up and top-down approaches or by implementing new business models (Lukman Kovačič et al., 2017), meaning that this is not only the responsibility of top management but a commitment from the entire organization.

2.1 Life cycle stages of a product or process

To design environmentally friendly products or services, it is essential to first assess their environmental impact throughout the entire life cycle. Life Cycle Assessment (LCA) has often been defined as the appropriate method for comprehensively evaluating the environmental impacts of a given product, as it assesses environmental impacts at all stages of the life cycle and provides a good overview of numerous environmental impacts that may not be immediately apparent. However, due to the large volume of data required and included in LCA, it is an extremely complex and time-consuming method for evaluating environmental impacts (Obrecht & Knez, 2017).

Figure 1 illustrates the life cycle stages of products and the system boundaries of LCA, focusing on all the major stages of the life cycle. Only after defining and assessing the environmental impacts throughout the entire life cycle can companies identify which impacts in their supply chain are most critical and begin to work towards environmental improvements or completely avoid these impacts. Typically (but not necessarily), the most common solution is to start optimizing the stages with the greatest environmental impact and those that seem to offer the most potential for savings.

LCA is the only standardized method (in the ISO 14000 series) for assessing environmental impacts throughout the entire life cycle. However, LCA alone is just the first step toward more environmentally friendly supply chains, as it only reveals environmental impacts without reducing them. The next step is, for example, the use of eco-design or similar tools that enable the reduction of environmental impacts identified through the environmental assessment. The essence of the life cycle perspective for most manufacturers is that their obligations are expanded and their (environmental and legal) responsibility does not end at the factory gates.

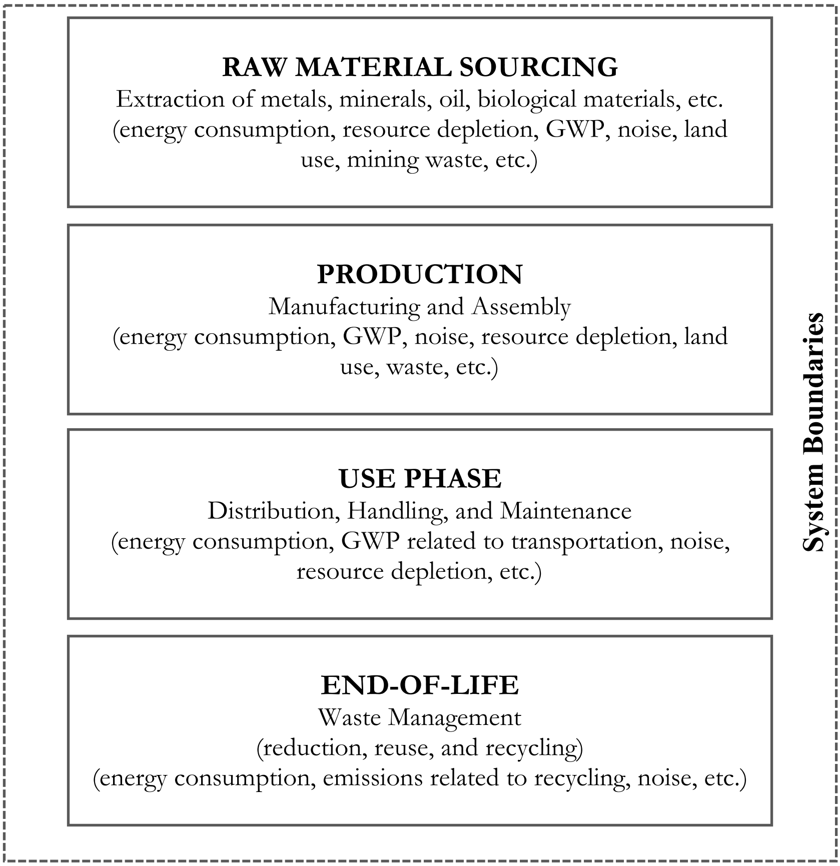


Figure 1: Lifecycle stages and system boundaries of the life cycle approach

Source: own

Case Study 2

IBM's and Apple's efforts to initiate life cycle thinking

IBM proposed an initiative based on the Electronics Industry Code of Conduct (EICC) to empower its partners in the market channels to adopt environmental measures. This meant that they did not focus solely on their own organization but sought to encourage the entire supply chain, across all stages of the product life cycle, to make improvements and become more transparent in presenting their environmental impacts to public stakeholders. They proposed four goals that their suppliers must meet, specifically:

- definition and implementation of an **Environmental Management System** (EMS);
- **measuring** existing environmental impacts and setting goals for their improvement;
- **public disclosure** of their parameters and also the results of the analysis;
- "**cascade**" these improvement requirements to all suppliers who are material suppliers of their (IBM's) products/components.

With this concept, they can trace the footprint of each phase of raw material extraction and product manufacturing, thereby influencing the potential for improving the environmental impact throughout the entire supply chain. Senior executives are aware that an environmentally friendly business development path is a legal obligation, and it is becoming increasingly profitable.

Since environmental analyses are often expensive and time-consuming, and their interpretation requires certain prior knowledge of environmental assessment methods, environmental impacts, company processes, etc., organizations are establishing departments and hiring experts capable of integrating the concepts of lean, smart, and green supply chains. They also focus on identifying and reducing environmental burdens beyond the walls of the company, thus adopting a life cycle thinking approach. Apple has already done this and reported its results in a consumer-friendly and straightforward way, as shown in Figure 2.

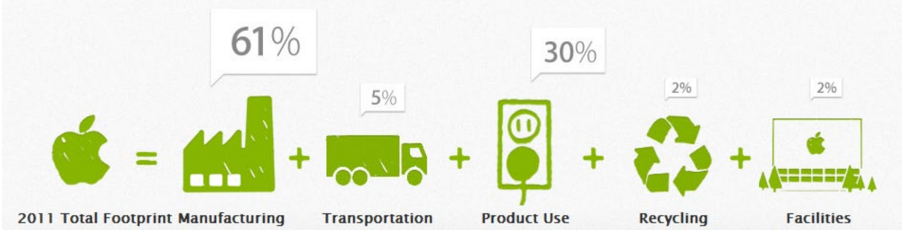


Figure 2: Apple's communication with stakeholders on environmental impacts with an integrated life cycle perspective

Source: summarized by Apple, 2012

3 Carbon footprint

Carbon footprint is a measure used to estimate the amount of greenhouse gases emitted into the atmosphere by an individual, organization, or society through their activities, processes, and operations. It is expressed in mass units, typically in tons of CO2 equivalent (CO2eq).

The background of carbon footprint calculation is based on the understanding that human (anthropogenic) activity is the primary cause of most environmental challenges. The most prominent cause is the use of fossil fuels (such as coal, oil, and gas) and other sources associated with the release of greenhouse gases (GHGs). The increasing concentration of these gases has long-term negative consequences for the climate, such as global warming, changes in precipitation patterns, sea level rise, ocean acidification, desertification, and more.

In order to adapt to and mitigate the effects of climate change, the interest in reducing greenhouse gas (GHG) emissions is recognized at various levels and promoted through international agreements (e.g., the Paris Climate Agreement) and EU-level regulations (e.g., formerly the IPPC Directive, and from 2024 onwards, the Corporate Sustainability Reporting Directive – CSRD). However, to reduce GHG emissions, we must first understand the emissions generated by a specific product, process, organization, or individual. Carbon footprint is a measure of GHG emissions that should also incorporate the life cycle perspective–meaning it should account for total GHG emissions throughout the lifetime of a product, for example–from raw material extraction to processing/reuse after the end of its primary life.

The calculation of a carbon footprint involves identifying and quantifying all sources of greenhouse gas emissions generated by an individual, organization, or process. These sources can include direct emissions, such as those from transportation and manufacturing facilities, as well as indirect emissions resulting from electricity production, transportation, product manufacturing, and other activities. The calculation is carried out using various methodologies based on emission factors, energy consumption data, emissions from specific sources, and other parameters. For an accurate assessment, it is important to consider the entire life cycle of a product or service, including production, transportation, use, and waste disposal or end-of-life reuse.

The calculation and presentation of the carbon footprint are also crucial steps in raising awareness about negative climate impacts and identifying opportunities for their reduction. By measuring their carbon footprint, individuals, companies, and organizations can be encouraged to adopt measures to reduce greenhouse gas emissions, such as improving energy efficiency, using renewable energy sources, making changes in production and consumption patterns, adopting sustainable mobility, or substituting energy-intensive materials with less resource-intensive alternatives.

In the EU and around the world, the most widely recognized framework in recent years has been the so-called GHG Protocol Standard, which is a globally accepted framework for measuring and reporting corporate greenhouse gas (GHG) emissions. It provides guidelines and principles for companies to measure, quantify, and report GHG emissions and to improve their performance in a consistent and transparent way.

Developed by the World Resources Institute (WRI, 2012), the standard helps companies understand their own carbon footprint and manage emissions effectively. It contains a set of guidelines and methodologies that establish a common language and approach for measuring GHGs.

The GHG Protocol Standard for measurement and reporting includes three main scopes:

Scope 1: direct GHG emissions: this includes emissions from sources that are owned or controlled by the organization, such as fuel combustion in company-owned vehicles or emissions from on-site production facilities.

Scope 2: indirect GHG emissions are from purchased electricity, heat, or steam. These are emissions associated with the generation of purchased energy that is consumed by the organization.

Scope 3: other indirect GHG emissions. These emissions occur along the value chain or depending on the activities of the organization, such as emissions from the supply chain, transportation, employee commuting, and the use and disposal of products. These emissions are not mandatory to report but they can often be higher than those under Scope 1 and Scope 2.

The GHG Protocol provides specific methodologies and guidelines for calculating emissions in each area, including emission factors, data collection approaches, and reporting requirements. Tracking enables organizations to accurately measure and report GHG emissions, set emission reduction targets, and implement strategies to reduce their environmental impact.

The GHG Protocol Standard has become a widely accepted framework for corporate sustainability reporting and is used worldwide for monitoring emissions.

3.1 Advantages and disadvantages of carbon footprint calculation

Advantages of carbon footprint calculation:

1. Identification of key emission sources. Calculating the carbon footprint helps identify the key sources of greenhouse gas emissions. This enables targeted efforts to reduce emissions, as it allows organizations to focus on sectors or activities that have the greatest impact on the carbon footprint.
2. Awareness and education. Calculating the carbon footprint enables individuals, companies, and organizations to become aware of their contribution to climate change. This promotes awareness of their environmental and climate impact, which is the first step toward taking actions to reduce their impacts and their carbon footprint.

3. Monitoring progress. Calculating the carbon footprint allows for monitoring progress in reducing emissions over time. By comparing past data with current figures, it is possible to determine whether emission reduction efforts are improving or not, and adjust strategies as needed.
4. By comparing past data with current figures, we can determine whether the implementation of measures to reduce impacts (emissions) is improving or not, and adjust strategies and actions as needed.

Despite the advantages, it is important to also highlight the shortcomings:

1. The carbon footprint focus is solely on GHG emissions, which constitutes just one of many potential impacts that a particular process, product, organization, or individual can have on the environment.
2. It does not consider water consumption, land use, eutrophication, carcinogenicity, radiation, which are included in more comprehensive environmental assessments, such as Life Cycle Impact Assessment (LCIA).
3. Sometimes, the calculation requires large amounts of data and complex conversion factor methodologies, which can be difficult for employees in organizations not directly involved in the field to understand. A particular challenge is obtaining accurate and reliable data for the entire life cycle of a product or service.
4. Lack of standardization. There is a lack of uniform standards and methodologies for calculating the carbon footprint, which can lead to inconsistent results between different calculations. This can make comparisons between entities difficult and hinder effective monitoring of progress.
5. Disregard for indirect effects. The carbon footprint calculation focuses on direct greenhouse gas emissions but may overlook other indirect effects (i.e., "Scope 3"). This is voluntary, even though it can sometimes be more significant than direct emissions and limits the transparency and comprehensiveness of such environmental assessments.

Despite its weaknesses, carbon footprint calculation remains one of the leading tools for assessing environmental impacts. Methodologies are being developed, supplemented, and procedures standardized, which means that in the future, it will become more reliable, and consequently, results will be more comparable. This will enable us to move towards climate-responsible practices.

Different greenhouse gases (GHGs) have different global warming potential (GWP) factors. GWP, or "Global Warming Potential," is defined based on their impact on atmospheric warming over a 100-year period compared to carbon dioxide (CO2), whose GWP factor is 1. These factors are used to convert emissions of various greenhouse gases into equivalent CO2 emissions for easier calculation of their impact and for comparing them. The most commonly used GWP factors for frequent GHGs are shown in Table 1.

Table 1: Most commonly used GWP factors of common GHGs

TGP	GWP	Note
Carbon dioxide (CO2)	1	This value is used as a reference point for comparison with other greenhouse gases.
Methane (CH4)	21	This means that its impact on atmospheric warming is 25 times stronger than that of CO2 over a 100-year period.
(Dinitrogen) oxide (N2O)	310	This means that its impact on atmospheric warming is 298 times stronger than that of CO2 over a 100-year period.
Sulfur hexafluoride (SF6)	23.900	Extremely high, 23,500 times stronger than CO2.
Chlorofluorocarbons (CFC)	Extremely high, ranging from 4,470 to 10,720.	CFCs are potent greenhouse gases that were commonly used in industry in the past.

Source: IPPC, 1995

4 Conclusion

Carbon footprint calculation is one of the tools for assessing environmental impacts, which includes the identification and quantification of all sources of greenhouse gases (GHGs) caused by an individual, organization, or process. These sources can include direct emissions, such as those from transportation and manufacturing facilities, as well as indirect emissions, such as those caused by the production of electricity. The primary purpose of calculating the carbon footprint is not just to display the impact but to allow for the evaluation of the current situation with potential scenarios and process improvements. Only by measuring and assessing the current and future environmental impacts that could result from implementing different scenarios can we determine which business decision is the most environmentally sound–just as we use economic calculations to determine which investment makes the most sense from an economic perspective. Carbon footprint is becoming one of the most important tools for assessing environmental impacts due to trends in international policies aimed at reducing greenhouse gas emissions. With the development of methodology and standardization, both the calculation process and emission factors are becoming increasingly comparable and reliable. However, it is important to recognize that, although it covers environmental impacts across the entire supply chain or lifecycle, its main limitation is that it is focused solely on emissions expressed in CO2 equivalent, while neglecting other equally important environmental impacts, such as water consumption, land use, radiation, human health impacts, biodiversity effects, and others.

References

Albino V, Balice A, Dangelico RM. (2009). Environmental startegies and green product development: an overview on sustainability-driven companies. Business Strategy and the Environment, 18: 83 – 96. https://doi.org/10.1002/bse.638.

Alexandratos, N. in Bruinsma, J. (2012). World agriculture towards 2030/2050: the 2012 revision. ESA Working Paper 3. Food and Agricultural Organisation [FAO] of the United Nations. Rim.

Ammenberg J, Sundin E. 2005. Products in environmental management systems: drivers, barriers and experiences. Journal of Cleaner Production 13: 405–415. https://doi.org10.1016/j.jclepro.2003.12.005.

Bešter, J. (2017). Economically efficient circular economy. Ljubljana: Institute for economic research.

Cerovac, T., Ćosić, B., Pukšec, T. and Duić, N., (2014). Wind energy integration into future energy systems based on conventional plants – The case study of Croatia. Applied Energy. 135, 643-655.

Dangelico RM, Pujari D, Pontrandolfo P. (2017). Green Product Innovation in Manufacturing Firms: A Sustainability-Oriented dynamic Capability Perspective. Business Strategy and the Environment, 26 (4): 490-506. https://doi.org/10.1002/bse.1932

Denac, M., Obrecht, M. and Radonjič, G. (2018). Current and potential ecodesign integration in small and medium enterprises : construction and related industries. Business strategy and the environment, pp: 1-13. https://doi.org/10.1002/bse.2034.

Gerstlberger W, Præst Knudsen M, Stampe I. (2014). Environmental Requirements, Knowledge Sharing and Green Innovation: Empirical Evidence from the Electronics Industry China. Business Strategy and the Environment, 23 (2): 131-144. https://doi.org/10.1002/bse.1746.

Ghisellini, P., Cialani, C. in Ulgiati, S. (2016). A review on circular economy: the expected transition to a balanced interplay of environmental and economic systems. Journal of Cleaner Production, 114: 11-32. https://doi.org/10.1016/j.jclepro.2015.09.007

Intergovernmental Panel for Climate Change (IPCC). (1995). Second Assessment Report (SAR), Climate Change 1995. UNEP.

International Energy Agency. (2017). World Energy Outlook 2017 – Executive Summary. Paris, France. https://www.iea.org/publications/freepublications/publication/WorldEnergyOutlook2016ExecutiveSummaryEnglish.pdf Accessed 20 Sep 2018.

Kovačič Lukman, R., Glavič, P., Carpenter, A., Virtič, P. (2016). Sustainable consumption and production : research, experience, and development : the Europe we want. Journal of cleaner production,138: 139-147, doi: 10.1016/j.jclepro.2016.08.049

Lieder, M. in Rashid, A. (2016), Towards circular economy implementation: a comprehensive review in context of manufacturing industry. Journal of Cleaner Production, 115:. 36-51. https://doi.org/10.1016/j.jclepro.2015.12.042

Obrecht M, Knez M. 2017. Carbon and resource savings of different cargo container designs. Journal of Cleaner Production, 155: 151 – 156. https://doi.org/10.1016/j.jclepro.2016.11.076

Plouffe S, Lanoie P, Berneman C, Vernier MF. 2011. Economic benefits tied to ecodesign. Journal of Cleaner Production, 19: 573–579. https://doi.org/10.1016/j.jclepro.2010.12.003

Preston, F. (2012). A Global Redesign? Shaping the Circular Economy. Briefing Paper. London: Chatham House.

Szegedi, Z., Gabriel, M. and Papp, I. (2017). Green supply chain awareness in the Hungarian automotive industry. Polish Journal of Management Studies,16(1): 259-268.

Širec, K., Bradač Hojnik, B., Denac, M., Močnik, D., Rebernik, M. (2018). Slovenska podjetja in krožno gospodarstvo : slovenski podjetniški observatorij 2017, Maribor: University of Maribor publishing house. (in slovenian language only)

The 2030 Water Resource Group. (2009). Charting Our Water Future Economic Frameworks to Inform Decision-making. https://www.mckinsey.com/~/media/McKinsey/Business%20Functions/Sustainability%20and%20Resource%20Productivity/Our%20Insights/Charting%20our%20water%20future/Charting%20our%20water%20future%20Full%20Report.ashx Accessed Jan 2 2018.

UNEP – United Nations Environmental Programme. (2006). UNEP Guide to Life cycle Management. Report, Jensen AA, Remmen A (eds.), UNEP: Paris.

Environmental Impact Assessment with LCA

Matjaž Denac
University of Maribor, Faculty of Economics and Business, Maribor, Slovenia
matjaz.denac@um.si

Every activity can be correlated with environmental impacts. But designing effective measures to reduce them requires an evaluation of the impacts first. To date, life cycle assessment (LCA) is the only standardised and most comprehensive method for assessing environmental impacts. Slovenian companies do not use the LCA method to the same extent as their competitors abroad and therefore cannot take advantage of the benefits that LCA can offer. LCA is a job for engineers and can only be carried out by trained professionals with a broad knowledge of materials, technologies, energy, appropriate software and access to databases. However, an LCA cannot be carried out without the client's input and notification of the intended use of the results. The purpose of this material is therefore to understand what an LCA is, how an LCA project should be designed so that contractors can prepare a suitable tender for the LCA service and then carry out the assessment. In order to avoid misleading expectations of potential clients, some examples of the results of LCA studies will be presented to show the reader will thus learn what data and in what form the client has to provide and how it will be used to create responsible business.

DOI
https://doi.org/10.18690/um.fl.4.2026.4

ISBN
978-961-299-100-5

Keywords:
environmental impact assessment,
LCA,
Environmental Life Cycle,
environmental data,
environmental indicators

Univerzitetna založba
Univerze v Mariboru

1 Introduction to LCA

Business operations today are intertwined with global connections. Manufacturing processes are becoming increasingly technologically diverse, and supply chains are geographically dispersed. As a result, companies want to understand the potential environmental impacts of sourcing materials, production and assembly, usage, and, ultimately, disposal of products. This global expansion, along with the increasing awareness of sustainability and responsibility towards environmental, economic, and social dimensions, has prompted environmental managers and decision-makers to adopt a broader, more holistic view of products and services, considering them 'from cradle to grave.' The need for a tool that helps users gather data and information for accurate and consistent measurement of resource consumption and the environmental impacts of their activities has never been more pressing. It is crucial for people to realize that decisions should not lead to the improvement of one part of the industrial system at the expense of another. In the decision-making process, it is key to recognize and avoid unintended consequences. This need gave rise to Life Cycle Assessment (LCA) (Curran, 2012).

Companies can approach the realization of environmental and sustainability goals in various ways. In recent years, the most common environmental goals include: reducing carbon footprints and water consumption, increasing the share of energy from renewable sources, establishing circular flows, and others. These goals are usually very ambitious, which raises the legitimate question of whether companies and national governments will be successful in achieving them (PRe, 2016).

Tools to support business decisions are also diverse. Some tools, such as the concept of 'cradle to cradle' or circular economy, are successful because they offer an appealing narrative that users can easily relate to the activities in companies. Other tools, such as life cycle environmental analysis, can convince us with a large number of environmental indicators.

Environmental and sustainability goals in companies are most often set by management (e.g., regarding energy, water, and climate change), after which individual business units and departments begin implementing measures to achieve these goals within a specific timeframe. However, these goals are often not aligned with the operational capabilities at the implementation level, where the improvements are supposed to be achieved. As a result, individual business units undertake measures to reduce greenhouse gas emissions without knowing the current state of emissions, nor are they aware of which measures in their plant/unit can contribute the most to improvements, or where it would be appropriate to prioritize actions and what their contribution will be to achieving the overall goals. Such an approach often proves inadequate and does not yield the desired results. Successful companies typically first review the characteristics of individual business units or products, using LCA to determine indicator values and identify critical points in business processes or the supply chain. They then assess which goals are important for each department, unit, or product and attempt to achieve them through actions at the previously identified critical points. To achieve their goals, they continuously plan measures for updates and improvements that are implemented at the critical points (PRe, 2016).

The combined use of LCA and sustainability or the circular economy enables product developers to effectively measure environmental performance, compare circular strategies, and ensure a positive environmental balance from new products designed based on circular flows. Furthermore, LCA requires many of the same data as, for example, the calculation of the material circularity indicator in the circular economy. Therefore, these measurements complement each other with relatively little effort. The material circularity indicator can also be calculated using the same software as LCA. It is important to note that the material circularity indicator focuses on the flow of material between the production and use of the product, explicitly encouraging the use of recycled or reused materials and extending the product's lifespan. In contrast, LCA focuses on determining environmental impacts at the level of the entire life cycle (PRe, 2017). As the LCA method is increasingly used in practice, we will now present it in more detail.

The use of LCA in Slovenia is not as widespread as abroad. LCA analysis is a task for engineers and can only be carried out by qualified professionals with a broad understanding of materials, technologies, energy, with appropriate software and access to databases. However, LCA analysis cannot be conducted without data from the client and communication regarding the intended use of the results. Therefore, the purpose of this material is to improve the understanding of what LCA actually is, how an LCA project should be structured so that contractors can prepare an appropriate proposal for conducting the environmental impact assessment using the LCA method, and later carry out the assessment. To avoid misconceptions among potential clients, some examples of results from conducted LCA studies are presented. The reader will thus understand which data and in what format the client must prepare it, and how they will be used. The provided content will be useful for all those who will encounter the need to evaluate environmental impacts and demonstrate environmentally responsible practices.

2 Understanding and usability of LCA analysis results

2.1 General information about the LCA method

To implement an effective environmental policy, every company (regardless of its activity) needs relevant environmental data. The data that companies acquire, for example, for establishing an environmental management system (ISO 14001, EMAS), is often insufficient for the comprehensive development of more environmentally friendly products and services or for understanding the impacts along supply chains. In this case, only data on emission values from technological processes or energy consumption during product use are not enough to actually optimize products environmentally. For this purpose, other additional data, obtained based on different methodologies, are now required and used. We can expect that in the future, the demand for credible and increasingly comprehensive environmental data for products and services will continue to grow (in the areas of communication, ISO standards, product development, etc.)

For this purpose, life cycle assessment (LCA) of products has become widely established worldwide. However, when introducing this concept, we need tools that can quantitatively determine such comprehensive impacts. One such tool is the LCA method, which has become one of the most important tools for assessing the environmental impacts of products globally. Through LCA, we evaluate all the environmental impacts caused by a product throughout its life cycle, with the aim of environmentally optimizing the product. It is a collection of all inputs, outputs, and potential environmental impacts of a specific production system throughout its entire life cycle (ISO, 2006a).

LCA is the only internationally standardized environmental assessment method (ISO 1997, 1998, 2000a, b). ISO standard 14040 defines LCA as a technique for evaluating environmental aspects and potential impacts associated with a product. It is conducted using the following steps:

- preparation of a list of relevant inputs and outputs of the system (inflows and outflows);
- assessing the potential environmental impacts associated with these inputs and outputs;
- interpreting the results of the inventory and environmental impacts in relation to the study's objectives.

The goal of LCA is to identify and quantitatively define all environmental impacts associated with a product. LCA achieves this with a 'cradle-to-grave' approach, considering all impacts related to the product throughout its life cycle, i.e., from raw material extraction ('cradle') through production, use, and disposal ('grave'). In this way, LCA highlights the aspects of the product that have the greatest environmental impact. Manufacturers can then focus their efforts on these aspects in order to reduce the product's environmental footprint (EEA, 1998).

The environmental life cycle of a product generally includes the following stages: extraction and preparation of raw materials, production, distribution and transport, consumption or use, and disposal of products. The consideration of the environmental cycle of a product always includes the acquisition of the energy required for the extraction of raw materials, their processing, production, transport, distribution, use, etc., which also begins with the acquisition of the necessary energy sources. Therefore, using the LCA method, companies not only obtain data on the impacts in individual phases of life cycles but also data on environmental impacts that cannot be determined using other methods (Denac, Radonjič, 2023).

According to the methodology outlined in the ISO 14040 standard, the LCA method consists of 4 steps or structural elements: (i) definition of the goal and boundary, (ii) data inventory, (iii) assessment of environmental impacts and (iv) interpretation of results.

2.2 Application of environmental life cycle assessment

In recent decades, we have witnessed the increasing use of LCA to support decision-making regarding environmental protection. Much effort has been made to integrate the life cycle concept into society and to facilitate its use at all levels – from the regulatory and governmental level, through industry and production, to citizens and consumers. The spread of LCA has been facilitated by numerous initiatives to support and harmonize the use of this tool at a global level (e.g. the international standard ISO 14040, the global partnership known as the Life Cycle Initiative (LCI), the establishment of the European LCA Platform and others), which have also been followed by initiatives to support the use of LCA at a national level. Recently, LCA services have been reflected in environmental product declarations (EPDs) and greenhouse gas emissions monitoring. Universities, research institutions and private companies often work closely together in commercial projects or doctoral theses for industry (Hauschild et al., 2018). The immense popularity of the life cycle concept has led to its use in a variety of assessment approaches, including those focused on a single environmental aspect. Increased concern about climate change is reflected in individuals and organizations making significant efforts to measure the release and impact of greenhouse gases. For example, the term LCA is often used in writing about carbon monitoring, even though the results only address climate change and not other equally or even more important impacts. The precise meaning of the methodology is often misunderstood, resulting in carbon footprint and LCA being used interchangeably, which is incorrect. By narrowing the assessment to a single environmental category, the results will not reflect the necessary breadth that only LCA provides (Curran, 2012).

The usefulness of the LCA method for decision-makers at the national level

The use of LCA and life cycle approaches can support policy design, policy implementation and regulation, and can also be used for policy evaluation. The European Commission has identified LCA as one of the reference models for assessing the impacts of policies in the EU in the Better Regulation Guidelines (EC, 2015b). This indicates a potential increased use of LCA for assessing existing policy frameworks (e.g., compliance assessment or verification) and for assessing future possible policy options.

The applicability of the LCA method in business and industry

The use of LCA in companies can be classified into five main groups according to purpose: (i) decision support in product and process development, (ii) marketing purposes (e.g., environmental labeling), (iii) development and selection of indicators used in monitoring the environmental performance of products or production facilities, (iv) selection of suppliers or subcontractors, and (v) strategic planning (Hauschild et al., 2018).

We note that the use of LCA within an industry can serve more than one purpose well, and often the same results can be used for different purposes within a company (e.g., product development is often combined with marketing). As a company gains more experience using LCA, one analysis can trigger another (e.g. insight into the environmental impacts of a product can lead to decisions about choosing other suppliers or changing strategies). It is also noted that although LCA was developed as a tool to be used at the product level, there is increasing interest in using LCA at the corporate level to reflect the performance of a company or individual plants throughout their entire life cycle. This is especially important for large companies (Hauschild et al., 2018). (For more information, see Bradač Hojnik et al., 2020; Bradač Hojnik et al., 2020).

There are several reasons for performing an LCA. These may include the following:

- Financial benefits. LCA examines the life cycle of a product and identifies where the main environmental impacts occur. Often these environmental impacts can be reduced by increasing the efficiency of the use of input materials and energy. Increasing the efficiency of resource use will reduce the amount of input streams used and waste generated, thereby reducing costs. Costs are also associated with environmental charges due to the environmental damage caused.
- Product and design. LCA can be used as an aid in decision-making about the design or redesign of a product or process. LCA can be used to compare the environmental impacts of different design alternatives and to assess whether any alternative has potentially significant environmental advantages or disadvantages.
- Marketing. Large companies have often used LCA as a marketing tool. Manufacturers exploit the environmental friendliness of their products as a means of increasing sales. LCA can be used as a basis for advertising claims that a product has a lower environmental impact than other similar products. However, the use of LCA for this purpose has sometimes been controversial (EEA, 1998).
- In the past, the initiator of LCA was usually the marketing department, which wanted to present the environmental benefits of products. However, the

marketing department most often found that the results of LCA were very difficult to use in marketing communications. Later, the role of initiator was taken over by other departments, usually the R&D department or the environmental protection department, which led to frequent difficulties in implementing LCA due to lack of clarity regarding purpose and use. Today, sustainable business operations are slowly changing from current activities to activities that are integrated into the company's current operations, with LCA being used to monitor and measure environmental impacts. The Sloan survey showed that in 2012 already, approximately 70% of managers ensured that achieving sustainable business operations was their goal, which was regularly included in the content of work meetings in companies. This report shows that sustainability is becoming a tool for creating value and not a tool for reducing costs. The focus is shifting from cost-cutting activities and strategies to better products with larger market shares (Goedkoop et al. 2013, 6).

– Many large companies now care not only about their own environmental performance, but also about the performance of their suppliers and vendors throughout the supply chain. In other words, they care about the environmental performance of all companies involved in the entire life cycle of their products. By encouraging companies to improve their environmental performance, large companies can reduce the environmental impacts of their products throughout their life cycle (EEA, 1998).
– This means that suppliers to a large company will have to demonstrate good environmental management and provide their customers with information that will enable them to carry out an LCA for their products. The ability to demonstrate good environmental management and provide adequate information for an LCA will undoubtedly put the company in a good position to continue doing business with existing customers, whereas if the company does not do this, customers might switch suppliers (EEA, 1998).

2.3 Some features of the current LCA methodology

The fundamental feature of LCA is the consideration of environmental impacts that occur throughout the entire life cycle of a product, from raw material extraction, production, use and disposal. However, considering the entire life cycle for individual environmental issues can be carried out in different ways. This issue has been the main driving force of all methodological discussions in recent decades (Werner 2005, 29).

LCA environmental assessment methods are constantly evolving, and LCA results may only be valid for decision support for a limited time, until new environmental impact calculation models are developed or updates to the databases used are published. For this reason, environmental impact assessments should be carried out continuously.

The main characteristics of LCA compared to other decision-making tools are the following:

LCA is a tool for modeling the environmental aspects of business operations;

- LCA is used as a tool in the decision-support process, but it does not encompass the entire decision-making process;
- LCA is designed to support decision-making at the micro-level, where the subject of analysis is products, including services and processes or production facilities;
- LCA evaluates changes caused by specific human activities or average human activities and cannot describe the state of the environment or social responses to environmental pressures;
- LCA assesses environmental interventions and the resulting damage by assuming/considering consistent (global) data with average meteorological and environmental conditions;
- LCA is based on monitoring input and output flows;
- LCA, in both the modeling phase and the environmental impact assessment phase, reflects only the current time component; therefore, continuous implementation of analyses with data updates in mathematical models is necessary (Werner, 2005, p. 31).

As already mentioned, LCA is the only internationally standardized method for assessing environmental impacts. The first LCA studies were conducted as early as the 1970s and 1980s. The historical development of LCA is summarized in Klöpffer (2006), with special emphasis on the role of the SETAC (Society of Environmental Toxicology and Chemistry) in this process. International standards were revised and updated in 2006 (ISO 2006a, b; Finkbeiner et al., 2006). These updated standards replaced the old series that had been in use prior to October 2006. LCA is an active research field, where further methodological development can be expected. The leading standards for LCA are ISO 14040 and ISO 14044. ISO 14040 addresses the principles and framework for LCA, while ISO 14044 defines the requirements and guidelines for conducting an LCA study (Goedkoop et al., 2013, p. 7). In addition to the standards, it is also necessary to follow the guidelines from the ILCD (International Reference Life Cycle Data System) manuals when conducting LCA analyses. ISO standards are defined rather loosely, which makes it difficult to assess whether an LCA study has been conducted in accordance with the standard. Unlike ISO 14001, it is not possible to obtain official accreditation for LCA that would confirm whether an LCA study, LCA methodology, or the use of LCA software has been carried out in compliance with the ISO standard (Goedkoop et al., 2013, p. 7). For example, ISO 14044 does not permit weighting between environmental impact categories if the results are intended for public comparisons between products. However, weighting is explicitly allowed for other applications, which is why some software tools, such as SimaPro, support the use of weighting. This means that it is the responsibility of the LCA practitioner to apply weighting appropriately. Similar issues arise with rules for the allocation of environmental impacts, system boundaries, and so on (Goedkoop et al., 2013, p. 7).

The most important consequence of striving to comply with the ISO standard is the need for careful documentation of the study's goal, scope, and interpretation issues. The practitioner may carry out an LCA study in several different ways, as long as they thoroughly document what was done. Another consequence of adhering to the standards is that you may also need validation or a peer review of the conducted LCA study by independent experts (Goedkoop et al., 2013, p. 7).

It is up to the LCA practitioner, in agreement with the client, whether to adhere to these standards or to (intentionally) deviate from them. However, in the case of deviation, it will be more difficult to convince other stakeholders of the reliability of the results (Goedkoop et al., 2013, p. 7). In addition to the LCA approach, which analyzes multiple environmental impact categories, there have recently been approaches developed that focus on just one environmental category. A typical example is the calculation of a carbon footprint or water footprint. These approaches also follow the life cycle perspective, but they focus solely on one impact category and therefore do not provide a complete picture. In response to society's growing need for transparency regarding greenhouse gas emissions associated with products, several methods and standards for determining carbon footprint have been developed or are still under development (Goedkoop et al., 2013, p. 7).

2.4 LCA guidelines at European level

At the European level, the International Reference Life Cycle Data System (ILCD) provides a common basis for consistent, reliable, and quality-assured life cycle data and studies. Such data and studies support coherent sustainable consumption and production instruments, such as environmental labeling, eco-design, carbon footprinting, and green public procurement. The ILCD Handbook was published in 2010. This handbook is based on the ISO 14040 and ISO 14044 standards but it provides much more detailed technical guidelines. The ILCD Handbook spans more than 400 pages, whereas ISO 14040 and ISO 14044 together comprise around 60 pages. The ILCD Handbook includes detailed descriptions and requirements to reduce the flexibility of interpretation and to support consistency and quality assurance in LCA results. Additionally, several ILCD handbooks have been published, each addressing specific steps in the implementation of LCA studies in detail.

Between June 2011 and February 2012, the Directorate-General for the Environment (DG Environment) and the Joint Research Centre – Institute for Environment and Sustainability (JRC-IES) developed and tested a harmonized methodology for calculating the environmental footprint of products and organizations, known as the draft Product Environmental Footprint (PEF) and the draft Organization Environmental Footprint (OEF) methods. These two methods were based on the ISO 14040 and ISO 14044 standards and the ILCD handbook, but they are stricter and more concise. In parallel, the Product Environmental Footprint Category Rules (PEFCR) and Organization Environmental Footprint Category Rules (OEFCR) are being developed. PEFCR/OEFCR are based on the ISO 14025 standard for environmental product labeling and complement the general methodological guidelines for environmental footprinting with additional specifications at the product level. PEFCR/OEFCR will enhance the repeatability and consistency of environmental footprint studies. Over time, these two methods could become part of future European policies on sustainable consumption and production (EC 2021, 18). This will significantly increase the demand for knowledge in the field of LCA among all stakeholders.

3 LCA methodological structure

The methodological structure of LCA is defined by the environmental standards of the ISO 14040 series. The ISO/SIST EN ISO 14040 standard defines LCA as "the collection and evaluation of input and output data and potential environmental impacts of a production system throughout its life cycle" (ISO 14040, Chapter 3.9). The introduction of the ISO 14040 standard (ISO, 2006a) states that "LCA addresses environmental aspects and potential impacts (e.g., resource consumption and environmental consequences of emissions) throughout the product's life cycle; from material extraction to production, use, and disposal (i.e., cradle to grave)" (Klöpffer and Renner, 2008). Environmental impact assessments can, of course, be conducted within different boundaries: (i) 'cradle to gate' (from resource extraction to the end of the production process of a given product), (ii) 'gate to gate' (only the production process of a given product), (iii) 'cradle to cradle' (from resource extraction to the reuse of the product or its components).

The LCA methodology is somewhat complex and requires in-depth knowledge from the practitioner, so it will not be explained in detail here. As shown in Figure 1, the LCA analysis is carried out in four steps: (i) definition of the goal and scope, (ii) inventory analysis, (iii) impact assessment, and (iv) interpretation of results.

Definition of Goal and Scope. In the first step of the LCA study, the initial framework for conducting the research is established. At this stage, it must be clearly stated who the results of the LCA study are intended for and why they will be used. The subject of the research must be precisely defined, and the functional unit and reference flow should be specified. Considering the environmental life cycle, the system boundaries are also defined, the method of allocating environmental impacts is determined, the set of environmental categories is specified, along with the corresponding calculation methods, data requirements, the type of critical review, and the format of the report (Werner, 2005).

Inventory analysis (Life Cycle Inventory analysis) involves the collection of data and recalculation procedures to quantitatively assess the environmental impacts that occur throughout the environmental life cycle of a product. These inputs and outputs must include resource consumption and emissions to air, water, and soil that can be linked to the system under study. The collection of all environmental interventions throughout its life cycle is also called the Life Cycle Inventory (LCI)

(Werner, 2005). Inventory analysis is a complex and in-depth process, during which data on materials and energy used are collected, constituting the most demanding and time-consuming step of the entire LCA analysis. The inventory analysis is usually carried out by consultants or several internal working groups with knowledge and experience in each phase of the life cycle. If the necessary information in various forms or databases is already available within the company, it can be compiled/assembled to complete the inventory analysis (IMA, 1996). A portion of the inventory data is always obtained from business partners involved in the supply chain.

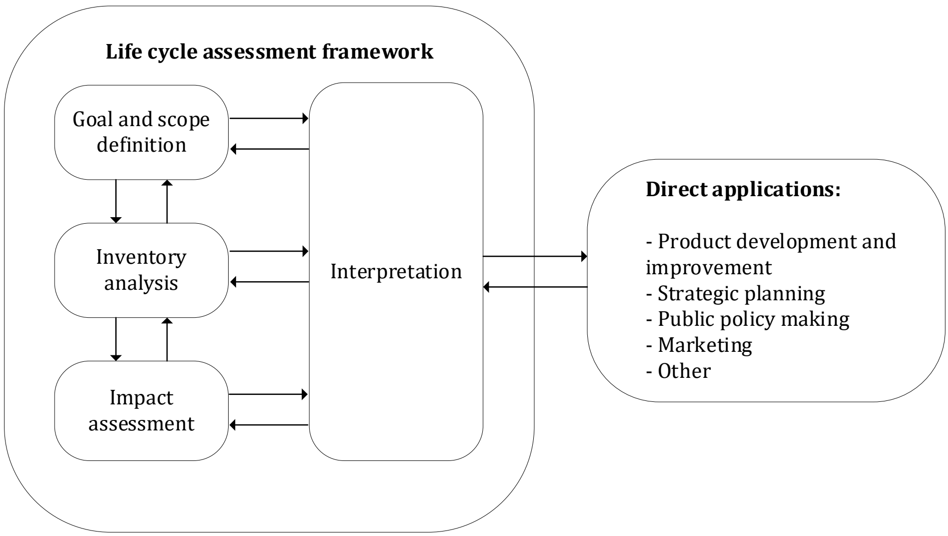


Figure 1: Methodological Structure of LCA
Source: (ISO, 2006a).

An LCA study cannot be conducted without the use of specialized databases. One of the most prominent is the Ecoinvent database, which is the most comprehensive, extensive, and probably the most widely used database in the world. Currently, the database includes over 4,000 products and 19,000 processes, available for three different system models, and the data is updated and supplemented at least once a year (PRe, 2023). Due to the very high dynamics of data availability and validity, the client should verify which databases will be used for calculations before each LCA analysis (Hauschild et al., 2018).

The Life Cycle Impact Assessment (LCIA) evaluates the inputs and outputs of substances based on their environmental impacts. The assessment consists of several steps: classification (sorting inventory data into impact categories), characterization (weighting classified inventory data within individual impact categories), and valuation (combining environmental categories through normalization and summation) (Werner, 2005). In the environmental impact assessment, the selection of the calculation method and the impact categories is crucial, and these are determined based on the definition of the study's goal and scope. It is also important to consider the desired level of integration of the results (i.e., which results to display and how detailed the breakdown should be). There are more than 40 different qualitative methods for conducting LCA. The eco-indicator concept appears to be the most successful in practical use within LCIA, as it also allows for the comparison of environmental impacts across different environmental categories (Zbicinski et al., 2006). This method has been upgraded several times and is currently used as the ReCiPe 2016 method, the most widely applied method for assessing environmental impacts on a global scale. The environmental assessment results are presented through 18 indicators of environmental categories (midpoint approach) and 3 indicators of the resulting environmental damage (endpoint approach) (PRe, 2020).

The international standards ISO 14040 and ISO 14044 (ISO, 2006a; ISO 2016b) distinguish between mandatory and optional steps within the LCIA. The mandatory steps are:

- selection of environmental categories, their indicators, and characterization models (during the modeling process, the LCA practitioner does this by choosing one of the existing LCIA methods);
- classification: linking inventory data to environmental categories based on known potential impacts;
- characterization: calculating the values of environmental indicators by converting the contributions of inventory flows to specific environmental categories.

The results of characterization do not provide information about the relative impacts of environmental categories in relation to each other. They also do not provide information about which environmental category has a greater impact compared to all environmental impacts in a specific geographic area.

The optional steps of LCIA according to the requirements of ISO 14040 and ISO 14044 standards are:

- Normalization: Expressing LCIA results relative to the reference system data. Normalization allows us to assess the contribution of a specific environmental category to the overall impact in a given geographic area, or the contribution per capita in a particular region. Normalization can be a useful step in LCA analysis if we want to compare environmental impacts across different geographic areas;
- Weighting: Determining priorities or weights for individual environmental categories;
- Aggregation: Combining various environmental impact indicators into groups of environmental damages.

It should be emphasized that ISO 14044 states regarding weighting of environmental impacts: "Weighting shall not be used in LCA studies intended to be used in comparative assertions intended to be disclosed to the public" (ISO, 2006b). The described environmental impact assessment (LCIA) is specific to the LCA methodology and requires a thorough understanding of the models and the differences between all existing LCIA methodologies (Hauschild et al., 2018).

Interpretation of results involves explaining the findings from the inventory analysis and environmental impact assessment. The research findings and recommendations are also documented based on the goal and scope of the study. LCA analyses can also include various simplifications, assumptions, and value judgments about processes, meaning that LCA studies may yield different results, even though they appear to examine the same product. Differences can arise due to several factors: the differently defined goals, the use of different functional units, different system boundary settings, and varying assumptions made during data modeling. It is crucial to minimize the scope of simplifications and ensure that, during the reporting phase, the assumptions and values used are clearly specified. This way, the reader of the study can assess and decide on the acceptability of the simplifications and either accept the study results or reject them entirely as unsuitable (Curran, 2015).

4 Case studies

As an example of appropriately defining the problem and providing the necessary data for conducting an LCA study, the contribution of Ardente et al. (Ardente et al., 2006) is cited. The article presents the results of a simplified LCA study on the production of grapes and the processes of transforming them into high-quality bottled wines in Southern Italy. The results of the study were used to support decision-making within the framework of the Environmental Management System (EMS) and to obtain Type III environmental labels (EPD). The following steps were performed in the study:

- company analysis and definition of the functional unit;
- conducting the LCA study of the product, which included: (i) description and analysis of production processes, (ii) analysis of input and output flows, (iii) development of an eco-profile for the functional unit, and (iv) detailed analysis of environmental impacts;
- preparation of an environmental improvement program.

Company analysis and selection of the functional unit

The product under study is bottled red wine produced by a company located in Sicily. The production of red wine is the main activity of the company and accounts for 95% of its revenue. The company offers six types of high-quality, premium wines on the market. The company cultivates 77% of the grapes required for processing on 138 hectares of land, while the remaining 23%, grown on 43 hectares, is purchased from local producers. The average distance between the company's vineyards and the processing facility is 2.1 km, and the processing plant covers an area of 0.25 km^2. The company could be described as a typical smaller Italian winery, producing 950 m^3 of wine annually. The selected functional unit for the study was a 0.75litre bottle of red wine.

Conducting the LCA study of the product

When performing LCA for food products, certain specific challenges arise. It is quite evident that the production of agricultural goods is highly dependent on weather conditions, which means that some environmental impacts can vary significantly from year to year. The present study refers to the 2003 vintage, which represents an average year of production. Similar to most agricultural activities, winemaking impacts the environment through the use of pesticides and synthetic fertilizers. However, there is a lack of sufficient environmental information related to these products (Weidema et al., 1995). Furthermore, wine production involves several processing stages, which can vary between producers depending on the desired quality of the wine. As a result, LCA outcomes for different wineries are generally not directly comparable. The LCA study was conducted in accordance with the requirements of the international standard ISO 14040. The life cycle included the following phases: grape cultivation and transport to the processing facility, wine production and storage, bottling and packaging, as well as transport of the final products. The impacts from waste disposal were excluded from the assessment.

The analysis of the processes was limited to the input and output flows of materials and energy. Inventory data were obtained through direct measurements. Indirect environmental burdens related to material production, energy sourcing, and the transport of raw materials and final products were estimated. The materials included in the analysis are organic and synthetic fertilizers, sulfur and plant protection products, sodium carbonate, perlite, and bottling materials. The energy sources used include fuel for operating agricultural machinery, electricity consumed during viticulture processes, liquefied petroleum gas used for steam and hot water production as well as for building heating, and diesel fuel used for transportation. The collected data were logically grouped into specific categories.

<u>(i) Description and analysis of the production process.</u> Wine production consists of two main phases: the agricultural phase (grape cultivation) and the industrial phase (processing grapes into wine). The processes are presented in detail in the authors' contribution and will therefore not be repeated here. The studied system must also be presented graphically, with system boundaries clearly marked, including the phases that were not included in the LCA. The system boundaries for the analyzed case are shown in Figure 2.

<u>(ii) Analysis of input and output flows.</u> The next step in the LCA study is the collection of input and output data related to the consumption of raw materials, substances, energy sources, emissions, and waste. The most challenging aspect is the estimation of mass flows associated with the production of raw materials, which cause indirect environmental impacts (Ardente et al., 2005a, 2005b). The high

accuracy of the study requires a large number of data points, which extends the time of execution and thus increases costs. Therefore, some authors suggest simplifying the LCA to assist small organizations, which often lack the necessary resources and competencies (Luciani et al., 2003). However, it is not easy to specify what the "simplified" LCA should include. The main simplification could be related to exclusion rules, which allow for less precision in defining system boundaries and data quality (e.g., excluding materials whose quantities are below a certain percentage of the total mass used or using data that are not fully representative or up-to-date). All these "simplifications" require agreement between the client and the LCA practitioner.

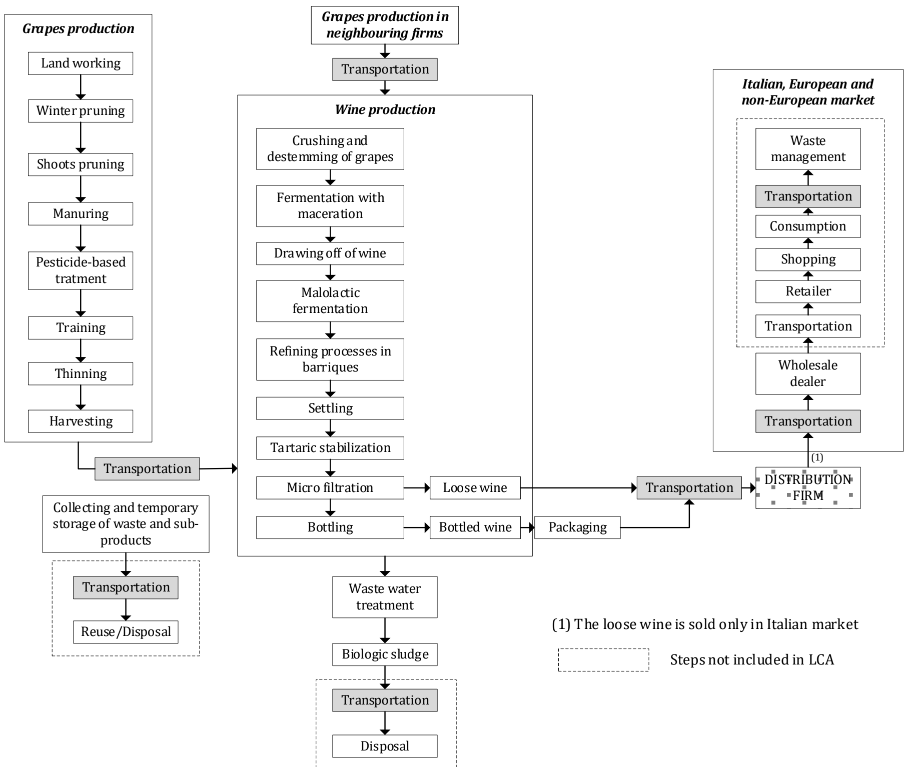


Figure 2: Bottled wine life cycle diagram

Source: Adapted from (Ardente et al., 2006)

Table 1 shows the input and output mass flows in the main stages of the processes, while Table 2 shows the energy flows. All quantities in Table 2 should be considered as primary, defined as: "energy embodied in natural resources (e.g., coal, crude oil, sunlight, uranium) that has not undergone any anthropogenic conversion or transformation" (Boustead, 2001). Secondary sources can be converted into primary quantities using specific conversion factors.

<u>(iii) Eco-profile for the functional unit.</u> In the next step, it is necessary to calculate the consumption of materials, energy, and emissions per functional unit. The analysis included the assessment of direct impacts (those directly related to the activities of the organization, i.e., emissions from greenhouses or agricultural machinery) and indirect impacts (i.e., impacts associated with input materials). The calculations for the functional unit can be performed by the client or the study contractor, as agreed. More information about the study and results is available in Ardente et al. (Ardente et al., 2006).

Table 1: Analysis of input and output flows for wine vintage 2003

Main inputs			Main outputs	
Raw materials			Products	
Grapes	1.269.400 kg		Bottled wine	377.000
Agriculture products			Loose wine	575.050
Compost	181.339 kg		Sub-products	
Potassium sulfate	54.402 kg		Marc	230.782
Urea	36.268 kg		Grape stems	57.123 kg
Fertilizer (phosphorous	36.268 kg		Lees	29.445 kg
Sulfur	23.175 kg		Agriculture wastes	
Fertilizer (nitrogen based)	15.232 kg		Exhausted oils	400 kg
Pesticides	3.919 kg		Packaging of chemicals	260 kg
Additives			Others	234 kg
Perlite	1.269 kg		Process wastes	
Potassium meta-bisulfite	222 kg		Plastics	10.000 kg
Albumin	286 kg		Carton	5.000 kg
Yeast	97 kg		Glass	3.765 kg
Bottling and packaging			Sludges	864 kg
Glass	262.750 kg		Special wastes (oils, packaging,	844 kg
Carton	19.167 kg		Undifferentiated wastes	118 kg
Wood crating	6.730 kg		Wastewaters	
Closures	2.257 kg		Wastewaters	1.728 m^3
Labels	903 kg			
Pallets	900 kg			
Water consumption				
Irrigation	98.104 m^3			
Process consumption	2.160 m^3			
Total	100.264 m^3			
Other				
Soda	2.500 kg			
Cleaning products	377 kg			
Peracetic acid	20 kg			
Laboratory chemicals	8 kg			

Source: Adapted from (Ardente et al., 2006)

(iv) Detailed analysis of environmental impacts. As mentioned earlier, the organization within the EMS should focus on the impacts that are considered the most significant to establish an effective improvement program. In relation to the case study of wine production and packaging, three indicators were analyzed in detail: energy consumption, carbon dioxide emissions, and water consumption.

The environmental impact indicators are determined by selecting the calculation method, which is defined by the client and the study executor. Tables 3 (a) – 3 (c) present examples of environmental categories included in the calculation methods Eco-indicator 99, ReCiPe 2008, and ReCiPe 2016. The results of the environmental assessment calculations differ in terms of the number of environmental categories, their definitions, units of measurement, and the final result. More information on this can be found in the furniture manual (Denac, Radonjič, 2022).

Table 2: Total energy consumed (in GJ)

Diesel	
Agriculture machines	2.870
Transports	66
Transports (input products)	346
Transport (output products)	1.013
Total	4.295
Electricity	
Agriculture (irrigation)	84
Process	5.814
Bottling	275
Total	6.173
LPG	
Hot water production	121
Steam production	33
Plant heating	88
Total	242

Source: Adapted from (Ardente et al., 2006)

In the following case study, we will present the difference in the presentation of LCA study results when they are provided solely in the format required by the international standard ISO 14040 versus other formats enabled by professional software. The presented formats are based on the use of the software SimaPro Analyst 9.3.0.2. Different result presentation formats require different configurations of the environmental life cycle model and therefore must be agreed upon already in the project planning phase. Such discussions require the client to have prior knowledge of the LCA concept.

Table 3: Environmental categories considered within the framework of different LCA assessment methods: (a) Eco-indicator 99, (b) ReCiPe 2008, (c) ReCiPe 2016

(a) Eco-indicator 99			(b) ReCiPe 2008 Midpoint			(c) ReCiPe 2016 Midpoint	
Environmental categories	**Units**		**Environmental categories**	**Units**		**Environmental categories**	**Units**
Carcinogens	DALY		Climate change	kg CO2 eq		Global warming	kg CO2 eq
Respiratory organics	DALY		Ozone depletion	kg CFC-11 eq		Stratospheric ozone depletion	kg CFC-11 eq
Respiratory inorganics	DALY		Terrestrial acidification	kg SO2 eq		Ionizing radiation	kBq Co-60 eq
Climate change	DALY		Freshwater eutrophication	kg P eq		Ozone formation, Human health	kg NOx eq
Radiation	DALY		Marine eutrophication	kg N eq		Fine particulate matter formation	kg PM2.5 eq
Ozone layer	DALY		Human toxicity	kg 1,4-DB eq		Ozone formation, Terrestrial ecosystems	kg NOx eq
Ecotoxicity	PAF*m2yr		Photochemical oxidant formation	kg NMVOC		Terrestrial acidification	kg SO2 eq
Acidification/Eutrophication	PDF*m2 yr		Particulate matter formation	kg PM10 eq		Freshwater eutrophication	kg P eq
Land use	PDF*m2 yr		Terrestrial ecotoxicity	kg 1,4-DB eq		Marine eutrophication	kg N eq
Minerals	MJ surplus		Freshwater ecotoxicity	kg 1,4-DB eq		Terrestrial ecotoxicity	kg 1,4-DCB
Fossil fuels	MJ surplus		Marine ecotoxicity	kg 1,4-DB eq		Freshwater ecotoxicity	kg 1,4-DCB
			Ionizing radiation	kBq U235 eq		Marine ecotoxicity	kg 1,4-DCB
11 environmental categories			Agricultural land occupation	m2a		Human carcinogenic toxicity	kg 1,4-DCB
			Urban land occupation	m2a		Human non-carcinogenic toxicity	kg 1,4-DCB
			Natural land transformation	m2		Land use	m2a crop eq
			Water depletion	m3		Mineral resource scarcity	kg Cu eq
			Metal depletion	kg Fe eq		Fossil resource scarcity	kg oil eq
			Fossil depletion	kg oil eq		Water consumption	m3
			18 environmental categories			18 environmental categories	

Source: (PRe, 2020)

As part of the environmental suitability assessment of solutions in the field of electromobility, two different vehicle configurations are compared – a vehicle with an electric drive combined with an internal combustion engine, and a vehicle with an internal combustion engine equipped with a conventional mechanical transmission (Dobnik, 2023).

Goal and Scope Definition. The objective of this study is to conduct an LCA (Life Cycle Assessment) to support the results obtained from the simulation of powertrain systems. The LCA results provide deeper insight into environmental impacts, especially when raw material usage and fuel consumption of each system are taken into account. The LCA study incorporates estimated data on the components that make up either the mechanical transmission or the electric drive of the freight vehicle. Additionally, fuel consumption data obtained from prior simulations will be considered. The LCA study covers the entire life cycle, within the boundaries from cradle (raw material extraction) to grave (recycling or disposal of components).

Inventory Analysis. At this stage of the analysis, precise data on the individual powertrain components–such as the mass of components and the materials they are made from–are not yet available. Therefore, we will assume a typical distribution of component masses and materials commonly used in the production of such parts (Tables 4 and 5). The baseline mass distribution of individual components is based on a 3D model of a comparable transmission, the GAZ A32R22-1700010. At the end, each powertrain was assigned the corresponding fuel consumption, taking into account the expected service life (10 years) and total driving distance (1,000,000 km) at an average speed of 90 km/h. This results in 313,800 liters or 265,161 kg of diesel fuel (D-2) for the conventional mechanical drivetrain, and 213,900 liters or 180,745 kg of D-2 for the electric drivetrain.

The weight of the Eaton Fuller T-955ALL transmission, which was selected for the driving simulation, is 293 kg. For the electric drivetrain analysis, the competing electric motor ZF CeTrax was used, with a weight of 285 kg. It is assumed that this is the total weight of both the generator and the electric motor, as they have similar characteristics and each contributes approximately half of the total mass.

Table 4: Weight distribution of individual components of a mechanical transmission

Mechanical transmission component	Materials	Mass fraction (%)	Mass (kg)
Housing	Grey cast iron (EN-GJL-350)	50	146,5
Gears, axles, bearings	Steel SCr420	30	87,9
Non-load-bearing parts	Aluminium Si11Cu2	10	29,3
Non-load-bearing parts	Bronze CuSn12	10	29,3

Source: (Dobnik, 2023)

Table 5: Weight distribution of individual electric motor components

Electric motor component	Materials	Mass fraction (%)	Mass (kg)
Housing	Aluminium Si11Cu2	39	111,15
Stator winding	Copper Cu	10	28,5
Rotor and stator core	Steel S235 JR	43	122,55
MAgnets	Neodymium NdFeB	8	22,8

Source: (Dobnik, 2023)

The study utilized material and processing data from the Ecoinvent 3.6 database, which is described in more detail in the Master's thesis. For waste management modeling, average data for France were used. The environmental life cycle model is presented in Figure 3.

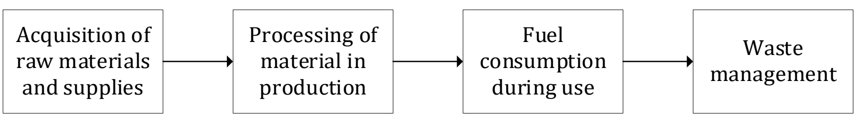


Figure 3: Environmental life cycle model of a mechanical transmission
Source: (Dobnik, 2023)

Environmental Impact Assessment. The environmental life cycle modeling was carried out using SimaPro Analyst 9.3.0.2 software, applying the ReCiPe 2016 (H) method. Using the midpoint approach, results were obtained for 18 environmental impact indicators, which are a mandatory part of the characterization phase in an LCA study report. The endpoint approach provided values for 22 environmental indicators, which were further aggregated into three damage categories: human health, ecosystems, and resources. Using weighting, the total environmental impacts were calculated and expressed in ecopoints, which allow for comparison of environmental impacts across different impact categories. A process diagram was also created to highlight the most influential processes. While such a presentation of results is not mandatory according to ISO 14040, it provides key insights for environmental optimization of processes and products. Below, we present a selection of results for the conventional powertrain with a mechanical transmission. The figures indicate which outputs are required under ISO 14040 and which go beyond the standard's requirements. The results are shown for demonstration purposes and will not be discussed in detail. They are presented in their original form as generated by the SimaPro Analyst 9.3.0.2 software, since real-world LCA reports will also provide results in the same format.

In the characterization phase, the results of the LCA study are presented using environmental impact indicators, which depend on the method applied. As shown in Table 6, the ReCiPe 2016 method provides assessment results through 18 environmental impact categories. The results within each category are expressed in equivalent amounts of selected reference substances; however, this does not imply that the selected reference substances are the most impactful within their respective categories. The results can be analyzed either in aggregated form or broken down, depending on the objectives of the analysis (e.g. most impactful processes, materials used, or life cycle stages). Based on the characterization results alone, it is not possible to determine which environmental category is the most burdensome. According to ISO 14040, characterization results are a mandatory element in every LCA assessment report.

For the environmental optimization of products, it is therefore necessary to use additional tools and result presentation methods that are not required by ISO 14040. One example of a more detailed analysis includes normalization and weighting of results, which provide insights into the overall environmental damage caused. The results are expressed in ecopoints (Pt), which are additive and allow for direct comparison. Figure 4 and Table 7 present the weighted results both graphically and in tabular form, broken down by individual life cycle stages: production, use, and end-of-life treatment. Higher bars in Figure 4 or higher values in Table 7 indicate greater environmental impact, while the contributions of individual environmental categories in Figure 4 can be interpreted using the accompanying legend.

Table 6: LCA characterization results for the life cycle of a conventional gearbox drive. Assessment performed according to ReCiPe 2016 Midpoint (H) (mandatory step according to ISO 14040)

Se	Impact category	Unit	Total	Gearbox production	Machine operation, diesel, >= 74.57 kW,	Waste (waste scenario) {FR}|
☑	Global warming	kg CO2 eq	1,03E6	9,57E3	1,02E6	32,4
☑	Stratospheric ozone depletion	kg CFC11 eq	0,372	0,00318	0,368	3,2E-5
☑	Ionizing radiation	kBq Co-60 eq	5,79E3	720	5,07E3	0,116
☑	Ozone formation, Human health	kg NOx eq	5,38E3	23,5	5,35E3	0,0368
☑	Fine particulate matter formation	kg PM2.5 eq	1,04E3	22,9	1,02E3	0,00816
☑	Ozone formation, Terrestrial ecosystems	kg NOx eq	5,59E3	25,1	5,56E3	0,0376
☑	Terrestrial acidification	kg SO2 eq	2,57E3	39,4	2,53E3	0,0199
☑	Freshwater eutrophication	kg P eq	40,6	5,39	35,2	0,00598
☑	Marine eutrophication	kg N eq	23,3	0,752	22,5	0,000728
☑	Terrestrial ecotoxicity	kg 1,4-DCB	1,31E6	1,66E5	1,15E6	20
☑	Freshwater ecotoxicity	kg 1,4-DCB	6,42E3	1,58E3	4,76E3	75,3
☑	Marine ecotoxicity	kg 1,4-DCB	9,65E3	2,06E3	7,5E3	91,9
☑	Human carcinogenic toxicity	kg 1,4-DCB	4,42E4	4,53E3	3,97E4	4,24
☑	Human non-carcinogenic toxicity	kg 1,4-DCB	1,42E5	2,56E4	1,16E5	337
☑	Land use	m2a crop eq	7,25E3	231	7,02E3	0,0423
☑	Mineral resource scarcity	kg Cu eq	2,02E3	364	1,65E3	0,02
☑	Fossil resource scarcity	kg oil eq	3,36E5	2,45E3	3,33E5	1,15
☑	Water consumption	m3	1,15E3	57,1	1,1E3	0,0981

Source: (SimaPro)

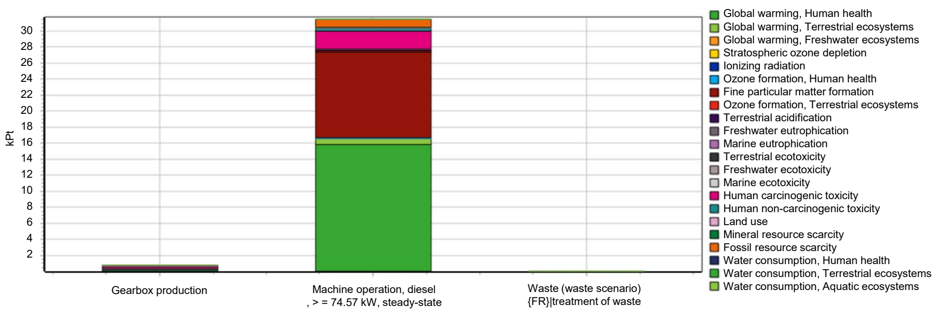


Figure 4: LCA single score results for the life cycle of a conventional gearbox drive. Assessment performed according to ReCiPe 2016 Endpoint (H), results expressed in ecopoints (Pt). (optional step according to ISO 14040)
Source: (SimaPro)

Just like in the characterization phase, the results related to environmental damage (i.e., normalized and weighted results) can also be presented either in aggregated form or broken down in various ways, depending on the intended use of the LCA study results. Figure 5 shows the contributions of individual processes involved in the production of the conventional transmission. Higher bars indicate greater contributions to environmental burdens, while the contributions of individual environmental categories can be interpreted using the accompanying legend. This type of result presentation enables product eco-design, which is not possible with other presentation methods. Therefore, a well-structured LCA study design is essential for ensuring the practical applicability of its results. Presenting results in the manner shown in Figure 5 is not a mandatory step under ISO 14040.

Table 7: LCA weighting results for the life cycle of a conventional gearbox drive. Assessment performed according to ReCiPe 2016 Endpoint (H), results expressed in ecopoints (Pt). (optional step according to ISO 14040)

Se	Impact category	Unit	Total	Gearbox production	Machine operation,	Waste (waste scenario) {FR}|
	Total	kPt	32,2	0,756	31,5	0,00215
	Global warming, Human health	kPt	16	0,148	15,8	0,000501
	Global warming, Terrestrial ecosystems	kPt	0,782	0,00725	0,775	2,45E-5
	Global warming, Freshwater ecosystems	kPt	2,14E-5	1,98E-7	2,12E-5	6,7E-10
	Stratospheric ozone depletion	kPt	0,00329	2,82E-5	0,00326	2,83E-7
	Ionizing radiation	kPt	0,00082	0,000102	0,000718	1,64E-8
	Ozone formation, Human health	kPt	0,0816	0,000357	0,0813	5,58E-7
	Fine particulate matter formation	kPt	11	0,24	10,7	8,56E-5
	Ozone formation, Terrestrial ecosystems	kPt	0,195	0,000875	0,194	1,31E-6
	Terrestrial acidification	kPt	0,147	0,00226	0,145	1,14E-6
	Freshwater eutrophication	kPt	0,00735	0,000975	0,00638	1,08E-6
	Marine eutrophication	kPt	1,07E-5	3,45E-7	1,04E-5	3,35E-10
	Terrestrial ecotoxicity	kPt	0,00404	0,000514	0,00353	6,18E-8
	Freshwater ecotoxicity	kPt	0,0012	0,000296	0,000894	1,41E-5
	Marine ecotoxicity	kPt	0,000274	5,86E-5	0,000213	2,61E-6
	Human carcinogenic toxicity	kPt	2,45	0,251	2,2	0,000235
	Human non-carcinogenic toxicity	kPt	0,54	0,0975	0,442	0,00128
	Land use	kPt	0,0174	0,000555	0,0168	1,02E-7
	Mineral resource scarcity	kPt	0,00333	0,000601	0,00273	3,29E-8
	Fossil resource scarcity	kPt	1,05	0,00418	1,04	2,96E-6
	Water consumption, Human health	kPt	0,0144	0,000786	0,0136	8,3E-7
	Water consumption, Terrestrial ecosystem	kPt	0,00265	0,000111	0,00254	1,18E-7
	Water consumption, Aquatic ecosystems	kPt	4,51E-7	2,15E-8	4,3E-7	8,86E-12

Source: (SimaPro)

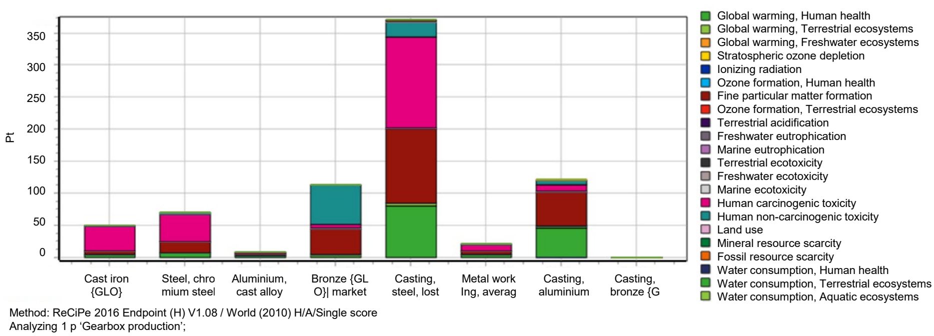


Figure 5: LCA single score results for the production process of a drive with a conventional gearbox. Assessment performed according to ReCiPe 2016 Endpoint (H), results expressed in ecopoints (Pt). (optional step according to ISO 14040)

Source: (SimaPro)

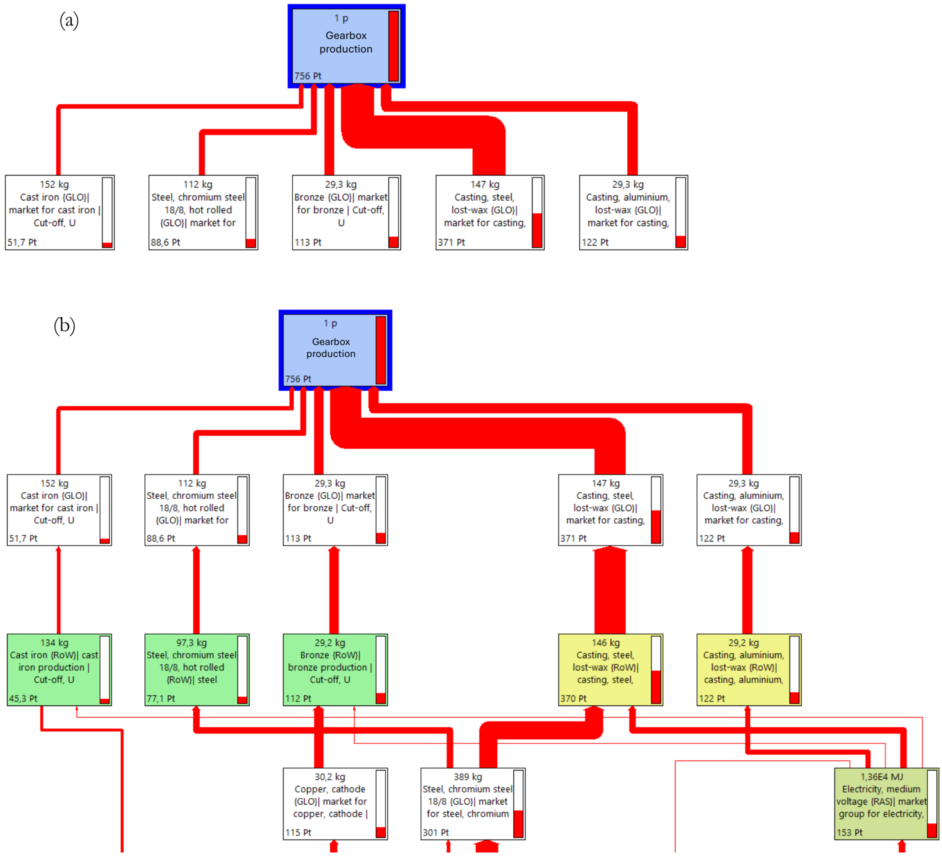


Figure 6: LCA single score results for the production process of a drive with a conventional gearbox: Display of the most influential processes (Figure 6a), More detailed display of the impacts of individual processes (Figure 6b). Assessment performed according to ReCiPe 2016 Endpoint (H), results expressed in ecopoints (Pt). Thicker arrows represent the environmentally more burdensome phases/processes. (optional step according to ISO 14040)
Source: (SimaPro)

Damage data can also be presented using Sankey diagrams. This involves visualizing environmental burdens, where thicker arrows represent more environmentally burdensome phases/processes, and the scope of the processes shown can be adjusted. Such a presentation (Figure 6) is also not mandatory according to ISO 14040, which is why it is less commonly found in LCA study reports. Figure 6a shows a Sankey diagram for the process of manufacturing a conventional transmission, which, similar to Figure 5, highlights the most impactful processes during production. Meanwhile, the Sankey diagram in Figure 6b further clarifies the sources of the results, which is crucial for the environmental optimization of processes and products.

While characterization results in LCA studies cannot be directly compared, comparisons are possible at the level of environmental damage, provided that the assessment results were obtained using the same methodology. Figure 7 presents the results of a comparative analysis for the process of manufacturing an electric powertrain and a conventional powertrain, where the height of the bars represents the total environmental burdens associated with the production of each alternative. From Figure 7, it is evident that the production of the electric powertrain results in half the environmental burdens compared to the production of the conventional powertrain. However, this does not mean that the environmental burdens of the electric powertrain are lower throughout the entire life cycle, which would need to be verified through a full calculation. Such a presentation is also not a mandatory step according to ISO 14040.

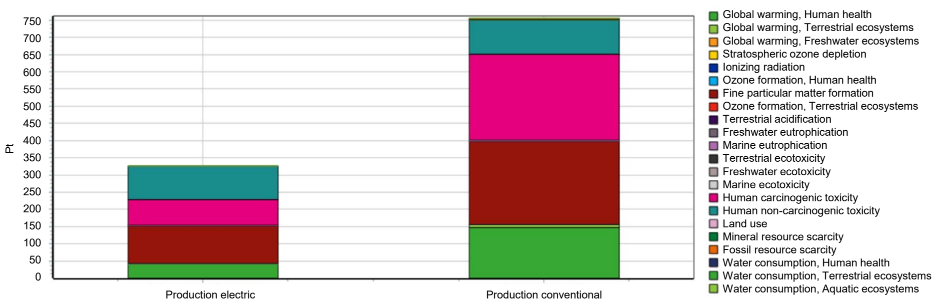


Figure 7: Results of a comparative single score LCA analysis for the production process of an electric drive and a drive with a conventional gearbox. Assessment performed according to ReCiPe 2016 Endpoint (H), results expressed in ecopoints (Pt). (optional step according to ISO 14040)

Source: (SimaPro)

References

Ardente, F., G. Beccali, M. Cellura, and V. Lo Brano. 2005a. Life cycle assessment of a solar thermal collector: Sensitivity analysis, energy and environmental balances. *Renewable Energy* 30:109–130.

Ardente, F., G. Beccali, M. Cellura, and V. Lo Brano. 2005b. Life cycle assessment of a solar thermal collector. *Renewable Energy* 30:1031–1054.

Ardente F., Beccali G., Cellura M., Marvuglia A. (2006). POEMS: A Case Study of an Italian Wine-Producing Firm, Environmental Management Vol. 38, No. 3, pp. 350–364, DOI: 10.1007/s00267-005-0103-8

Boustead Consulting Ltd. 2001. Environmental database, ver. 4.4. Boustead Consulting, Ltd., Black Cottage, West Sussex, UK.

Bradač Hojnik, B., Primec, A., Denac, M., Močnik, D. (2020) Slovenska podjetja in izzivi transformiranja poslovanja. Rebernik M-, Širec K. (ur.), Slovenski podjetniški observatorij 2019, Univerza v Mariboru, Univerzitetna založba, 2020.

Curran, M. A. (Ed.) (2012). Life Cycle Assessment Handbook. A Guide for Environmentally Sustainable Products, Wiley Scrivener Publishing.

Denac, M., Radonjič, G. (2022) Primerjalna analiza metod za ocenjevanje vplivov pohištvenih izdelkov na okolje. V: Volfand J. (ur.) Izzivi in rešitve za ponovni vzpon pohištvene industrije, Zelena Slovenija, str. 90-93.

Denac, M., Radonjič, G., (2023) LCA analiza varnostnega sefa Starprim: poročilo o raziskavi. Pripravljeno za podjetje Primat tovarna kovinske opreme d.d., Maribor, Univerza v Mariboru, Ekonomsko poslovna fakulteta.

Dobnik, L. (2023). Simulacija vozila z električnim pogonom v kombinaciji z motorjem z notranjim zgorevanjem, Magistrsko delo-gospodarsko inženirstvo, Univerza v Mariboru

EC. (2015b). Better Regulation Guidelines. Commission staff working document, COM(2015) 215 final; SWD(2015) 111 final. Pridobljeno s http://ec.europa.eu/smart-regulation/guidelines/docs/swd_br_guidelines_en.pdf

EC. (2021). *Recommendation on the use of Environmental Footprint Methods, Annex 1 to 2* (Recommendation No. C(2921) 9332 final. *Official Journal of the European Union.* Pridobljeno s https://environment.ec.europa.eu/publications/recommendation-use-environmental-footprint-methods_en

EEA (1998): Environmental Management Tools for SMEs: A Handbook. Starkey, R. (ed.). European Environment Agency.

Finkbeiner, M., Inaba, A., Tan, R.B.H., Christiansen, K. & Klüppel, H.J. (2006): The new international standards for life-cycle assessment: ISO 14040 and ISO 14044. *International Journal of LCA*, 11(2), 80–85.

Goedkoop M., Oele M., Leijting J., Ponsioen T. & Meijer E. (2013): Introduction to LCA with SimaPro. PRé, www.pre-sustainability.com (Acessed: August 2016).

Hauschild, M.Z., Rosenbaum, R.K., Olsen, S.I. (2018). Life Cycle Assessment. Theory and Practice. Springer International Publishing.

IMA - Institute of Management Accountants (1996): Institute of Management Accountants: Statements on Management Accounting: Tools and Techniques of Environmental Accounting for Business Decisions, http://www.imanet.org/docs/default-source/thought_leadership/external_reporting_systems/tools_and_techniques_of_environmental_accounting_for_business_decisions.pdf?sfvrsn=2 (Accessed: 17.07.2016).

ISO (1997): Environmental management–Life-cycle assessment: Principles and framework. Geneva: International organisation for standardisation.

ISO (1998): Environmental management–Life-cycle assessment: Goal and scope definition and inventory analysis. Geneva: International organisation for standardisation.

ISO (2000a): Environmental management–Life-cycle assessment: Life-cycle impact assessment. Geneva: International organisation for standardisation.

ISO (2000b): Environmental management–Life-cycle assessment: Interpretation. Geneva: International organisation for standardisation.

ISO (2006a): Environmental management–Life-cycle assessment: Principles and framework. Geneva: International organisation for standardisation.

ISO (2006b): Environmental management–Life cycle assessment: Requirements and guidelines. Geneva: International organisation for standardisation.

Klöpffer, W. (2006): The role of SETAC in the development of LCA. *International Journal of LCA*, 11(1), 116–122.

Klöpffer, W., Renner, I. (2008): "Life-Cycle Based Sustainability Assessment of Products", in: Schaltegger, S. et al. (eds.): Environmental Management Accounting for Cleaner Production. Springer Science + Business Media B.V., 91-102.

Luciani, R., L. Andriola, and S. Sibilio. 2003. I sistemi di gestione ambientale orientati al prodotto: POEMS, un nuovo strumento (in Italian). *Ambiente* 8:789–796.

PRe. (2016). 2020 – the year of the perfectly sustainable world? Pridobljeno s https://www.pre-sustainability.com/news/2020-the-year-of-the-perfectly-sustainable-world/

PRe. (2017). Why circular economy business models need LCA – Part 1. Pridobljeno s https://www.presustainability.com/news/why-circular-economy-business-models-need-lca/

PRé Consultants. (2020). SimaPro Database Manuel. Methods Library. Dostopno: https://simapro.com/wp-content/uploads/2020/10/DatabaseManualMethods.pdf (6.10.2022).

PRe (2023). Environmental Footprint database 3.1 in SimaPro, webinar, 20.6.2023

SimaPro (verzija 9.3.0.2) programska oprema SimaPro Analyst (2023), Amersfoort, The Netherlands . PRe Sustainability B.V.

Weidema, B. P., R. Pedersen, and T. S. Drivsholm. 1995. Life cycle screening of food products: Two examples and some methodological proposals. Danish Academy of Technical Sciences, Lyngby, Denmark.

Werner, F., (2005): "LCA as a Method and its Modelling Characteristics ". in: Tukker, A. (ed.) Ambiguities in Decision-oriented Life Cycle Inventories. Springer, 27-39.

Zbicinski, I., Stavenuiter, J., Kozlowska, B. & van de Coevering, H.P.M. (2006): Product Design and Life Cycle Assessment. The Baltic University Press.

Circular Economy and Value Chains (Life Cycle Analysis)

DOI
https://doi.org/
10.18690/um.fl.4.2026.5

ISBN
978-961-299-100-5

Rebeka Kovačič Lukman,[1] Kristijan Brglez[2]

[1] University of Maribor, Faculty of Logistics, Celje, Slovenia
rebeka.kovacic@um.si
[2] University of Maribor, Faculty of Natural Sciences and Mathematics, Maribor, Slovenia
kristijan.brglez1@um.si

Adopting the circular economy concept is of paramount significance for sustainable development, societal metamorphosis, and alleviating pressures on natural systems. This paradigm shift transcends linear consumption models, championing a resource-efficient system where conservation, renewal, and judicious resource use prevail. Integral to this transformation are value chains, pivotal in reshaping production methods, prolonging product longevity, and advocating reuse and recycling. A cornerstone tool in translating circular economy principles into action is Life Cycle Analysis (LCA). LCA meticulously evaluates products' holistic environmental, social, and economic ramifications, pinpointing areas for enhancement and empowering informed decisions towards sustainability. A profound grasp of the circular economy coupled with instrumental tools such as LCA facilitates the sustainable stewardship of resources, an imperative for harmonizing human advancement with environmental preservation in times ahead.

Keywords:
circular economy,
value chains,
sustainable development,
Life Cycle Analysi,
reverse logistics

University of Maribor Press

1 Circular economy

The idea of a circular economy was shaped by two key factors. The first relates to the flow of materials through the economy, while the second concerns the consideration of economic conditions that could lead to such a flow. Both aspects of this thinking originated in the 1960s and 1970s, when various environmental movements began to emerge with the goal of preserving the environment (Ekind et al., 2020). The current concept of the circular economy is not new, as its early foundations began to take shape in the early 1980s. One of the key milestones in the development of the circular economy was a report prepared by the Club of Rome in 1973. It is an international organization of experts, policymakers, and scientists focused on analysing global challenges such as economic growth, environmental impacts, and sustainable development. In the mentioned report, titled The Limits to Growth, members of the Club presented the results of simulations that warned of both the unsustainability of existing economic systems and the limitations of natural resources (Meadows et al., 1973). Their findings sparked further discussions on the necessity of transitioning to more sustainable economic models.

1.1 Beginnings of the Circular Economy

The first serious approach to the conceptualization of the circular economy was undertaken by Walter Stahel and Genevieve Reday-Mulvey (1981), who aimed to address the then-ongoing crisis of high oil prices and unemployment in Europe. Their approach was based on job creation through extending the lifespan and refurbishment of products, as well as replacing the use of primary resources with recycled materials. The result of their vision of such a "looped" economy was the first visual representation of the circular economy, in which they summarized its impact on job creation, economic competitiveness, resource savings, and the prevention of additional waste generation.

The concept of a circular economy was first put forward by the environmental economists Pearce and Turner in 1989. In their book *The Economics of Natural Resources and the Environment*, they emphasized that the traditional open economy developed without an inherent tendency toward recycling, which was reflected in the treatment of the environment as a dumping ground for waste. Pearce and Turner (1989) made a distinction between the (circular) natural system and the (linear) economic system, drawing on the contribution of Kenneth E. Boulding in his work *The Economics of the Coming Spaceship Earth* (1966).

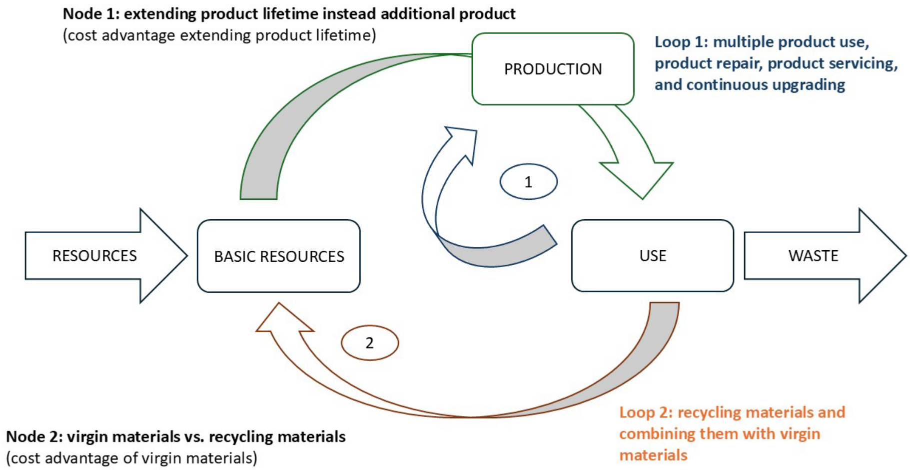


Figure 1: Conceptualization of the circular economy
Source: Stahel & Reday-Mulvey (1981)

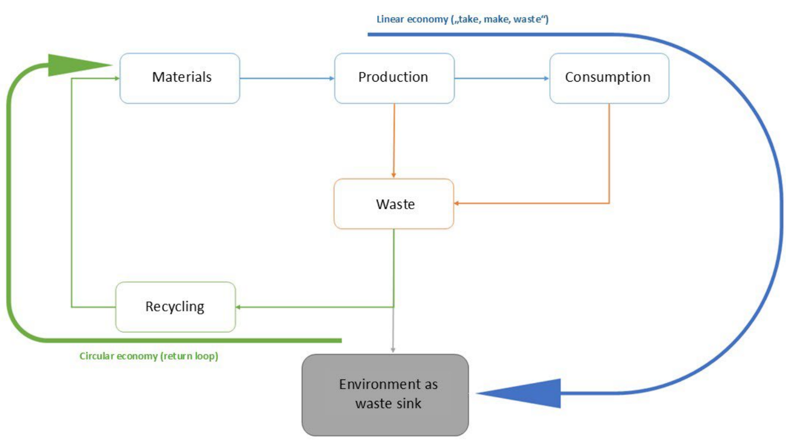


Figure 2: Conceptualization of the circular economy
Source: Pearce & Turner (1989)

In this essay, Boulding highlighted the importance of the laws of thermodynamics, particularly the concept of limited resources and energy. He emphasized the need to shift from the linear "cowboy economy", characterized mainly by unlimited resource consumption, to a "spaceship economy" in which the Earth functions as a closed system with finite amounts of resources. Boulding emphasized, as Pearce and Turner further developed in their model, that the economy and the environment are not linear and mutually separate entities, but are interconnected in a circular loop, where all resources must enter flows that can be reused. In such a system, which forms the basis of today's concept of the circular economy, each resource becomes an input for another.

After the sudden emergence of the circular economy, the idea somewhat faded for twenty years, as in the 1990s there was little research or publications on the topic (Ekins et al., 2020). The moment that sparked further research and work was the publication by McDonough and Braungart in the book *Cradle to Cradle: Remaking the Way We Make Things*. The concept of cradle-to-cradle design views the production processes of natural “biological metabolism” as models for developing a 'technical metabolism' for industrial materials. All products can be designed for continuous reprocessing and reuse as biological or technical nutrients in processes (McDonough and Braungart, 2002).

Then, in 2010, Ellen MacArthur and her organization, the Ellen MacArthur Foundation, emerged. This is the most authoritative global network on the topic of the circular economy, which has brought awareness of the circular economy to a broader public level. While the circular economy had been mostly a topic of scientific discussions for decades, Ellen MacArthur succeeded in bringing it closer to policymakers and businesses. As a result, the circular economy became an important topic on a global level. The accelerated development of the circular economy was also supported by the changing attitude of companies, where corporate social responsibility now goes beyond ecological practices and has become more of a rule than an exception. The result of their efforts was also the conceptualization of the so-called "butterfly diagram" of the circular economy, where both sides of the diagram are important for the environment.

The right side of the diagram represents the technical cycle, closing the resource loops enabled by circular strategies such as reuse, refurbishment, and recycling, while the left side of the diagram illustrates the biological cycle, with loops and cascades that ensure the sustainable management of biological resources, creating renewable flows and stocks. The ultimate goal of the circular economy economic model is to minimize the extraction of raw materials and the generation of waste as much as possible. In December 2015, the European Commission adopted and presented an ambitious new package for the circular economy, aimed at promoting Europe's transition to a circular economy that would strengthen global competitiveness, encourage sustainable economic growth, and create new jobs. This new package will help European businesses and consumers transition to a circular economy, where resources are used in a more sustainable way.

The proposed measures will contribute to "closing the loop" of product life cycles through higher rates of recycling and reuse, bringing benefits for both the environment and the economy. The plan was to promote the maximum value and use of raw materials, products, and waste, while generating energy savings and reducing greenhouse gas emissions. The proposals put forward by the European Commission cover the entire life cycle, from production and consumption to waste management and the market for secondary raw materials. The European Commission has financially supported this transition with funds from the ESIF, 650 million EUR from the Horizon 2020 program (the EU program for research and innovation), 5.5 billion EUR from structural funds for waste management, and investments in the circular economy at the national level.

This circular economy package sent a clear signal to economic actors that the EU is using all available tools to transform its economy, opening the way for new business opportunities and enhancing competitiveness. The broad measures highlighted by the European Commission go beyond a narrow focus on the product utilization rate and encompass the entire life cycle, emphasizing the European Commission's clear ambition to transform the EU economy and achieve results. Due to the incentives introduced by the European Commission, it is expected that increasingly innovative and efficient methods of production and consumption will emerge. The circular economy has the potential to create numerous jobs in Europe, while preserving valuable and increasingly scarce resources, reducing environmental impacts, and adding new value to products (European Commission, 2015). Furthermore, the European Commission prepared an updated Action Plan for the Circular Economy and presented it in early 2020, along with the European Green Deal in 2019.

2.1 Definitions of the circular economy

The circular economy is a rapidly developing field. In line with its development, various definitions of the circular economy are emerging, among which it is important to mention the definition provided by the Ellen MacArthur Foundation: "The circular economy is an industrial system that is designed to be restorative or regenerative by intention and design." The concept of "end-of-life" is replaced with restoration, shifting towards the use of renewable energy sources, eliminating the use of toxic chemicals that hinder reuse, and striving to eliminate waste through the superior design of materials, products, and systems, within which new circular business models are also developed (EMF, 2013: 7).

Table 1: Overview of the development of circular economy definitions

Št.	Authors	Content	Main findings
1	Ghisellini et al. (2016)	Summary of 155 articles on the circular economy	The circular economy requires a systemic approach, where all stakeholders (policy, public, and industry) must be involved. Policy should promote sustainable production and consumption.
2	Lieder and Rashid (2016)	Comparing the concept of circular economy and sustainability	The development of a circular economy and sustainability requires systems that include both the environment, material resources and economic contribution for all stakeholders.
3	Blomsma and Brennan (2017)	Summary of literature on the circular economy in the manufacturing industry	The circular economy serves as a catalyst for the formulation of policies and strategies for waste management and resource management, with the development of technologies in the field of industrial ecology being crucial.
4	Sauvé et al. (2016)	Explanation of the origin of the circular economy concept	The need for an interdisciplinary approach in the conceptualization of the circular economy. The issue of establishing a unified concept that would be practically feasible in the real world.
5	Murray et al. (2017)	Comparing the concept of the circular economy with environmental sciences and sustainable development	Circular economy as a tool for implementing sustainable development, developing strategies (9R), and managing resources. The main issue related to the current limitations of the concept and its contribution to the public, not just industry.
6	Geissdoerfer et al. (2017)	Comparing the concept of circular economy and sustainable business enterprise	Although sustainability and circular economy are gaining traction in academia, industry, and politics, there is no clear connection between the two

Št.	Authors	Content	Main findings
			concepts that would enable integration in the real world.
7	Lewandowski (2016)	Conceptualization of a circular business model	The circular economy is implemented by companies for financial, social, and environmental benefits. A comprehensive approach needs to be established to enable effective implementation at all levels (businesses, cities).
8	Kirchher et al. (2017)	Overview of 114 definitions of the circular economy	The need for a systemic approach is crucial for the effective implementation of the circular economy. There is often an excessive focus on economic prosperity and environmental quality, while social justice (the social aspect of sustainability) is largely neglected.
9	Kovačič Lukman et al. (2016)	The positioning of the circular economy in sustainable development	The circular economy is a tool that enables the introduction of sustainability into existing production and service processes in businesses and societal environments, primarily through comprehensive systemic approaches and global policies.

Source: Kovačič-Lukman et al. (2016)

From the images in section 1.1, it is evident that recycling (circulation) was a key element in the conceptualization of the circular economy from its very inception. Over time, however, the number of "R's" has increased. For example, the Japanese government's "3R" initiative (reduce, reuse, recycle) was launched in 2004. Furthermore, the European Commission introduced the "4R" concept (reduce, reuse, recycle, recover) in the Waste Framework Directive of 2008 – reduce, reuse, recycle, and recovery.

After reviewing 114 existing definitions at the time of their publication, Kirchherr et al. (2017) proposed an updated definition, stating: "A circular economy describes an economic system that is based on business models which replace the concept of the end-of-life with reducing, alternatively reusing, recycling, and recovering materials in production/distribution and consumption processes. These processes operate at the micro level (products, companies, consumers), meso level (eco-industrial parks), and macro level (city, region, nation, and beyond), with the aim of achieving sustainable development, which implies creating environmental quality, economic prosperity, and social equity, to the benefit of current and future generations" (Kirchherr et al., 2017, 224–225).

If we once again focus on both definitions–those by the Ellen MacArthur Foundation (EMF) and Kirchherr et al.–we can observe that the EMF definition is broadly formulated and uses terminology aligned with ecological and symbiotic ideas, which formed the foundation of the circular economy concept in its early development (Ekins et al., 2020). It is important to note that it does not mention recycling.

The definition by Kirchherr et al. (2017), on the other hand, defines the circular economy as an **economic system** (rather than merely an industrial system, as in the EMF definition) and mentions four out of the nine R-strategies. The definition includes two key components: – 1) the idea of levels, and 2) the connection to sustainable development, both of which are discussed further below. The latter is presented as the ultimate goal of the circular economy (Kirchherr et al., 2017). The latter is presented as the goal of the circular economy (Kirchherr et al., 2017). Ekins et al. (2020) argue that the definition by Kirchherr et al. (2017) is utopian, as no known economy has yet succeeded in "simultaneously creating environmental quality, economic prosperity, and social equity for the benefit of current and future generations," although they believe this should indeed be a goal for global society. Ekins et al. (2020) also identify a common shortcoming in both definitions: the absence of policy. Finally, the definition by Kirchherr et al. (2017) also identifies two factors: business models (which also appear in the EMF definition) and "responsible consumers". Furthermore, Ekins et al. (2020), in connection with this definition, refer to these as enabling factors–business models and responsible consumers–while pointing out that the main point of contention among enabling factors is policy.

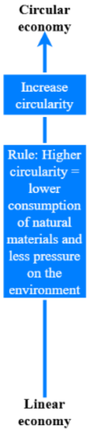
The OECD adopted a definition that focuses on the characteristics of the circular economy (McCarthy et al., 2018), identifying its key features as: increased repair and refurbishment of products, enhanced material recycling, more robust and durable products, greater remanufacturing, reuse and repair, improved material productivity, better resource utilization, and changed consumer behavior. The anticipated effects of these features are listed as: reduced demand for new goods (and virgin materials), substitution of secondary raw materials in production, an expanded secondary sector, more durable and repairable products, and a growing sharing and service economy (McCarthy et al., 2018).

2 Circular economy policies, strategies and directives

As explained by Ekins et al. (2020), public policy intervention in environmental policy, sustainable development, and the circular economy can be defined and categorized in various ways, depending on the purpose and interests of the classifier. One approach is to group interventions according to how they operate, particularly by using three broad categories that are well established in environmental policy literature and regulation:

- setting requirements or prohibitions;
- changing economic incentives and
- providing information to actors in the economy or society, on the basis of which they can make informed decisions.

These categories align and aim to address classic market failures, and they represent an important, though insufficient, set of tools for promoting radical innovations and transformations. Another approach is categorizing by sectors or stages of the value chain (or circularity strategies) that the political initiative seeks to address (or encourage), as shown in figure (4). However, such an approach can be cumbersome, as many interventions affect various sectors or elements of the value chain (Ekins et al., 2020). In 2015, the EMF published a document titled "Circular Economy Policy Makers' Guide," aimed at supporting "policy makers who have committed to transitioning to a circular economy in designing strategies to accelerate this process" (EMF, 2015: 39). Although the document is primarily intended for national policy makers, the authors emphasize that this tool is useful for policy makers at all levels, from municipal to supranational. The guide includes six categories of policy interventions (as shown in Figure 5). This categorization reflects the three categories aimed at addressing classic market failures, but it is complemented by categories of interventions that seek to further encourage and support innovations and bring them to the market.



Smarter product use and manufacture	R0 Refuse	Make product redundant by abandoning its function or by offering the same function with a radically different product.
	R1 Rethink	Make product use more intensive (e.g., by sharing product).
	R2 Reduce	Increase efficiency in product manufacture or use by consuming fewer natural resources and materials.
Extend lifespan of product and its parts	R3 Reuse	Reuse by another consumer of discarded product which is still in good condition and fulfils its original function.
	R4 Repair	Repair and maintenance of defective product so it can be used with its original function.
	R5 Refurbish	Restore and old product and bring it up to date.
	R6 Remanufacture	Use parts of discarded product in a new product with the same function.
	R7 Repurpose	Use discarded product or its parts in a new product with a different function.
Useful application of materials	R8 Recycle	Process materials to obtain the same (high grade) or lower (low grade) quality.
	R9 Recover	Incineration of material with energy recovery.

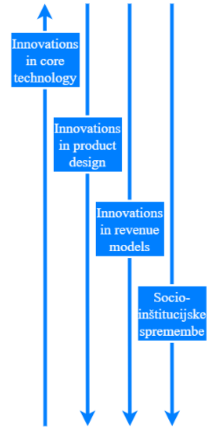


Figure 3: Circular economy strategies

Source: Potting et al. (2017)

POLICY INTERVENTION TYPES	EXAMPLES
EDUCATION, INFORMATION & AWARENESS	Integration of circular economy/systems thinking into school and university curricula.
	Public communication and information campaigns.
COLLABORATION PLATFORMS	Public-private partnership with businesses at national, regional and city level.
	Encouragement of voluntary industry collaboration platforms, encouraging value-chain and cross-sectoral initiatives and information sharing.
	R&D programmes in the fields of, for example, material sciences and biosystems.
BUSINESS SUPPORT SCHEMES	Financial support to business, for example direct subsidies, provisions of capital, financial guarantees.
	Technical support, advisory, training and demonstration of best practices to business.
PUBLIC PROCUREMENT & INFRASTRUCTURE	Public procurement.
	Public investment in infrastructure.
REGULATORY FRAMEWORKS	Government (sector) strategy and associated targets on resource productivity and circular economy.
	Product regulations, including design, extended warranties and product passports.
	Waste regulations, including collection and treatment standards and targets, the definition of waste, extended producer responsibility and take-back systems.
	Industry, consumer, competition and trade regulations, for example on food safety.
	Accounting, reporting and financial regulations including accounting for natural capital and resources, and the fiduciary duty of investors.
FISCAL FRAMEWORKS	VAT or excise duty reductions for circular products and services.
	Tax shift from labour to resources.

Figure 4: European Commission policy guidelines on the circular economy

Source: Evropska komisija (2015)

The establishment of a circular economy is a complex, multifaceted challenge that must be addressed with appropriate mixes of policies. There is no one-size-fits-all political direction, but basic policy interventions, in order to be effective, must be consistent in their implementation (both within and across governance levels), aligned with their objectives, and sufficiently credible to build trust among stakeholders in the economy (Wilts & O'Brien, 2019). Key to this is learning and disseminating lessons from past experiences, such as the OECD guidelines on resource efficiency policy (OECD, 2016a). However, in an increasingly interconnected global economy, establishing circularity at the required scale and level will involve substantial international cooperation in data and knowledge sharing, investments, and political alignment. Specifically, Geng et al. (2019) propose five priority measures to facilitate the "globalization" of the circular economy: (1) establish a global database to capture links between resource use; 2) create a global platform for knowledge exchange on the circular economy; (3) establish international alliances to promote large-scale experiments; (4) develop international standards for measuring performance, reporting, and accounting for key products; and (5) develop approaches for enforcing regulations, resolving disputes, and implementing sanctions. They suggest that these efforts should be coordinated to form an international agreement on sustainable resource management.

In line with the development of the circular economy, in 2015 the European Commission adopted its first Circular Economy Action Plan. It included measures to promote Europe's transition to a circular economy, enhance global competitiveness, foster sustainable economic growth, and create new jobs. The Action Plan outlined specific and ambitious measures covering the entire lifecycle: from production and consumption to waste management and the secondary raw materials market, as well as the revised waste legislative proposal (European Commission, 2015). It included 5 key action areas for the circular economy that needed to be restructured: production (product design, manufacturing processes), consumption, waste management, secondary resources, and supporting systems (innovation, investments, and monitoring). In line with these areas, priority sectors were established, which the European Commission specifically targeted, primarily to ensure the consideration of interactions across the entire value chain (European Commission, 2015). These were: plastic materials, food waste, critical raw materials, the construction sector, and biomaterials.

The original Action Plan was followed by the second Circular Economy Action Plan (2020), which is a key element of the European Green Deal. The European Commission anticipates that the EU's transition to a circular economy will reduce pressure on natural resources and create sustainable growth and jobs. It also sees the circular economy as a prerequisite for achieving the EU's climate neutrality goal by 2050 and halting biodiversity loss. The new action plan announces initiatives across the entire product life cycle (European Commission, 2021a). In line with the action plan, a framework policy for sustainable products was established, aimed at increasing incentives for manufacturers to transform the current linear system into a circular one, thereby reducing the environmental impact throughout the entire product life cycle (European Commission, 2020). In accordance with the provisions, the European Commission focused primarily on three specific goals: The goals included: designing sustainable products, empowering consumers and public buyers, and promoting circularity in manufacturing processes. Since the greatest impact of a product occurs during the manufacturing process, a significant portion of these provisions is directed at manufacturers within the value chains of key products, such as: electronics and ICT, batteries and vehicles, packaging, plastics, textiles, construction and buildings, as well as food, water, and nutrients (European Commission, 2020).

Recently, there has been a strong emphasis on integrating logistics and value chains into the circular economy itself. This primarily refers to reverse and green logistics. The goal of green logistics is to ensure that logistics processes are carried out correctly, while minimizing their negative impact on the natural environment as much as possible. Green logistics is a multi-level concept that includes both "green" logistics activities and social activities that support green logistics management, standardization, and reverse logistics as its subsystem (Zheng & Zhang, 2010). From the definitions of green logistics, it is clear that this concept not only serves to conserve natural resources but also ensures a connection between natural resources and products, as well as between products and consumers. It represents a tool for closing the loop in the circular economy system. Key activities of green logistics in implementing the circular economy concept include: green packaging, green transportation, storage, and material flows (Seroka-Stolka & Ociepa-Kubicka, 2019). Understanding the principles of circular economy is the first step toward understanding why it is necessary and how it is implemented in practice.

3 Life cycle analysis and LCT

To understand life cycle analysis, one must first comprehend what the life cycle actually represents and how it is considered within this context. LCT, or "Life Cycle Thinking" is an approach that seeks to define possible improvements for products and services in terms of reduced environmental impacts and lower resource use throughout all stages of the life cycle. LCT begins with raw material extraction, is maintained during production and distribution, use and/or consumption, and ends with the reuse and recycling of materials, energy recovery, and final disposal (Mazzi, 2020).

In this context, LCT aims to prevent burden shifting. In a generalized sense, this refers to reducing impacts at one stage of the life cycle in a geographical region or a specific impact category without increasing the burden elsewhere. If we return to the chapter on circular economy, a simplified example could be the production of a product where we replace energy from a thermal power plant with solar energy. Although we have reduced the burden of energy, we have increased the burden of waste solar panels, as well as the burden of their production, theoretically resulting in a reduction or increase within the product's production line. In this sense, LCT has a much broader perspective, as it needs to consider not only environmental impacts but also raw materials, materials, value chains, product use, and ultimately the effects of disposal, reuse, or recycling (Mazzi, 2020).

LCT largely relies on the theory of systems thinking, which is a methodology where the main lever is primarily a holistic approach. Value chains should not be viewed as isolated systems but rather as a collection of individual systems, with the main focus being on the interconnections and interdependencies between them. In the context of systems thinking and, consequently, LCT, the key points are the connections and interactions within the system and the external environment surrounding the system, and we consider it as a whole rather than as individual units or subsystems (Kim, 1999). In practical terms, this primarily means focusing on:

– interrelations, meaning the search for context and connections within the system or between individual components and the external environment;

- perspectives, where we recognize that each actor within and outside the system has their own unique view and opinion about the current state of the system or the situation;
- boundary setting, where we must be aware of the optimal boundaries of a system, its limitations and weights, by which we will evaluate and adjust the boundaries, and ultimately, what improvements or corrections within the system are advisable and will further enhance it.

The introduction of LCT into the circular economy offers a great opportunity for the transition from a linear to a circular system. Although there is much discussion about the implementation of circularity, it should be noted that the theoretical perspective alone does not provide sufficient evidence of the practicality of the circular economy. Authors thus support the introduction of the circular economy, while also emphasizing the need to measure and monitor its practical implementation in the economy, to ensure statistical evidence of improvements. In this regard, there is a strong emphasis on incorporating LCT into the circular economy itself, as it would provide a platform or tools to conduct both preliminary and subsequent analyses of circular activities and also gain insights into potential improvements as well as possible deterioration of the current state. This systematic approach is key to enabling further improvements (Gheewala & Silalertruksa, 2020). For this purpose, tools have been conceptually designed, among which the most well-known is "Life Cycle Analysis" (LCA).

3.1 Life Cycle Assessment (LCA)

LCA (Life Cycle Assessment) is the original and fundamental model upon which other similar models and concepts, including comprehensive LCM, have been developed and implemented. Iyyanki & Manickam (2017) define LCA as a technique for assessing the environmental aspects of a product throughout its entire life cycle, while Cowie et al. (2019) define LCA as a framework for assessing the environmental impacts of product systems and making decisions. Algren et al. (2021) understand LCA as a systematic, standardized approach to quantifying the potential environmental impacts of products or processes, from the extraction of primary raw materials to the end of the life cycle. By using LCA, organizations can gain insights into the entire life cycle of their products or processes and make more informed decisions to achieve sustainability goals. In doing so, they can contribute to reducing negative impacts on the environment and society and improve their sustainability practices.

In general, LCA includes four key stages based on the ISO standard 14040, which are as follows (Iyyanki & Manickam, 2017):

- defining boundaries, where we need to be aware of what the optimal boundaries of a system are, what the limitations and weights are, by which we will assess and adjust the boundaries, and ultimately, what improvements or adjustments within the system are meaningful and will further enhance the system;
- the first step is defining the goals and scope of the study, where we specify which stages of the product's life cycle we will include in the assessment and what the final results will be used for. This step also includes defining the criteria for system comparison and specific timeframes.
- the second step is the inventory analysis, which allows us to understand the mass and energy flows of the product system and its interactions with the environment, such as the consumption of primary raw materials and emissions. Key processes, secondary energy sources, and material flows are described in detail at this stage, which serves as the basis for further analysis;
- the third step summarizes the details from the inventory analysis and uses them to assess the environmental impacts. The results of indicators from all impact categories are described in detail at this stage, where the significance of each impact category is assessed through normalization and the assignment of weights;
- the fourth step demands the synthesis of all the aforementioned steps and includes the explanation of the life cycle, along with a critical review of the data and preparation of the presentation of results;
- by using LCA, organizations can gain insights into the entire life cycle of their products or processes and make more informed decisions to achieve sustainability goals. This helps reduce negative impacts on the environment and society, and improve their sustainable practices.

3.2 Implementing LCT/LCA in practice

By considering life cycle perspectives, organizations, governments, and society can develop products, offer services, and implement strategies, policies, and initiatives to promote the "green economy." Understanding the life cycle and expanding horizons based on the principles of this approach opens up extensive opportunities to reduce impacts on the economy, environment, and society, allowing decision-makers to make more informed choices. The use of the life cycle approach enables the selection of strategies that proactively foresee and prevent the transfer of environmental issues from one stage or phase of the life cycle to another stage or phase, to other impact categories, society, and the global level, including other countries and regions worldwide. Similar to the sustainability approach, this method also contributes to the protection and preservation of the environment for future generations (LCI, 2012).

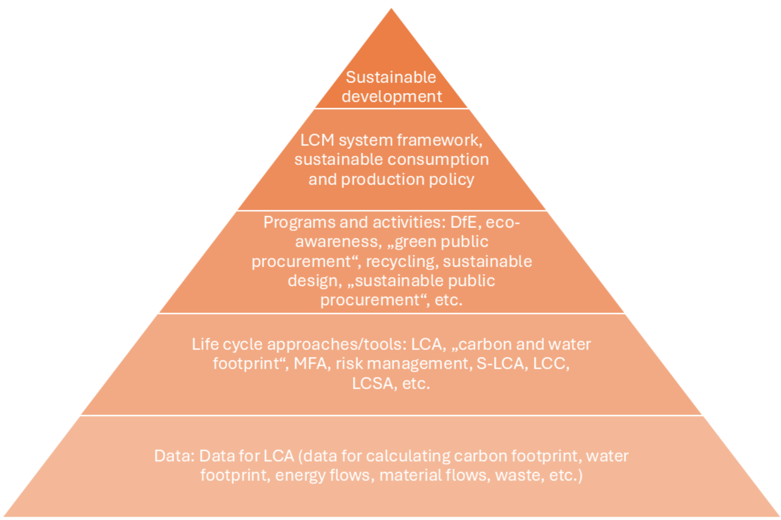


Figure 5: Schematic representation of LCT implementation in practice
Source: LCI (2022)

As mentioned, LCT represents the theoretical aspect of systems thinking or the approach to sustainable circular economy, while LCM provides practical tools, methodologies, and systems that enable the execution of measurements, analyses, and the feasibility of implementing sustainable and consequently circular activities within a selected system or product. In line with this, the LCI organization has developed a schematic approach for implementing LCT in practice, along with extensive documentation that describes all the steps, procedures, and methodologies for successful execution.

LCT largely follows the methodology provided for the implementation of other LCA analyses. The presented scheme shows only the key reference points for execution, while the actual methodology for conducting LCA analyses is much more extensive, and it is recommended that it is read thoroughly before beginning the analysis. As mentioned numerous times in the previous subsections, LCA analyses are only meaningful if they are correctly conducted, with data collected systematically and comprehensively reviewed and verified, and the analysis conducted according to pre-qualified methods and methodologies provided by organizations in the field of LCA techniques (LCI, 2012).

The integration of LCT and the circular economy enables a holistic approach to achieving sustainable development. The circular economy represents a new type of economic concept, which is gradually being introduced in certain sectors of the economy and is already being implemented in practice. On the other hand, LCT is an approach that guides us toward sustainable thinking in the current economy and is more theoretical in nature, as it is not yet as widely implemented in practice. The key connection between both concepts is that the circular economy introduces concrete and practical changes, while LCT allows us to verify and assess the effectiveness of the implementation of circular practices. By using LCT, we can evaluate how successfully we have implemented circular practices and assess their impact on the product or service lifecycle. LCT enables us to examine the current state and identify areas where it would be most meaningful to introduce circular approaches to achieve more sustainable outcomes (LCANZ, 2020).

By combining the circular economy and LCT, we can make progress toward a sustainable society. The circular economy introduces practical changes based on sustainability principles, while LCT enables a comprehensive analysis and assessment of the effectiveness of these changes. By combining knowledge of the lifecycle and sustainable development, we can achieve a holistic approach to creating a more sustainable future. This enables better planning, more thoughtful decisions, and more efficient use of resources, which is crucial for creating a more sustainable and responsible society. This ensures that products, services, and strategies are directed toward sustainable development and contribute to the protection of our planet and the well-being of all.

References

Algren, M., Fisher, W., & Landis, A. E. (2021). Machine learning in life cycle assessment. V J. Dunn, & P. Balaprakash, Data Science Applied to Sustainability Analysis (str. 167-190). Amsterdam: Elsevier. doi:10.1016/B978-0-12-817976-5.00009-7

Blomsma, F., & Brennan, G. (2017). The Emergence of Circular Economy: A New Framing Around Prolonging Resource Productivity. Journal of Industrial Ecology, Vol. 21, 603-614.

Boulding, E. K. (1956). General Systems Theory--The Skeleton of Science. Management Science, 2(3), 197-208. doi:http://dx.doi.org/10.1287/mnsc.2.3.197

Boulding, E. K. (1966). The Economics of the Coming Spaceship Earth. In *H. Jarrett (Ed.), Environmental Quality in a Growing Economy* (pp. 3-14). Baltimore: Johns Hopkins University Press.

Cowie, A. L., Brandao, M., & Soimakallio, S. (2019). Quantifying the climate effects of forest-based bioenergy. V T. M. Letcher, Managing Global Warming An Interface of Technology and Human Issues (str. 399-418). Cambridge: Academic Press. doi:https://doi.org/10.1016/B978-0-12-814104-5.00013-2

EC. (2016). Buying green! A handbook on green public procurement. Bruselj: Evropska Unija. doi: 10.2779/246106

Ekins, P., Domenech, T., Drummond, P., Bleischwitz, R., Hughes, N., & Lotti, L. (2019). "The Circular Economy: What, Why, How and Where?". Paris: OECD. Pridobljeno iz https://www.oecd.org/cfe/regionaldevelopment/Ekins-2019-Circular-Economy-What-Why-How-Where.pdf

Ellen MacArthur. (2017). A new Textiles Economy: Redesigning fashion's future. Cowes: Ellen MacArthur.

EMF. (2013). Towards the Circular Economy Vol. 1: an economic and business rationale for an accelerated transition. Cowes: Ellen MacArthuer Foundation.

EMF. (2015). Delivering the Circular Economy: A Toolkit for Policymakers. Cowes: Ellen MacArthur Foundation.

European Commission. (15.. Januar 2015). Closing the loop: Commission adopts ambitious new Circular Economy Package to boost competitiveness, create jobs and generate sustainable growth [Press Release]. Pridobljeno iz EC: https://ec.europa.eu/commission/presscorner/detail/en/IP_15_6203

Evropska komisija. (11.3.2020). COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS A new Circular Economy Action Plan For a cleaner and more competitive Europe (COM(2020) 98 final izd.). Bruselj: European Commission.

Evropska komisija. (2.12.2015). COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS Closing the loop - An EU action plan for the Circular Economy (COM(2015) 614 final izd.). Bruselj: European Commission.

Evropska komisija. (2021). Critical raw materials. Pridobljeno 18. januar 2022 iz European Commission: https://ec.europa.eu/growth/sectors/raw-materials/areas-specific-interest/critical-raw-materials_en

Evropska komisija. (2021a). Circular economy action plan. Pridobljeno 18. januar 2022 iz European Commission: https://ec.europa.eu/environment/strategy/circular-economy-action-plan_en

Geissdoerfer, M., Savaget, P., Bocken, N. M. P., & Hultink, E. J. (2017). The Circular Economy – A new sustainability paradigm? *Journal of Cleaner Production*, 143, 757-768. https://doi.org/10.1016/j.jclepro.2016.12.048

Geng, Y., Sarkis, J., & Bleischwitz, R. (2019). How to globalize the circular economy. Nature, 565, str. 153-155. doi:https://doi.org/10.1038/d41586-019-00017-z

Gheewala, S. H., & Silalertruksa, T. (2020). Life Cycle Thinking in a Circular Economy. V An Introduction to Circular Economy, str. 35-53. Singapur: Springer. https://doi.org/10.1007/978-981-15-8510-4_3

Ghisellini, P., Cialani, C., & Ulgiati, S. (2016). A review on circular economy: the expected transition to a balanced interplay of environmental and economic systems. Journal of Cleaner Production, Vol. 114, 11-32.

ISO 14040 International Standard. (2006). Environmental management-Life cycle assessment - Principles and framework;. Ženeva: International Organization for Standardization.

ISO 14044 International Standard. (2006). Environmentalmanagement- Life cycle assessment - Requirements and guidelines. Ženeva: International Organization for Standardization.

Iyyanki, M., & Manickam, V. (2017). Life Cycle Assessment. V M. Iyyanki, & V. Manickam, Environmental Management: Science and Engineering for Industry (str. 57-75). Oxford: Butterworth-Heinemann. doi:https://doi.org/10.1016/B978-0-12-811989-1.00005-1

Kim, D. H. (1999). Introduction to Systems Thinking. Waltham: Pegasus Communications .

Kirchher, J., Reike, D., & Hekkert, M. (2017). Conceptualizing the circular economy: An analysis of 114 definitions. Resources, Conservation and Recycling, 127, 221-232. doi:https://doi.org/10.1016/j.resconrec.2017.09.005

Kovačič Lukman, R., Glavič, P., Carpenter, A., & Virtič, P. (2016). Sustainable consumption and production – Research, experience, and development – The Europe we want. Journal of Cleaner Production, 138(2), str. 139-147. https://doi.org/10.1016/j.jclepro.2016.08.049

LCANZ. (2020). LCA, LCT and transitioning to a Circular Economy. Wellington: LCANZ.

LCI. (2012). Greening the Economy Through Life Cycle Thinking - Ten Years of the UNEP/SETAC Life Cycle Initiative. Nairobi: UNEP.

LCI. (2022). Life Cycle Management. Pridobljeno 8. januar 2022 iz Life Cycle Initiative: https://www.lifecycleinitiative.org/starting-life-cycle-thinking/life-cycle-approaches/life-cycle-management/

Lewandowski, M. (2016). Designing the Business Models for Circular Economy–Towards the Conceptual Framework. Sustainability, 8(1), 43. https://doi.org/10.3390/su8010043

Mazzi, A. (2020). Chapter 1 - Introduction. Life cycle thinking. V Life Cycle Sustainability Assessment for Decision-Making, str. 1-19. https://doi.org/10.1016/B978-0-12-818355-7.00001-4

McDonough, W., & Braungart, M. (2002). Cradle to Cradle: Remaking the Way We Make Things. New York: North Point Press.

Meadows, D. H., Meadows, D. L., Randers, J., Behrens, W., & Club of Rome. (1972). The limits to growth: A report for the Club of Rome`s project on the predicament of mankind. New York: Universe Books.

Murray, A., Skene, K., & Haynes, K. (2017). The Circular Economy: An Interdisciplinary Exploration of the Concept and Application in a Global Context. *Journal of Business Ethics*, 140(3), 369-380. https://doi.org/10.1007/s10551-016-3174-3

OECD. (2016a). Policy Guidance on Resource Efficiency. Pariz: OECD Publishing. doi:https://dx.doi.org/10.1787/9789264257344-en

Pearce, D. W., & Turner, R. K. (1990). Economics of Natural Resources and the Environment. Baltimore: John Hopkins University Press.

Potting, J., Hekkert, M., Worrell, E., & Hanemaaijer, A. (2017). Circular economy: Measuring innovation in the product chain. The Hague: PBL Netherlands Environmental Assessment Agency. Pridobljeno iz https://www.pbl.nl/sites/default/files/downloads/pbl-2016-circular-economy-measuring-innovation-in-product-chains-2544.pdf

Reday-Mulvey, G., & Stahel, W. R. (1977). The potential for substituting manpower for energy : final report 30 July 1977 for the Commission of the European Communities. Geneva: Bastelle, Geneva Reseach Centre.

Seroka-Stolka, O., & Ociepa-Kubicka, A. (2019). Green logistics and circular economy. Transportation Research Procedia, 39, 471-479. doi:https://doi.org/10.1016/j.trpro.2019.06.049

Stahel, W. R., & Reday-Mulvey, G. (1981). Jobs for tomorrow : the potential for substituting manpower for energy. New York: Vantage Press.

Wilts, H., & O'Brien, M. (2019). A Policy Mix for Resource Efficiency in the EU: Key Instruments, Challenges and Research Needs. Ecological Economics, 155, 59-69. doi:https://doi.org/10.1016/j.ecolecon.2018.05.004

Zheng, L., & Zhang, J. (2010). Research on green logistics system based on circular economy. Asian Social Science, 6(11). doi:10.5539/ass.v6n11p116

Integration of Eco-design in Supply Chain Management

DOI
https://doi.org/10.18690/um.fl.4.2026.6

ISBN
978-961-299-100-5

Matevž Obrecht
University of Maribor, Faculty of Logistics, Celje, Slovenia
matevz.obrecht@um.si

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.

Keywords:
eco-design,
sustainable development,
cleaner production,
sustainable supply chain,
green organization

University of Maribor Press

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).

ISSUE	Source	Transport	Manufacture	Packaging	Distribution	Use	End of Life
Materials							
Energy							
Water							
Waste							
Pollution of air, water and land							
Social							

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.

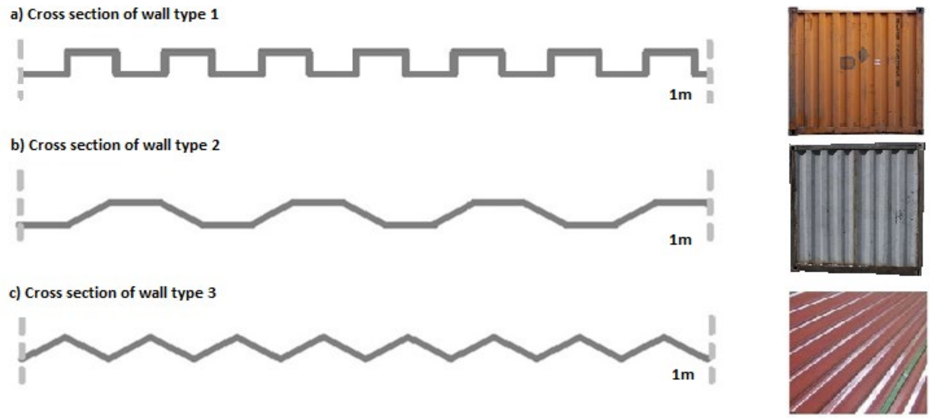


Figure 2: Cross-sections and images of the three types of container walls examined
Source: (Obrecht & Knez, 2017)

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.

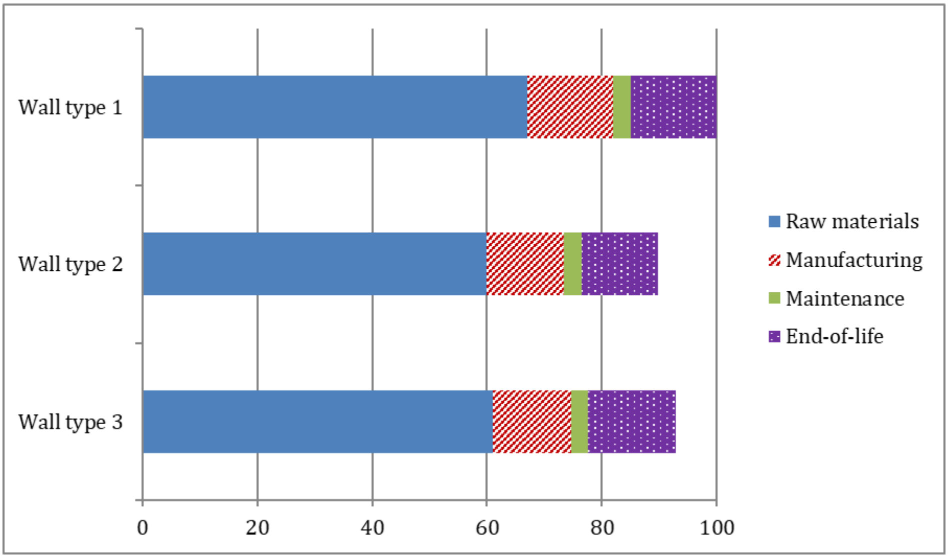


Figure 3: Comparison of the relative GWP of different studied container wall types
Source: (Obrecht & Knez, 2017)

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 m^2 or 4.86 m^2 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 CO_2 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 CO_2 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 CO_2 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 CO_2 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

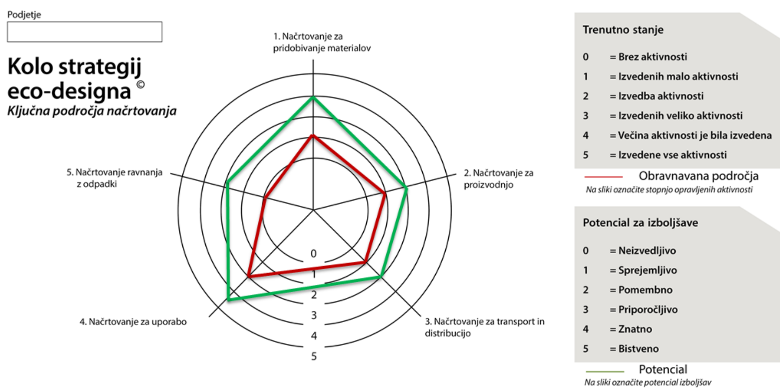


Figure 4: Graphical representation of key strategies for planning improvements
Source: (Maribor Development Agency & Enterprise Europe Network, 2013; Obrecht, 2010)

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.

References

Albino, V., Balice, A., & Dangelico, R. M. (2009). Environmental strategies and green product development: An overview on sustainability-driven companies. *Business Strategy and the Environment*, *18*(2), 83–96. https://doi.org/10.1002/bse.638

Alexandratos, N., & Bruinsma, J. (2012). *World Agriculture Towards 2030/2050: The 2012 Revision*.

Ammenberg, J., & Sundin, E. (2005). Products in environmental management systems: Drivers, barriers and experiences. *Journal of Cleaner Production*, *13*(4), 405–415. https://doi.org/10.1016/j.jclepro.2003.12.005

Andriankaja, H., Vallet, F., Le Duigou, J., & Eynard, B. (2015). A method to ecodesign structural parts in the transport sector based on product life cycle management. *Journal of Cleaner Production*, *94*, 165–176. https://doi.org/10.1016/j.jclepro.2015.02.026

Annunziata, E., Testa, F., Iraldo, F., & Frey, M. (2016). Environmental responsibility in building design: An Italian regional study. *Journal of Cleaner Production*, *112*, 639–648. https://doi.org/10.1016/j.jclepro.2015.07.137

Bešter, J. (2017). *Economically efficient circular economy*. Institute for economic research.

Brezet, H., Hemel, C. van, & Instituut, R. (1997). *Ecodesign: A Promising Approach to Sustainable Production and Consumption*. United Nations Environment Programme, Industry and Environment, Cleaner Production.

Dangelico, R. M., Pujari, D., & Pontrandolfo, P. (2017). Green Product Innovation in Manufacturing Firms: A Sustainability-Oriented Dynamic Capability Perspective. *Business Strategy and the Environment*, *26*(4), 490–506. https://doi.org/10.1002/bse.1932

Dekoninck, E. A., Domingo, L., O'Hare, J. A., Pigosso, D. C. A., Reyes, T., & Troussier, N. (2016). Defining the challenges for ecodesign implementation in companies: Development and consolidation of a framework. *Journal of Cleaner Production*, *135*, 410–425. https://doi.org/10.1016/j.jclepro.2016.06.045

Denac, M., Obrecht, M., & Radonjič, G. (2018). Current and potential ecodesign integration in small and medium enterprises: Construction and related industries. *Business Strategy and the Environment*, *27*(7), 825–837. https://doi.org/10.1002/bse.2034

European Commission. (2014). *Towards a circular economy: A zero waste programme for Europe*. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52014DC0398

Gerrard, J., & Kandlikar, M. (2007). Is European end-of-life vehicle legislation living up to expectations? Assessing the impact of the ELV Directive on 'green' innovation and vehicle recovery. *Journal of Cleaner Production*, *15*(1), 17–27. https://doi.org/10.1016/j.jclepro.2005.06.004

International Energy Agency. (2009). *World Energy Outlook 2017 – Executive Summary*. IEA. https://www.iea.org/publications/freepublications/publication/WorldEnergyOutlook2016 ExecutiveSummaryEnglish.pdf

Johansson, G. (2002). Success factors for integration of ecodesign in product development: A review of state of the art. *Environmental Management and Health*, *13*(1), 98–107. https://doi.org/10.1108/09566160210417868

Maribor Development Agency, & Enterprise Europe Network. (2013). *Ecodesign – environmentally friendly design in construction industry*. MRA.

Miedzinski, M., Charter, M., Doranova, A., Castel, J., & Roman, L. (2013). *Eco-Innovate! A Guide to Eco-innovation for SMEs and Business Coaches*. https://doi.org/10.13140/RG.2.1.4107.3048

Niinimäki, K. (2006). Ecodesign and Textiles. *Research Journal of Textile and Apparel*, *10*(3), 67–75. https://doi.org/10.1108/RJTA-10-03-2006-B009

Obrecht, M. (2010). *Ecodesign of buildings*. Faculty of Economics and Business.

Obrecht, M., & Knez, M. (2017). Carbon and resource savings of different cargo container designs. *Journal of Cleaner Production*, *155*, 151–156. https://doi.org/10.1016/j.jclepro.2016.11.076

Plouffe, S., Lanoie, P., Berneman, C., & Vernier, M.-F. (2011). Economic benefits tied to ecodesign. *Journal of Cleaner Production*, *19*(6), 573–579. https://doi.org/10.1016/j.jclepro.2010.12.003

Prendeville, S., & Bocken, N. (2015). *Design for Remanufacturing and Circular Business Models*.

Szegedi, Z., Gabriel, M., & Papp, I. (2017). Green supply chain awareness in the hungarian automotive industry. *Polish Journal of Management Studies*, *16*, 259–268. https://doi.org/10.17512/pjms.2017.16.1.22

Širec, K., Hojnik, B. B., Denac, M., & Močnik, D. (2018). *Slovenska podjetja in krožno gospodarstvo: Slovenski podjetniški observatorij 2017*. Univerzitetna založba Univerze.

The 2030 Water Resource Group. (2009). *Charting Our Water Future Economic Frameworks to Inform Decision-making*. McKinsey. https://www.mckinsey.com/capabilities/sustainability/our-insights/charting-our-water-future

UNEP. (2017). *Life cycle management: A business guide to sustainability*. UNEP. http://www.unep.org/resources/report/life-cycle-management-business-guide-sustainability

van Hemel, C., & Cramer, J. (2002). Barriers and stimuli for ecodesign in SMEs. *Journal of Cleaner Production*, *10*(5), 439–453. https://doi.org/10.1016/S0959-6526(02)00013-6

Verghese, K., Lewis, H., & Fitzpatrick, L. (2012). *Packaging for Sustainability*. https://doi.org/10.1007/978-0-85729-988-8

Wong, S. K. S. (2013). Environmental Requirements, Knowledge Sharing and Green Innovation: Empirical Evidence from the Electronics Industry in China. *Business Strategy and the Environment*, *22*(5), 321–338. https://doi.org/10.1002/bse.1746

SUSTAINABLE ENERGY SELF-SUFFICIENCY

MATEVŽ OBRECHT, MARTIN FALE
University of Maribor, Faculty of Logistics, Celje, Slovenia
matevz.obrecht@um.si, martin.fale1@um.si

Energy self-sufficiency means that we are capable of generating enough electrical energy on a micro-level to power all systems that require electricity to operate. Solar power can be used to generate electrical energy. Through these devices, we convert solar energy into electrical energy. If we cannot store the excess electricity produced, we feed it back into the electrical grid. Since solar power plants cannot provide continuous production, we either need to store excess electrical energy or obtain the missing energy from the electrical grid. For storage, we require energy storage systems, such as batteries. A battery pack from electric vehicles can also be used as an energy storage system. By managing these storage systems, we can regulate the daily demand for electrical energy on a micro-level. Through an energy marketplace, we can trade electricity and manage the generated electrical energy of the micro-location. Combining a solar power plant with a heat pump on a micro-level can create a fully self-sufficient energy system for the micro-location, capable of operating independently of the electrical grid.

DOI
https://doi.org/10.18690/um.fl.4.2026.7

ISBN
978-961-299-100-5

Keywords:
energy self-sufficiency,
battery storage systems,
solar power plants,
smart grid,
energy management•

University of Maribor Press

1 Sustainable electricity management

1.1 Presentation of the environment

The need for electricity is growing. In Slovenia, final energy consumption is 82 kWh per capita per day, of which 33 kWh is used for transport, 28 kWh for heating households and industry, and 20 kWh for electricity for households and industry (GEN Group, 2025a). The largest share of energy in households and the public sector is used for heating. The largest energy consumers in the public sector are educational institutions and student dormitories, as well as health and social care institutions. Most of the energy in transport is used for driving, with more than 60% for driving in passenger cars (GEN Group, 2025b).

Electricity can be produced using fossil fuels, nuclear reactors or renewable energy sources. Fossil fuels are dominated by gas and coal, while renewable energy sources include wind, hydropower and the sun. Renewable energy sources are those sources that are obtained from natural processes and are renewed as a result of natural processes or human activity. They can then be used again to produce energy (Lucey, 2023; GEN Group, 2025d). In Slovenia, approximately the same share of electricity is produced in nuclear power plants, thermal power plants and hydroelectric power plants, while other renewable sources, mainly solar power plants, account for a smaller share (GEN Group, 2025c).

The electricity produced is traded on energy exchanges. The price of electricity is determined based on the most expensive energy source (currently gas), taking into account the principle of the order of economy. The cheapest electricity is sold first. This is electricity produced from renewable sources. If this electricity is not enough, electricity is sold from other, more expensive sources of electricity, such as gas-fired power plants or thermal power plants. However, electricity is not sold at a price according to the production source, but according to the price of the most expensive method of electricity production (Consilium, 2023). Therefore, distribution companies can generate significant profits by selling electricity generated from cheaper sources of electricity, especially from renewable sources. Energy self-sufficiency eliminates dependence on energy imports, which reduces the potential negative consequences of energy supply, especially price fluctuations in the market.

Energy self-sufficiency means the ability of an area to meet its energy needs on its own and thus not depend on energy imports from surrounding areas. A self-sufficient area has the capacity to produce and distribute energy to end users. It is important to highlight the rarity of areas that have all the types of energy we need. Energy sources are unevenly distributed, so there are differences between areas in the presence of different energy sources, which means that we have to obtain the necessary energy from elsewhere. Energy self-sufficiency partially eliminates losses that occur when transmitting energy through the distribution network (Lucey, 2023; Iberdrola, 2025).

1.2 Energy pyramid

Sustainable electricity management consists of several steps. Let's illustrate this with an energy pyramid. The first step is to use electricity more wisely. Reducing electricity consumption costs us nothing and the thoughtful use of electrical devices can bring us savings. The next step is energy efficiency. By replacing and installing more energy-efficient technological options, we achieve savings in electricity consumption. Here, the electricity savings are greater than when reducing electricity consumption. The top of the pyramid is the use of renewable sources to generate electricity, e.g. installing a solar power plant on a micro-location (see Figure 1) (comorinsolar.com, b. d.).

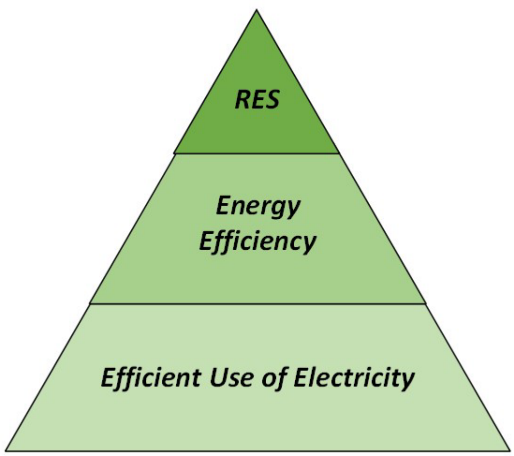


Figure 1: Energy pyramid diagram
Source: own

1.3 Energy management

Energy management allows us to manage electricity to reduce electricity costs by monitoring electricity consumption. Monitoring electricity consumption is enabled by built-in electricity meters. Electricity meters allow remote reading and thus monitoring consumption remotely, which can be used in energy management (Energy card, n. d.).

Since the production of electricity by solar power plants is influenced by the strength of the sun, the amount of energy produced cannot be adjusted to our daily needs. During the illuminated part of the day, there may be a surplus of electricity, but when the strength of the sun is lower or it is night, there is no electricity production by solar power plants. We obtain the missing electricity for our needs from the electricity grid. The excess amount of electricity is transferred to the ownership of the electricity company, and some suppliers also buy it (see Figure 2) (Pi-solarus, b. d.; termoshop.si, 2023).

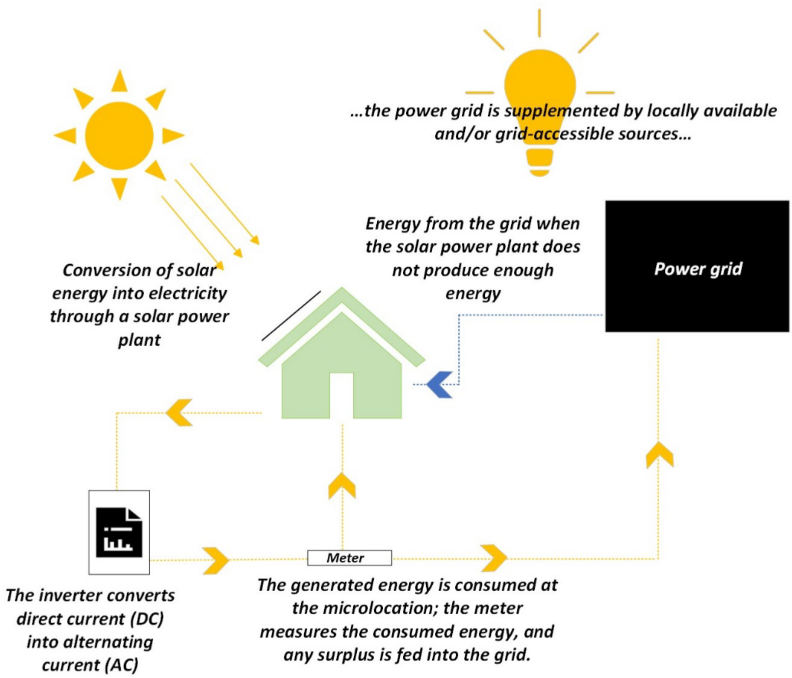


Figure 2: Management of generated electricity

Source: own

However, other options for managing excess electricity production are also used. Excess electricity produced by solar power plants can be transferred to another point of consumption in the network, or transferred to oneself for future use. Electricity can be transferred as kilowatt hours or as a percentage of the electricity produced (suncontract.org, 2023a). This allows several micro-locations to be combined into their own, self-sufficient system. For example, excess electricity generated in a holiday home in a solar-powered location can be used to charge a battery-powered electric vehicle at home. This way of managing excess electricity generation offers the potential to reduce electricity costs for consumers and increase revenue by selling electricity to producers without intermediaries (suncontract.org, 2023b).

Excess electricity management systems offer business customers the opportunity to buy or sell electricity at prices that change every hour, and users can also check electricity prices after auction trading for the day ahead (NGEN, b. d.a). They also offer users the opportunity to include electricity storage in the trading, which gives customers more options to buy electricity when it is cheap or to store generated electricity for later use (NGEN, b. d.b).

1.4 Smart grid

A smart grid is one that is able to balance production and demand on a daily basis. If we focus on electricity production during the day, we can see that more electricity is produced during the sunny part of the day, as shown in green in Figure 4. When solar radiation is optimal, we produce much more electricity from solar power plants than when it is cloudy. Given increased wind speed or higher river flows, we can produce more electricity through wind farms or hydroelectric power plants than we planned. Of course, the opposite is true when there is no wind or a drought. This leads to fluctuations in electricity production, which can contribute to a surplus or shortage of electricity at certain times of the day. In the event of a surplus, we need to store this energy, if possible. In case of shortage, outages can occur. Regarding consumption, which is shown in gray in Figure 4, we can highlight: household consumption is higher in the morning and evening than during the day when we are at work or school. Here we have the greatest shortage of electricity generated in the illuminated part of the day, as can be seen in Figure 4. The missing energy during the dark part of the day must be provided by the electricity grid from electricity storage or other continuously operating production sources, which is shown in red in Figure 3. The goal of the smart grid is that we will consume surplus electricity during the day, which has previously remained unused at a certain time, and thus eliminate excess demand when electricity production is less than current needs (see Figure 3 and Figure 4) (Let's Talk Science, 2019; Partlin, 2021; Ekart, 2023b).

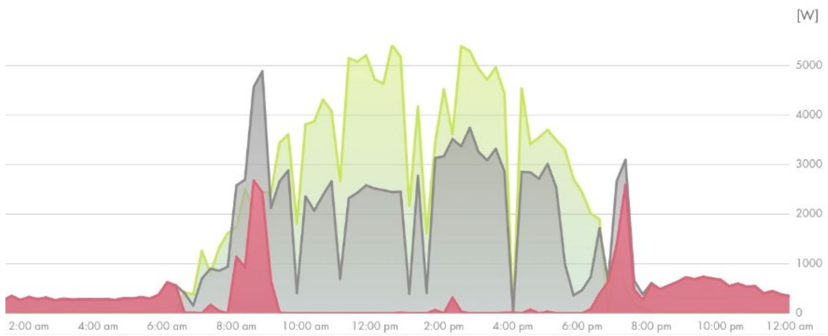


Figure 3: Display of fluctuations in electricity consumption over time
Source: Partlin, 2021.

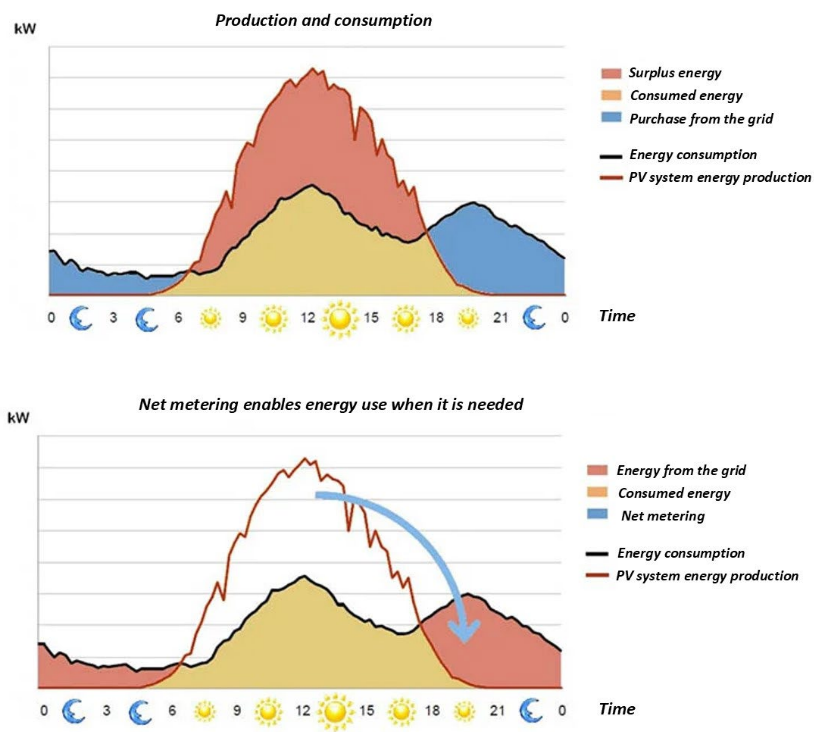


Figure 4: Demonstration of the concept of self-sufficiency in electricity
Source: Ekart, 2023b.

Self-sufficiency in electricity[1] is possible with a meter that can be rotated in both directions. At night, it measures the electricity used from the electricity grid, and during the day, it subtracts the electricity that is sent to the grid via the solar power plant. Self-sufficiency allows us to either send excess electricity to the grid or withdraw electricity from the grid (see Figure 4) (Ekart, 2023b).

1.5 Sustainable energy cycle

Renewable sources of electricity generation are not currently a reliable source of electricity production. Storing all electricity generated from renewable sources is not financially viable due to the high cost of large storage facilities. The sustainable energy cycle increases the possibility of using renewable energy sources in the electricity grid through electricity storage at micro-locations themselves. Each new battery electric vehicle or plug-in hybrid represents a new reservoir of electricity and provides us with a new location that can be used to store electricity and thus regulate electricity demand. In a sustainable energy cycle, this battery electric vehicle or plug-in hybrid becomes part of the electricity grid, capable of regulating both surpluses and deficits of electricity. Surplus energy can be stored in these electric vehicles or in a storage tank in the house, and when demand on the electricity grid increases, this stored electricity can be redirected from these micro-locations back to the grid to other consumers. The Metron Institute states that most of the battery capacity of these electric vehicles remains unused, as these vehicles are only used to cover short distances during the week. The use of "Vehicle-to-Grid" technology allows us to use the unused capacity of the battery pack in the vehicle to mitigate increased demand on the electricity grid and store surpluses. A larger number of micro-locations in the power system significantly increases the ability to store electricity generated from renewable energy sources. A group of micro-locations can also operate independently of the electricity distribution system as a stand-alone unit that can generate electricity from renewable sources and store it at micro-locations nearby until it is used (see Figure 5) (eauto.si, n. d.; Hanley, 2021).

[1]English Net Metering.

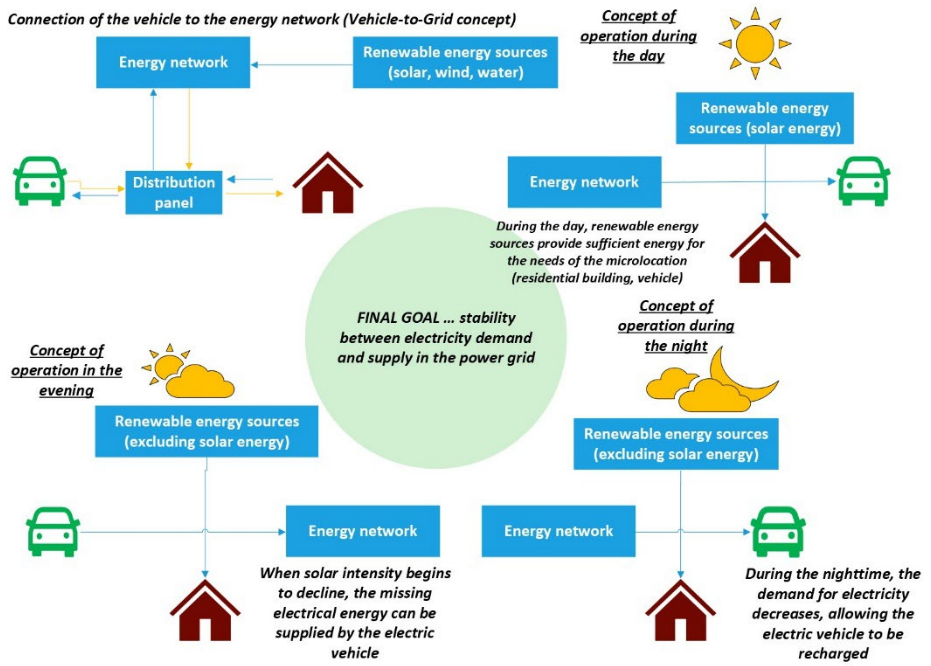


Figure 5: Vehicle-to-Grid (V2G, also P2X) concept
Source: own

2 Solar power plants

2.1 Definition of solar power plant

A solar power plant or photovoltaic system converts solar energy into electrical energy. We know photovoltaic solar power plants and thermal solar power plants. A photovoltaic solar power plant converts solar radiation into electrical energy. Through semiconductor materials, e.g. silicon, an electrical voltage is generated in the solar cell of the photovoltaic module, which drives the electric current. Such solar power plants have a low efficiency, somewhere between 10% and 20%. The most advanced systems achieve an efficiency of 25% (energija-solar.si, b. d.). The maximum efficiency of such a system is 60%. If we want to achieve the best possible performance of a solar power plant, the location must be taken into account during installation, i.e. where we intend to place the solar power plant. The chosen location should be as sunny as possible. Incorrect orientation and inclination of the solar power plant and possible shading in the surrounding area reduce the production of electricity. It is recommended that solar power plants be oriented towards the south, installed at an angle of 30° (trajnostnaenergija.si, p. d.). The photovoltaic module also works in cloudy weather, but the amount of electricity produced is lower (Fraile, Latour, El Gammail, Annett & Nemac, p. d., p. 3). In a thermal solar power plant, electricity is produced by concentrating solar energy into a substance, which then drives a turbine and produces electricity through the turbine. The operating principle of thermal solar power plants is the same as that of thermal power plants, except that instead of burning coal, solar energy is used to produce electricity (GEN Group, 2023).

2.2 Types of solar power plants

There are several types of solar power plants depending on the location of installation. Home solar power plants connected to the electricity grid generate electricity through modules installed on residential buildings (Valenčič, 2022). A direct connection to the grid allows for the sale of surpluses, and in the event of a shortage of electricity, it can be taken or purchased from the grid. Stand-alone solar power plants connected to the electricity grid produce larger amounts of electricity and are much larger than home solar power plants. They are installed on larger areas to make better use of space. Island systems for electrification of remote areas are intended for areas where there is no electricity grid. Such a system is supported by batteries for storing electricity and can supply electricity to a single facility or combine several locations into a smaller independent network. In hybrid systems, a solar power plant is combined with another energy source to provide an uninterrupted supply of electricity. Solar power plants on finished products are used on electrical appliances themselves and provide all or part of the energy needed to operate the electrical appliance. Island industrial plants are used to supply electricity to areas that are very far from the electricity grid. This eliminates the high costs of building a new electricity grid (Fraile, Latour, El Gammail, Annett & Nemac, b. d., pp. 10-11). Possible locations for the installation of individual types of solar power plants are listed in Table 1.

Table 1: Installation locations of individual types of solar power plants

Type of solar power plant	Installation locations
Home solar power plants	Roofs, exterior walls, facades and balconies of residential buildings, window blinds.
Standalone solar power plants	Roofs of larger industrial facilities or public buildings, in the area of airports or railway stations.
Island systems for electrification of remote areas	In all areas where there is no electricity network, mountain huts.
Hybrid systems	In wind turbines, next to generators.
Island power plants on finished products	Watches, pocket computers, toys, battery chargers, vehicles, traffic signs, lights, parking meters, telephone booths.
Island industrial facilities	Mobile communication poles, traffic signals, marine navigation, remote lighting, water treatment plants.

Source: Fraile, Latour, El Gammail, Annett & German, b. d., p. 10-11.

2.3 Advantages and disadvantages of using solar power plants

The advantages of using solar power plants are low operating costs, no noise pollution, and no emission of greenhouse gases during operation. They also enable distributed production, as collectors can be installed on individual devices that require electricity to operate, so there is no need for the consumer to be close to the power grid. While one of the advantages is low operating costs, a major disadvantage is high investment costs. The reliability of solar energy as an energy source should also be highlighted. The production of electricity with solar power plants depends on the amount of solar radiation, so there is a high probability that the production of electricity with solar power plants alone will not meet the demand for electricity (GEN Group, 2023). The use of solar energy is not limited to the production of electricity, as it can also be used for hot water preparation and space heating (trjanostnaenergija.si, b. d.). Due to their modular design, solar power plants can be upgraded to increase their capacity due to increased electricity demand, e.g. by installing a charging station for a battery electric vehicle or a heat pump (termoshop.si, 2023). Solar power plant modules can be recycled and reused in the production of photovoltaic modules. This closes the life cycle of photovoltaic modules (trajnostnaenergija.si, b. d.).

With every investment, we are interested in the payback period. This also applies to solar power plants. We have tools available to calculate the electricity savings and the time when the investment in a solar power plant will be paid back. For example, for a 100 m2 roof, the investment in a solar power plant with a power of 6.72 kW will be paid back in 6.5 years. If we currently pay an average of 70 EUR per month for electricity, in 30 years, the lifespan of a solar power plant, by installing it we save 7,669 EUR on the average monthly cost of electricity (vrhunskaemobilnost.si, b. d.).

2.4 Challenges in integrating solar power plants

The promotion of solar power plant installation by the state and solar power plant providers has encountered a major obstacle, specifically the capacity of the existing distribution network. As a result, distribution companies are rejecting applications for the installation of solar power plants. The introduction of the net metering system in 2016 has led to a tremendous increase in interest in the installation of solar power plants, as households have been able to significantly reduce their electricity costs by installing a solar power plant. Among other things, they were exempted from paying network fees, although solar power plant owners still use the distribution network both to send excess electricity produced and to receive electricity from the distribution network when production at the micro-location does not meet current demand (Zgonik, 2023).

Another problem is that solar power plants are oversized for household needs, which has actually led to an increase in household electricity consumption due to the desire to send as little surplus electricity as possible to the distribution network. As a result, households have started to combine a solar power plant with a heat pump or a charging station for electric vehicles in order to purchase such a vehicle. The problem with this way of thinking occurs during the period of the year when production is lower. Due to the installation of additional electricity consumers, households require even more electricity from the distribution network, which increases the need for electricity. Industry solves this problem by installing energy storage systems, and the advantage for industry is also the organization of the work process, which is adjusted to the part of the day when electricity production is highest. Greater self-sufficiency of industry also means less strain on the distribution network. The importance of incentives for the installation of solar power plants should also be emphasized. The net metering system has revived interest in the installation of solar power plants, which had completely died out after the abolition of state subsidies (Zgonik, 2023).

2.5 Projections for the implementation of solar power plants by 2050

As part of the LIFE Climate Path 2050 project, a study was conducted to determine the potential of rooftop solar power plants in Slovenia by 2050. To model the potential of solar power plants, data on insolation were used, broken down by the following factors: local units; an assessment of the share of available areas for the installation of solar power plants, which included existing buildings, parking lots and degraded environments suitable for the installation of solar power plants; an assessment of the impact of climate change due to rising average temperatures; an assessment of economic parameters and an assessment of other impacts on the operation of solar power plants, e.g. increasing the efficiency of solar panels due to technological advances. The research found that the technical potential of solar power plants in Slovenia for electricity production is 27 terawatt hours per year, which is almost double the amount of electricity produced in 2020, when Slovenia produced 16.5 terawatt hours of electricity. It was also found that the reference costs of solar power plants in 2050 will be between EUR 40 and EUR 105 per megawatt hour. For 2020, these costs were estimated to be between EUR 70 and 170 per megawatt hour, which means that these costs are expected to decrease significantly by 2050 (Kovač, Urbančič & Staničić, 2018, pp. 13-49).

3 Heat pumps

3.1 Definition of the term heat pumps

Heat pumps can be used for heating and cooling. A heat pump uses electricity to transfer heat from a heat source, such as air, water or soil, to a heating system. The heat pump gets all the energy it needs for heating from the environment. The heat pump uses renewable energy sources to operate and does not produce harmful greenhouse gas emissions. By combining a solar power plant and a heat pump, a microlocation can become completely self-sufficient (termoshop.si, 2023). Heat sources of heat pumps differ from each other. Earth and water offer a constant temperature throughout the year, while the temperature of air varies. With water, there may be a problem with the availability of the source due to fluctuating water levels and water quality, while with earth and air there are no such problems (Kronoterm, b. d.a).

We distinguish between heating heat pumps and sanitary heat pumps. Heating heat pumps are divided according to the heat source and the temperature range. Depending on the heat source, we distinguish between air/water heat pumps, water/water heat pumps, ground/water heat pumps and hybrid ground/air heat pumps. Depending on the temperature, we distinguish between heat pumps that operate in a high-temperature regime and heat pumps that operate in a low-temperature regime. Sanitary heat pumps operate using a single heat source, namely air (Kronoterm, b. d.a). The main characteristic of a heat pump is the heat index, which represents the ratio between the heat produced and the electrical energy input. It shows us how many kWh of thermal energy we get from 1 kWh of electrical energy input. For example, if we produce 3,000 kWh of electrical energy with a solar power plant and have a heat pump, we can use this electricity to obtain approximately 9,000 kWh of heat for heating buildings. The heating number in this case is 3. By integrating heat pumps and solar power plants, we can effectively achieve energy self-sufficiency, but only taking into account the net calculation over a longer period of time, e.g. on an annual basis. For self-sufficiency on a daily or weekly basis, it would be necessary to integrate an energy storage device in the form of a battery into such an energy circuit (Kronoterm, b. d.b).

Table 2: Comparison of savings with different energy sources, calculated as of September 6, 2023

Energy source	Price unit	Annual amount of energy required	Annual heating cost	Annual cost of water heating	CO_2 emissions	Saving CO_2 emissions with a heat pump
Heat pump	0,14 €	4.852,22 kWh	771,43 €	92,12 €	2.572 kg	
Natural gas	0,81 €	2.652,63 m³	1.832,09 €	316,54 €	5.090 kg	2.519 kg
LPG gas	0,97 €	3.625,90 m³	2.998,97 €	518,16 €	5.418 kg	2.846 kg
Pellets	222,00 €	5,14 m³	973,51 €	168,20 €	9.828 kg	7.256 kg
Firewood	55,00 €	25,20 m³	1.181,81 €	204,19 €	9.828 kg	7.256 kg
Fuel oil	1,08 €	2.500,00 l	2.302,23 €	397,77 €	6.678 kg	4.106 kg
Electricity	0,14 €	25.200,00 kWh	3.008,24 €	519,76 €	13.356 kg	10.784 kg

Source: Sagadin, b. d.

For example, let's take a 4-member family from Maribor, who lives in a residential building with 170 m2 of living space. They currently use an oil-fired stove for heating. They consume 2,500 liters of oil per year. They heat the rooms with radiators, and the amount of sanitary water used does not deviate from the average. By installing a heat pump, the family would save around EUR 2,000 annually, and

CO_2 emissions would be reduced by around 4 tons (Sagadin, b. d.). A more detailed comparison of savings with different energy sources for our example is given in Table 2.

Savings can also be calculated for different types of heat pumps and for a longer period. For example, let's take a family of 4 living on 170 m2 of living space. They currently use an oil-fired stove for heating. They consume 2,500 liters of oil per year. The age of the oil-fired stove is 20 years (ceu.ijs.si, b. d.). A more detailed comparison of savings with different energy sources for a longer period is given in Table 3.

Table 3: Comparison of savings with different energy sources showing total costs over 20 years, calculated as of September 6, 2023

Heating type	Annual costs	Total costs over 20 years	Annual savings in energy costs	Annual CO_2 emissions
District heating	1.300 EUR	26.600 EUR	1.620 EUR	6.900 kg
Water/water heat pump	1.700 EUR	33.260 EUR	1.810 EUR	1.900 kg
Ground source heat pump with horizontal collectors	1.700 EUR	33.820 EUR	1.820 EUR	1.900 kg
Ground source heat pump with geoprobes	1.700 EUR	34.600 EUR	1.850 EUR	1.800 kg
Air/water heat pump	1.800 EUR	35.920 EUR	1.470 EUR	2.700 kg
Heating with pellets	1.900 EUR	37.900 EUR	1.510 EUR	
Heating with logs	2.000 EUR	40.820 EUR	1.340 EUR	
Heating with wood chips	2.200 EUR	44.800 EUR	1.630 EUR	

Source: ceu.ijs.si, b. d.

4 Electric vehicles

4.1 Battery electric vehicles

Battery electric vehicles are vehicles that use electrical energy stored in the vehicle's battery pack to operate. This provides energy to the electric motor that enables the vehicle to move. The vehicle's battery pack is mostly charged by charging it with electricity from the electrical grid at charging points. Battery electric vehicles offer quiet, emission-free driving and are cheaper to maintain and charge than combustion engine vehicles. Barriers to the use of battery electric vehicles include: short range, higher purchase price, and the existing charging infrastructure network, which is significantly less extensive than the network of stations for combustion engine vehicles (DriveClean, 2021a).

The return on investment in a battery electric vehicle varies depending on the car segment. In the city car segment, the investment in the purchase of a battery electric vehicle is repaid in eight years after driving 200,000 kilometers, or in six years assuming free charging. In the SUV segment, cost equalization is achieved in 4.7 years, or after driving 118,000 kilometers, compared to a vehicle with a diesel engine, and in 15.6 years, or after driving 391,000 kilometers, compared to a vehicle with a gasoline engine. In the premium vehicle class, the investment is repaid in less than a year, as there are no such price differences between the powertrains of more expensive vehicles, as there are, for example, in the city car segment (Božin, 2022).

4.2 Plug-in hybrids

Hybrid vehicles are vehicles that use a combination of an internal combustion engine and an electric motor to move, powered by a battery pack in the vehicle. The advantages of combining both modes in hybrids are reduced fuel consumption and lower exhaust emissions (DriveClean, 2021b). Plug-in hybrids combine the characteristics of battery electric vehicles and hybrid vehicles. In one vehicle, an electric motor with a battery pack that can be charged via electric charging stations and a classic internal combustion engine are combined. A plug-in hybrid allows electric driving at both lower and higher speeds, of course over shorter distances. The range of electric driving is even shorter than that of battery electric vehicles. When the battery pack is discharged, the vehicle switches to the internal combustion engine. In this way, the range of a battery electric vehicle is significantly extended. The plug-in hybrid is charged with electricity at electric vehicle charging stations, while the fuel tank is filled at a gas station. The goal is to make as many daily journeys as possible purely electric, using the internal combustion engine only when necessary. This mode of operation significantly extends the vehicle's range, reduces exhaust emissions while driving, and provides a more extensive network of charging stations than for battery electric vehicles (DriveClean, 2021c).

4.3 Fuel cell vehicles and electric vehicle comparison

Fuel cell vehicles use fuel cells to convert liquid hydrogen (fuel for fuel cells) into electricity, which powers an electric motor and thus the vehicle. Like a battery electric vehicle, a fuel cell vehicle produces no emissions during operation. Water is produced as a byproduct of the conversion of hydrogen into electricity. In terms of range, refueling and driving characteristics, fuel cell vehicles are comparable to vehicles with an internal combustion engine (DriveClean, 2021d). The differences between the individual types of electric vehicles are given in Table 4.

Table 4: Comparison of electric vehicle types

Vehicle type	Battery electric vehicle	Hybrid vehicle	Hybrid vehicle	Fuel cell vehicle
Energy source	Electricity	Fuel	Electricity, fuel	Liquid hydrogen
Vehicle charging	Charging point for electric vehicles	Gas station	Gas station, electric vehicle charging station	Liquid hydrogen gas station
Greenhouse gas emissions	Emissions-free	Yes, when the vehicle is powered by an internal combustion engine	Yes, when the vehicle is powered by an internal combustion engine	Emissions-free

Source: DriveClean, 2021a; DriveClean, 2021b; DriveClean, 2021c; DriveClean, 2021d.

If we compare battery electric vehicles and hybrid vehicles with petrol or diesel versions, we can conclude that battery electric vehicles and hybrid vehicles have been comparable in price to vehicles with an internal combustion engine for several years. A 2018 comparison test (Lukić) showed the comparability of these vehicles based on costs per kilometer. If a vehicle travels 50,000 km in 5 years, the cost per kilometer for a battery electric vehicle is EUR 0.41, for a hybrid vehicle EUR 0.40, for a vehicle with a petrol engine EUR 0.40 and for a vehicle with a diesel engine EUR 0.41. However, if a vehicle travels 125,000 km in 5 years, the cost per kilometer for a battery electric vehicle is EUR 0.18, for a hybrid vehicle EUR 0.16, for a vehicle with a petrol engine EUR 0.16 and for a vehicle with a diesel engine EUR 0.18.

5 Energy storage devices

5.1 Definition of energy storage system

Energy storage devices or batteries are devices that convert stored chemical energy into electrical energy. Batteries can be divided into primary and secondary. Primary batteries are those that cannot be recharged and are discarded after use, while secondary batteries are those that can be recharged. They are also called accumulators (Linden, 1995, pp. 20-22).

5.2 Required battery characteristics

The characteristics of the battery depend on the type of consumer. Batteries for battery electric vehicles must have a sufficiently high energy density for sufficient range of the vehicle, enough power to accelerate the vehicle, a long battery life with minimal maintenance, and a low price. Batteries for hybrid vehicles must have enough power to accelerate the vehicle, the ability to continuously charge through regenerative braking, a very long life, and a low price. Electronic devices require cheap and accessible batteries that have high power and energy density. Batteries for devices that are part of the energy grid must have low investment costs, be reliable, and have high power and energy density. For all batteries for all consumers, safe operation and minimal environmental impact during production, use, and disposal are mandatory (Symons & Butler, 1995, p. 1187). Batteries used for storing electricity allow the use of electricity even in the event of failures, repairs, or power outages in the electricity grid, which is key to the self-sufficiency of a microlocation (termoshop.si, 2023).

5.3 Reusing batteries from used electric vehicles

It has been found that batteries that are part of the battery pack in electric vehicles still retain 70% of their original capacity after the end of their intended useful life as part of the vehicle's powertrain and would be useful as electrical energy storage for at least another ten years (nrel.gov, b. d). Research by Wood, Alexander and Bradley (2011), which focused only on plug-in hybrids, found that the proportion of remaining battery pack capacity in these vehicles is as high as 80%. As the number of electric vehicles on the road increases, the number of scrapped electric vehicles will increase over time, and so will the number of batteries suitable for energy storage. However, in order to store electricity in such storage systems, the price of such systems would need to fall by 90% to 0.05 EUR/kWh (batterycouncil.org, 2022). Currently, such storage of electricity is not economically viable (Lamp & Samano, 2022). However, savings can be made on electricity prices. A consumer with 5,000 kWh of annual electricity consumption can save 680 EUR through a solar power plant and a storage tank with 80% self-sufficiency in electricity at current regulated prices, and even more with the expected increase in electricity prices after the end of the regulation period. If the price were to rise to the level of prices for German households, the annual savings would amount to as much as 1,800 EUR (Ekart, 2023a).

The increasing emphasis of companies covering various links in supply chains and operating in different geographically distant parts of the world and households on increasing their own energy production, increasing efficiency and reducing energy consumption indicate that the energy management sector is among the priority areas, as the cost of energy can also be the dominant cost of a selected energy-intensive company. The energy management sector is one of a number of priority areas, stemming from the growth in companies covering various links in supply chains and operating in geographically distant parts of the world as well as households increasing energy production and efficiency and reducing consumption. We should also note that the cost of energy can be the dominant cost in an energy-intensive company. Due to the relatively high energy prices in the EU, this is all the more visible in our country. Sustainable energy self-sufficiency makes us more resistant to supply disruptions and reduces our dependence on suppliers. It enables the use of our own resources and, in combination with advanced flexibility systems in the electricity system, brings reliability and greater added value, which is created in the local environment. Self-sufficiency will be much more effective if it is established and operates at the level of the entire EU and not just in micro-locations. The production of electricity from renewable sources, as well as energy use, is dispersed, time-dependent and variable, so it makes sense to interconnect larger systems, thereby achieving a more stable and robust system.

References

batterycouncil.org. (2022). *DOE Says Lead Batteries Have Better Chance of Achieving Target Energy Storage Goals Than Lithium-Ion Batteries.* Pridobljeno 6. septembra 2023, s https://batterycouncil.org/lead-batteries-better-chance-to-achieve-energy-storage-goals/

Božin, U. (2022, 18. avgust). *Po koliko kilometrih se povrne nakup električnega avta.* Pridobljeno 6. septembra 2023, s https://si.bloombergadria.com/ostalo/avto/7333/elektricni-avto-po-koliko-kilometrih-se-povrne-nakup/news

ceu.ijs.si. (b. d.). *Replace Kalkulator menjave ogrevalnega sistema.* Pridobljeno 6. septembra 2023, s https://ceu.ijs.si/projekti/zamenjaj-star-kotel.html

comorinsolar.com. (b. d.). *Energy Pyramid – The Holy Grail of Energy & Sustainability.* Pridobljeno 14. avgusta 2023, s https://www.comorinsolar.com/blog/energy-pyramid-the-holy-grail-of-energy-sustainability/

Consilium. (2023). *Kako se proizvaja in prodaja električna energija v EU?* Pridobljeno 14. avgusta 2023, s https://www.consilium.europa.eu/sl/infographics/how-is-eu-electricity-produced-and-sold/

DriveClean. (2023a). *Battery-Electric Cars* Pridobljeno 14. avgusta 2023, s https://driveclean.ca.gov/battery-electric

DriveClean. (2023b). *Hybrid Electric Cars.* Pridobljeno 14. avgusta 2023, s https://driveclean.ca.gov/hybrid

DriveClean. (2023c). *Hydrogen Fuel Cell Electric Cars.* Pridobljeno 14. avgusta 2023, s https://driveclean.ca.gov/hydrogen-fuel-cell

DriveClean. (2023d). *Plug-in Hybrid-Electric Cars*. Pridobljeno 14. avgusta 2023, s https://driveclean.ca.gov/plug-in-hybrid

eauto.si. (b. d.). *Trajnostno energetski krog*. Pridobljeno 14. avgusta 2023, s https://eauto.si/sl/projekti-3/trajnostni-energetski-krog/

Ekart, J. (2023a, 11. februar). *Hranilnik električne energije - cena in prihranki*. Pridobljeno 6. septembra 2023, s https://www.varcevanje-energije.si/fotovoltaicne-elektrarne/powerwall-tesla-in-soncna-elektrarna.html

Ekart, J. (2023b, 4. september). *Kako deluje samooskrba z elektriko ali net metering in kaj se obeta?* Pridobljeno 6. septembra 2023, s https://www.varcevanje-energije.si/fotovoltaicne-elektrarne/kako-deluje-samooskrba-z-elektricno-energijo-net-metering-v-sloveniji.html

energija-solar.si. (b. d.). *Izkoristek sončnih celic*. Pridobljeno 6. septembra 2023, s https://www.energija-solar.si/30/izkoristek-soncnih-celic

Energetska izkaznica. (b. d.). *Meritve porabe energije*. Pridobljeno 14. avgusta 2023, s http://www.energetska-izkaznica.si/energetska-ucinkovitost/meritve-porabe-energije/

Fraile, D., Latour, M., El Gammail, A., Annett, M. & Nemac, F. (b. d.). *Sončne elektrarne Energija, ki nam jo nudi sonce*. Pridobljeno 14. avgusta 2023 na spletnem naslovu: http://www.ape.si/publikacije/brosura-soncne-elektrarne.pdf

Hanley, S. (2021, 5. september). *UK Energy Regulator Supports Vehicle-To-Grid Proposal*. Pridobljeno 18. avgusta 2023, s https://cleantechnica.com/2021/09/05/uk-energy-regulator-supports-vehicle-to-grid-proposal/

Iberdrola. (2025). *The major challenges of self-sufficiency and energy security*. Pridobljeno 8. januarja 2025, s https://www.iberdrola.com/sustainability/energy-transition/energy-self-sufficiency-security

Kovač, M., Urbančič, A. & Staničić, D. (2018, 14. junij). *Potencial sončnih elektrarn na strehah objektov v Sloveniji do leta 2050*. Pridobljeno 14. avgusta 2023, s https://www.podnebnapot2050.si/wp-content/uploads/2020/06/Deliverable_C_1_1-Part-5B-Potencial-son%C4%8Dnih-elektrarn-na-strehah-objektov-v-Sloveniji.pdf

Kronoterm. (b. d.a). *Kaj je toplotna črpalka?* Pridobljeno 14. avgusta 2023, s https://kronoterm.com/osnove-toplotne-crpalke/kaj-je-toplotna-crpalka/

Kronoterm. (b. d.b). *Zakaj toplotna črpalka Kronoterm?* Pridobljeno 6. septembra 2023, s https://kronoterm.com/zakaj-toplotna-crpalka-kronoterm/

Lamp, S. & Samano, M. (2022, marec). Large-scale battery storage, short-term market outcomes, and arbitrage. *Energy Economics Volume 107, 105786*.

Let's Talk Science. (2019). *Understanding Electricity Supply and Demand*. Pridobljeno 14. avgusta 2023, s https://letstalkscience.ca/educational-resources/backgrounders/understanding-electricity-supply-and-demand

Linden, D. (1995). Basic concepts. V Linden, D. & Reddy, T. B. (ur.). *Handbook of batteries Third Edition* (str. 20-22). McGraw-Hill.

Lucey, E. (2023, 13. februar). *What exactly is the role of renewable energy in a circular economy?* Pridobljeno 8. januarja 2025, s https://acehub.org.au/news/the-role-of-renewable-energy-in-a-circular-economy

Lukič, D. (2018, 3. avgust). *Kam vložiti prihranke: v električni, hibridni, dizelski ali bencinski avtomobil? Primerjalni test*. Pridobljeno 6. septembra 2023, s https://avto-magazin.metropolitan.si/avtomobilski-testi/elektricni-avto-hibrid-dizel-in-bencinec-osebna-izbira/

NGEN. (b. d.a). *Dobava in odkup električne energije*. Pridobljeno 14. avgusta 2023, s https://www.ngen.si/sl/ponudba/podjetja/dobava-in-odkup-elektricne-energije

NGEN. (b. d.b). *Hranilniki električne energije*. Pridobljeno 14. avgusta 2023, s https://www.ngen.si/sl/ponudba/podjetja/hranilniki-elektricne-energije

nrel.gov. (b. d.) *Battery Second Use for Plug-In Electric Vehicles Analysis*. Pridobljeno 17. avgusta 2023, s https://www.nrel.gov/transportation/battery-second-use-analysis.html

Partlin, S. (2021, 30. avgust). *Automatic Energy Cost Savings: With Solar power and the SMA Sunny Home Manager*. Pridobljeno 6. septembra 2023, s https://www.sma-sunny.com/en/automatic-energy-cost-savings-with-solar-power-and-the-sma-sunny-home-manager/

Pi-solarus. (b. d.). *Sončne elektrarne za samooskrbo - svetovanje in postavitev na ključ*. Pridobljeno 18. avgusta 2023, s https://www.pi-solarus.com/soncne_elektrarne_samooskrba-netmetering

Sagadin. (b. d.). *Izračun porabe energije objekta s toplotno črpalko*. Pridobljeno 6. septembra 2023, s http://www.sagadin.net/sl/izracun-za-toplotno-crpalko

Skupina GEN. (2023). *Sončna energija*. Pridobljeno 14. avgusta 2023, s https://www.esvet.si/drugi-viri-energije/soncna-energija

Skupina GEN. (2025a). *Koliko energije porabimo v Sloveniji?* Pridobljeno 8. januarja 2025, s https://www.esvet.si/energija-mi

Skupina GEN. (2025b). *Poraba energije v gospodinjstvih: največ je potrebujemo za ogrevanje*. Pridobljeno 8. januarja 2025, s https://www.esvet.si/energija/koliko-energije-porabimo-v-sloveniji

Skupina GEN. (2025c). *Oskrba z energijo danes*. Pridobljeno 8. januarja 2025, s https://www.esvet.si/energetska-oskrba-slovenije/oskrba-z-energijo-danes#viri-energije-za-oskrbo-slovenije

Skupina GEN. (2025d). *Trajnostni in netrajnostni viri energije*. Pridobljeno 8. januarja 2025, s https://www.esvet.si/energija/viri-pretvorbe-enote/trajnostni-netrajnostni-viri-energije

suncontract.org. (2023a). *Bodite sam svoj gospodar s presežki elektrike iz vaše sončne elektrarne*. Pridobljeno 14. avgusta 2023, s https://suncontract.org/si/prosto-razpolaganje-z-viski-samooskrba-soncna-elektrarna/

suncontract.org. (2023b). *Vaša energetska tržnica za obnovljivo energijo*. Pridobljeno 14. avgusta 2023, s https://suncontract.org/si/elektricna-trznica-proizvajalce-odjemalce-energije/

Symonds, P. C. & Butler, P. C. (1995). Advanced batteries for electric vehicles and emerging applications – Introduction. V Linden, D. & Reddy, T. B. (ur.). *Handbook of batteries Third Edition* (str. 1187). McGraw-Hill.

termoshop.si. (2023). *Sončna elektrarna: Kaj se zgodi s presežkom proizvedene električne energije?* Pridobljeno 14. avgusta 2023, s https://www.termoshop.si/novice/soncna-elektrarna-kaj-se-zgodi-s-presezkom-proizvedene-elektricne-energije/

trajnostnaenergija.si. (b. d.). *Sončna energija*. Pridobljeno 14. avgusta 2023, s https://www.trajnostnaenergija.si/Trajnostna-energija/Proizvajajte/Obnovljivi-viri-energije/Vse-o-obnovljivih-virih-energije/son%C4%8Dna-energija

Valenčič, M, (2022, 12. oktober). *Balkonske sončne elektrarne*. Pridobljeno 14. avgusta 2023, s https://zaensvet.si/balkonske-soncne-elektrarne/

vrhunskaemobilnost.si. (b. d.). *Izračunajte električni potencial vaše hiše*. Pridobljeno 6. septembra 2023, s https://www.vrhunskaemobilnost.si/orodja/izracunajte-si-elektricni-potencial-vase-hise/

Wood, E., Alexander, M. & Bradley, T. H. (2011, 12. februar). Investigation of battery end-of-life conditions for plug-in hybrid electric vehicles. *Journal of Power Sources, 5147–5154*.

Zgonik, S. (2023, 5. november). P*aradoks samooskrbe: Ko sončna elektrarna na strehi poveča porabo iz omrežja*. Pridobljeno 8. januarja 2025, s https://n1info.si/poglobljeno/paradoks-samooskrbe-ko-soncna-elektrarna-poveca-porabo-iz-omrezja/

MASTERING SUSTAINABILITY IN SUPPLY CHAINS

MATEVŽ OBRECHT (ED.)
University of Maribor, Faculty of Logistics, Celje, Slovenia
matevz.obrecht@um.si

DOI
https://doi.org/10.18690/um.fl.4.2026

ISBN
978-961-299-100-5

The higher education textbook "*Mastering Sustainability in Supply Chains*" is a comprehensive guide designed to support sustainability and the greening of logistics processes. It emphasizes modern approaches and concepts for environmental protection and minimizing environmental impacts while simultaneously increasing added value and productivity. The textbook covers the use of environmental assessment tools and the establishment of circular supply chains. An interdisciplinary approach integrates knowledge from various fields, including environmental management, eco-friendly product design, carbon footprint assessment, green logistics, energy supply, and the application of practical knowledge beyond logistics and supply chains. Readers are equipped with practical skills to enhance sustainability, productivity, and process transparency. The textbook covers topics such as: 1) Climate change, 2) Environmental assessment – carbon footprint, 3) Life cycle assessment (LCA), 4) Circular economy, 5) Sustainable energy self-sufficiency, 6) Eco-design. The entire content is aimed at strengthening sustainability competencies, which are crucial for the green transition of logistics companies and increasing the resilience of supply chains.

Keywords:
sustainable development,
environmental assessment,
interdisciplinary knowledge,
green logistics,
circular economy,
energy self-sufficiency

University of Maribor Press

University of Maribor

Faculty of Logistics

DigiGreen in Logistics Skills

Climate Change and Post-carbon Alternatives in Transport
Maja Vrčon

Sustainable Organizational Transformation
Matjaž Knez

Environmental Assessment: Integration of Carbon Footprint
Matevž Obrecht

Environmental Impact Assessment with LCA
Matjaž Denac

Circular Economy and Value Chains (Life Cycle Analysis)
Rebeka Kovačič Lukman, Kristijan Brglez

Integration of Eco Design in Supply Chain Management
Matevž Obrecht

Sustainable Energy Self-sufficiency
Matevž Obrecht, Martin Fale

NOO THE RECOVERY AND RESILIENCE PLAN

University of Maribor

REPUBLIC OF SLOVENIA
MINISTRY OF HIGHER EDUCATION, SCIENCE AND INNOVATION

Funded by the European Union
NextGenerationEU