Report:

_Sustainable manufacturing

Research of trends, challenges and future perspectives

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_Introduction

In just the last two and a half years the global economy has experienced the subsequent unexpected crises. Covid-19 has rebuilt our lives and behaviors. Broken supply chains influenced business behaviors. The consequences of the war in Eastern Europe limited access to important natural resources. Climate change is also affecting Europe a lot, in various forms, depending on the region. It leads to biodiversity loss, forest fires, decreasing crop yields and higher temperatures, even people's health. Global problems include inadequate access to clean water and sanitation. To face these challenges the world needs a strategy that will allow the economies to be transformed into modern, saving resources and a competitive one.

_General regulations

Fighting climate change recently became a priority for the European Parliament. Over the years, the European Union developed a vast set of legislative acts dealing with the topics of energy and climate change. Some of them regard reporting and monitoring and others provide for targets and/or instruments in order to operationalize the achievement of the overarching objectives [1].

Evidence shows that average global temperatures have risen since the industrial revolution from the end of the 19th century and nowadays are 0,95 to 1,2 °C higher. The last decade (2011–2020) was the warmest decade ever. The evidence indicates that this is due to the rise of greenhouse gas emissions (GHG) produced by human activity [2].

According to the European Environment Agency (EEA), the European Union in 2015 was the world's third biggest greenhouse gas emitter, after China and the US. The top five emitters in the EU were na 2019 Germany, France, Italy, Poland and Spain. The energy sector was responsible for 77 percent of greenhouse gasses emissions in the EU in 2019, followed by agriculture (10,5 percent), industry (9,1 percent) and the waste sector (3,3 percent) [3].

To overcome these challenges, the European Green Deal will transform the EU into a modern, resource-efficient and competitive economy, ensuring:

- no net emissions of greenhouse gasses by 2050,
- economic growth decoupled from resource use,
- no person and no place left behind [4].

Green Deal is a set of measures that aims to help the European Union transition to a green economy and achieve climate neutrality. The Commission aims to work with the EU and the Member States to launch initiatives and implement the legislation successfully. The proposals that have been included within the European Green Deal include the following: European Climate Pact, New Circular Economy Action Plan (including the Strategy for a Sustainable Built Environment), 8th Environment Action Programme (EAP), New Batteries Regulation, European Climate Law, Level(s) - European Framework for Sustainable Buildings, 2030 Climate Target Plan, EU Strategy for Energy System Integration, Revision of the Renewable Energy Directive, Revision of the Energy Efficiency Directive, New European Bauhaus Initiative, European Green

Deal Investment Plan (Sustainable Europe Investment Plan), Sustainable and Smart Mobility Strategy, Regulation setting CO2 emission performance standards for new passenger cars and for new light commercial vehicles, Revision of the EU System to Monitor, Report and Verify Co2 Emissions from Ships, FuelEU Maritime, ReFuelEU Aviation, Renovation Wave Strategy [5].

In 2008 the European Union set a target to cut greenhouse gas emissions by 20% by 2020 compared to 1990 levels. Significant progress has been made: in 2015 there was a decrease of 22 percent compared with 1990 levels. Transport is the only sector in which emissions are still higher than they were in 1990 [3].

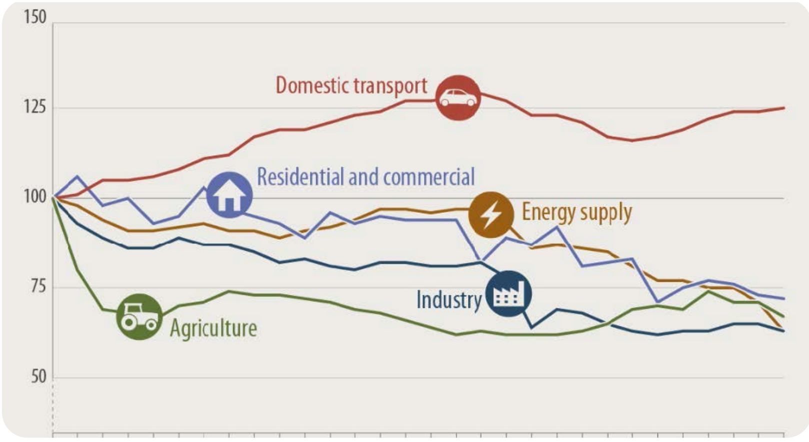

Figure 1. Change in emissions level by sector in the EU since 1990 (in CO2 equivalent), excluding the UK. Source: [6]

In December 2020, the European Union announced that it would slash at least 55% of carbon emissions by the year 2030, up from the previous target of 40 percent. The target is ambitious and some climate experts express doubts on reaching that goal. In order to achieve it a large-scale transformation of a number of industries, including the automotive industry, is necessary [7].

Following the climate targets set in the Paris Agreement, the European Union currently aims to make Europe the climate-neutral continent by 2050. On 12th December 2019, the European Council, together with the European Commission, established the European Green Deal (EGD), the core EU strategy to fight climate change and achieve climate neutrality. The first step proposed by the Commission includes an initial set of targets to be met by 2030 [10]. **The EU Green Deal "seeks to drive the fundamental business and value-chain transformation needed to address the climate emergency through its framework of regulation, incentives […]. It will affect procurement, supply-chain management, manufacturing, finance, ESG and human resources departments. These teams must work together to align their approach. To make the most of the incentives available for low-carbon transformation, and mitigate the impact of Green Deal levies, it is critical for companies to embrace a comprehensive, adaptive, long-term, transformational mind set" [11].**

_European Green Deal

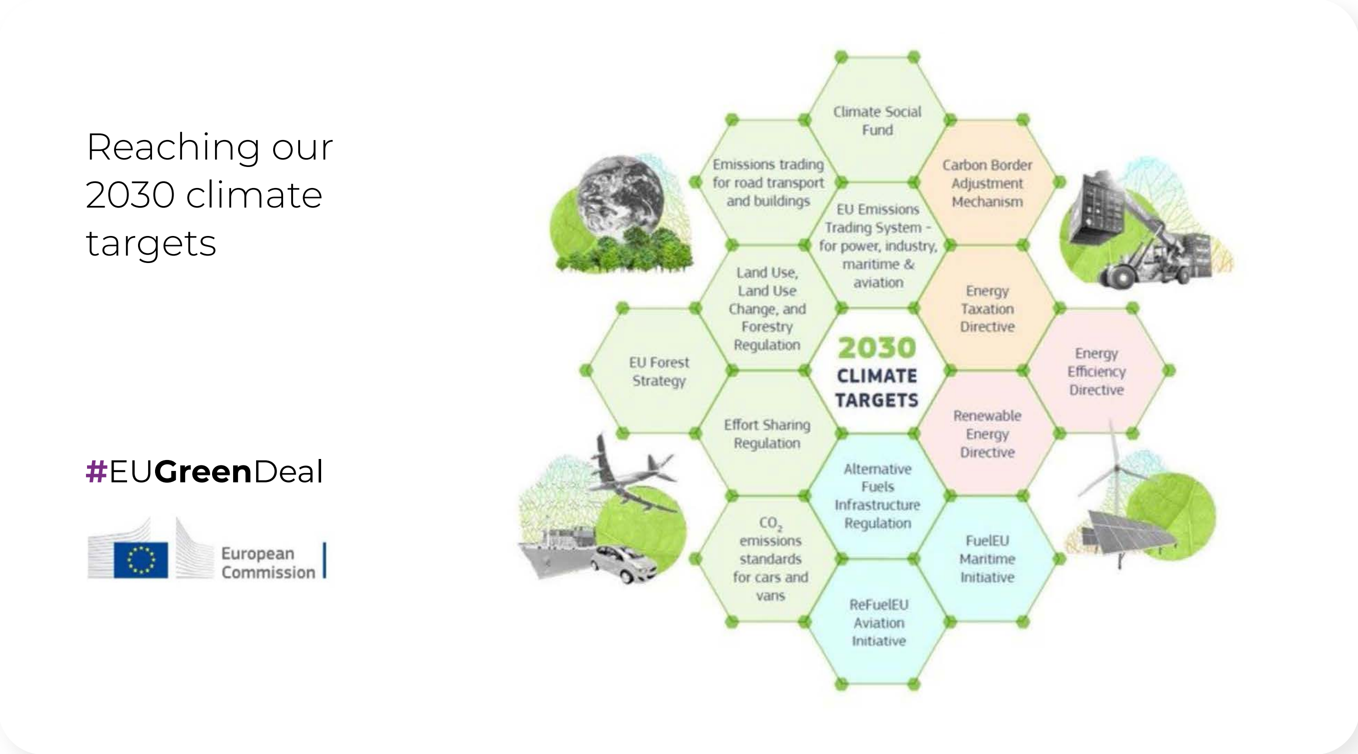

Figure 2. 2030 climate actions. Source: [12]

There are eight key areas that make up the Green Deal, as follows:

1. Increasing the EU's climate ambition for 2030 and 2050
2. Supplying clean, affordable, secure energy
3. Mobilising industry for a clean and circular economy
4. Building and renovating in an energy and resource efficient way
5. A zero pollution ambition for a toxic-free environment
6. Preserving and restoring ecosystems and biodiversity
7. Farm to Fork: a fair, healthy and environmentally friendly food system
8. Accelerating the shift to sustainable and smart mobility [13]

The European Commission estimates that at least 1 trillion EUR in sustainable investments will be needed over until 2030, including both public and private money. Key investment areas include Sustainable infrastructure; Research, innovation and digitisation; Small and Medium Sized Enterprises; Social Investment and Skills [13]. The investment plan has been presented in the figure below.

On 14 July 2021, the European Commission adopted "Fit for 55", a set of policy proposals preparing the implementation of the EU Green Deal [12]. While the EGD is a ge-neral action plan to fight climate change, the Fit for 55 package offers the preparatory path to meet the targets of the EGD. Na-mely, Fit for 55 focuses on specific topics that need particular attention [10].

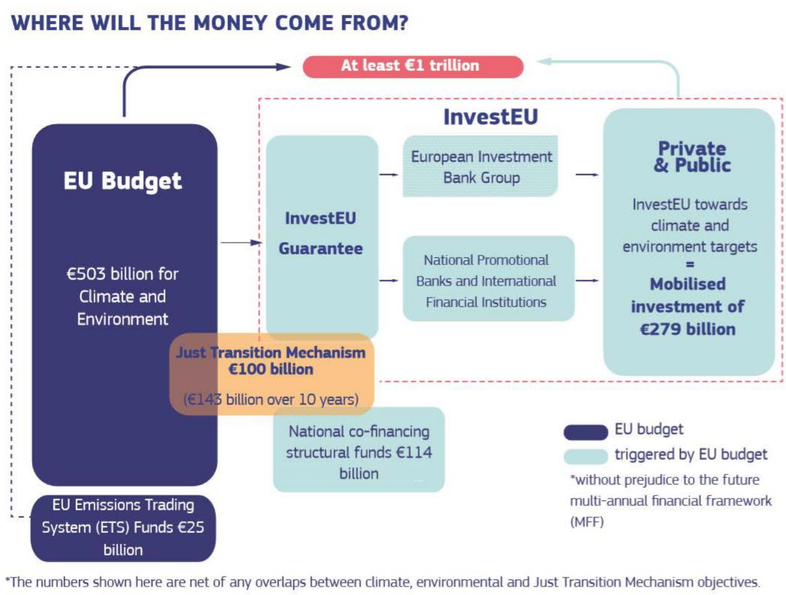

Figure 3. The European Green Deal Investment Plan. Source: [13]

In particular, the package adopted by The European Commission is a set of proposals to make the EU's climate, energy, transport and taxation policies fit for reducing net greenhouse gas emissions by at least 55% by 2030, compared to 1990 levels [4].

In order to achieve climate neutrality by 2050 the goal is to harness the significant potential in global markets for low-emission technologies, sustainable products and services. And achieving a climate neutral and circular economy requires the full mobilization of industry. All industrial value chains, including energy-intensive sectors, will have a key role to play [14].

The new Industrial Strategy for Europe will lead the twin green and digital transitions and become even more competitive globally. It will help industry to reduce their carbon footprint by providing affordable, clean technology solutions and by developing new business models. With the updated Strategy based on the lessons learnt from the COVID-19 pandemic the EU aims to ensure that European industry can lead the accelerated green and digital transitions.

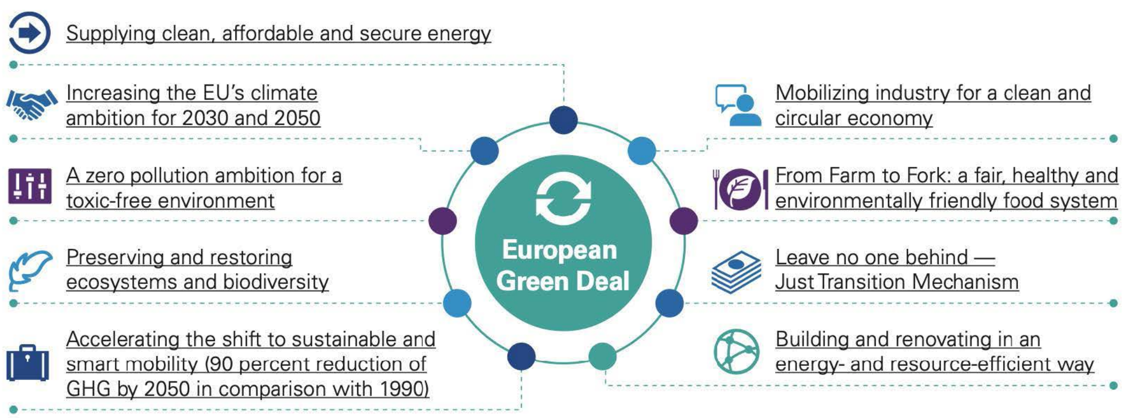

Figure 4. Policy areas in the EGD action plan. Source: [10]

The EU's emissions trading system (ETS) was introduced and launched in 2005 and it aims to reduce the industry's carbon emissions. The emissions trading scheme obliges power plants and factories to hold a permit for each tonne of CO2 they emit. It provides a financial incentive to pollute less, because less pollution comes with less payments. Companies have to buy aforementioned permits through auctions and the price is affected by demand and supply [15].

The Fit for 55 package includes changes in the emission allowance trading system (EU ETS) and aims to include road transportation in this system. Currently, the entire sector is responsible for approximately 28,2 percent. EU greenhouse gas emissions, of which as much as 20,4 percent It falls on road transport (taking into account car traffic), 4,0 percent for sea transport, and 3,8 percent for air transport. Therefore it is assumed that "Fit for 55" will be a revolution for road transport. Legislative package presented by the European Commission will strongly affect road transport by including transport companies in the emission trading system, as well as pressure on the very rapid development of the fleet of zero-emission vehicles. **The most important regulations** that are to apply to this sector can be summarized in three points as follows:

- **change in the alternative fuel directive,** which will determine the goals of the Member States in the development of the infrastructure of charging zero-emission vehicles. It is about investments in charging points of electric vehicles and hydrogen-powered (both passenger and delivery vans),
- **more stringent emission standards for new internal combustion cars.** They assume that in 2035 all the passenger vehicles sold in the EU will be zero-emission. In the case of new vans, indirect purposes are to be: 15 percent. emission reduction until 2025 and 50 percent reduction until 2030,
- **road transport is to be covered by the emission trade system (ETS) from 2026.** Transport companies will therefore have to buy CO2 emission rights at auctions, which are intended to make companies replace the fleet faster for low and zero-emission vehicles [16].

Important part of the package is **Carbon Border Adjustment Mechanism (CBAM),** adopted by the Commision on the same day - on 14th of July 2021. It puts a carbon price on imports of a targeted selection of products so that ambitious climate action in Europe does not lead to 'carbon leakage'. It ensures that European emission reductions contribute to a global emissions decline, instead of pushing carbon-intensive production outside Europe. It also aims to encourage industry outside the EU and our international partners to take steps in the same direction. The Commission plans CBAM to be fully effective in 2026 [17]. It will influence supply chain choices, as it penalizes carbon-intensive imports. If import levies are set at a high level, it may encourage European businesses to source their inputs from within the EU area [11].

The way energy is produced and consumed in the EU needs revolution as it accounts for more than 75 percent of the EU's greenhouse-gas emissions. Currently, in the EU energy mix dominates oil (a share of 34,8 percent), followed by natural gas (23,8 percent) and coal (13,6 percent). Renewables are growing in share but their role remains limited (13,9 percent), similarly to nuclear (12.6 percent). Current situation will change completely if the European Green Deal is successful by 2050 [18]. European Commission's projections in this area have been presented in the figure below.

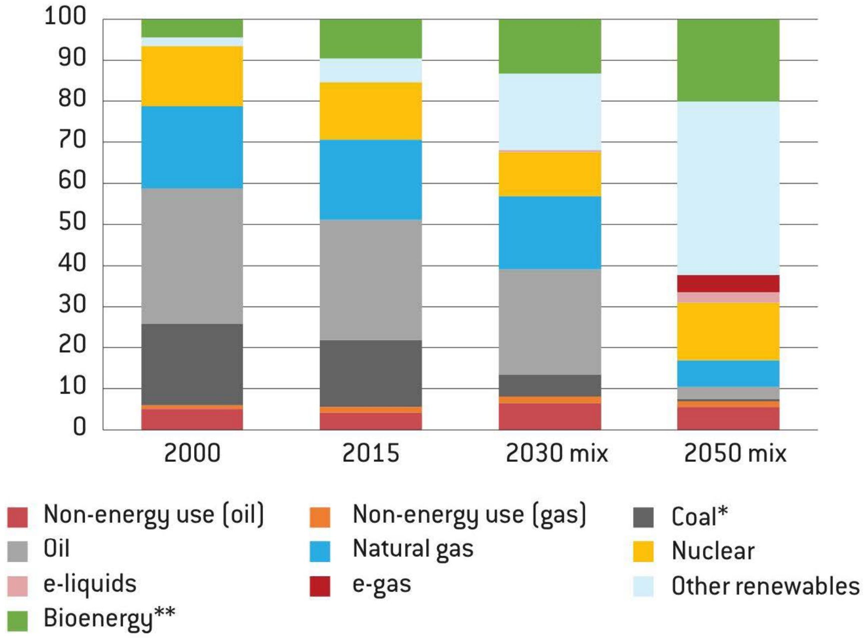

Figure 5. EU energy mix evolution. Source: [18]

Research on the use of renewable energy in the EU has been performed by Bassi and Dias in 2019 [19]. The results of the research has been presented in the figure below.

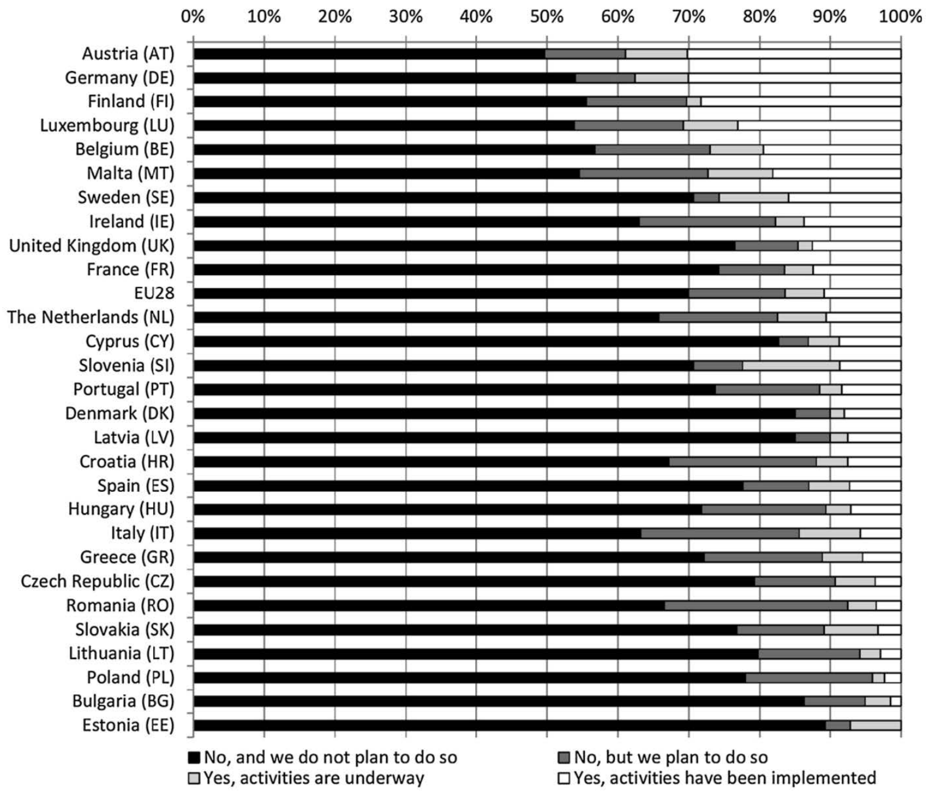

Figure 6. The use of renewable energy in the EU countries in 2016-2019. Source: [19]

_Transport and the Automotive Industry

The automotive industry is considered as one of the main contributors to the global environmental crisis. Moreover, the current practices in the automotive sector are shown to have a negative impact on the social and environmental dimensions. On the other hand, the automotive industry is critical to any country's economic development. Therefore, the industry requires a radical shift in the way they perform business-as-usual [20].

Transport is responsible for nearly 30 percent of the EU's total CO2 emissions, of which 72 percent comes from road transport, according to a report from the European Environment Agency. CO2 emissions from passenger transport vary significantly depending on the transport mode. Passenger cars are a major polluter, responsible for 61 percent of total CO2 emissions from EU road transport [6].

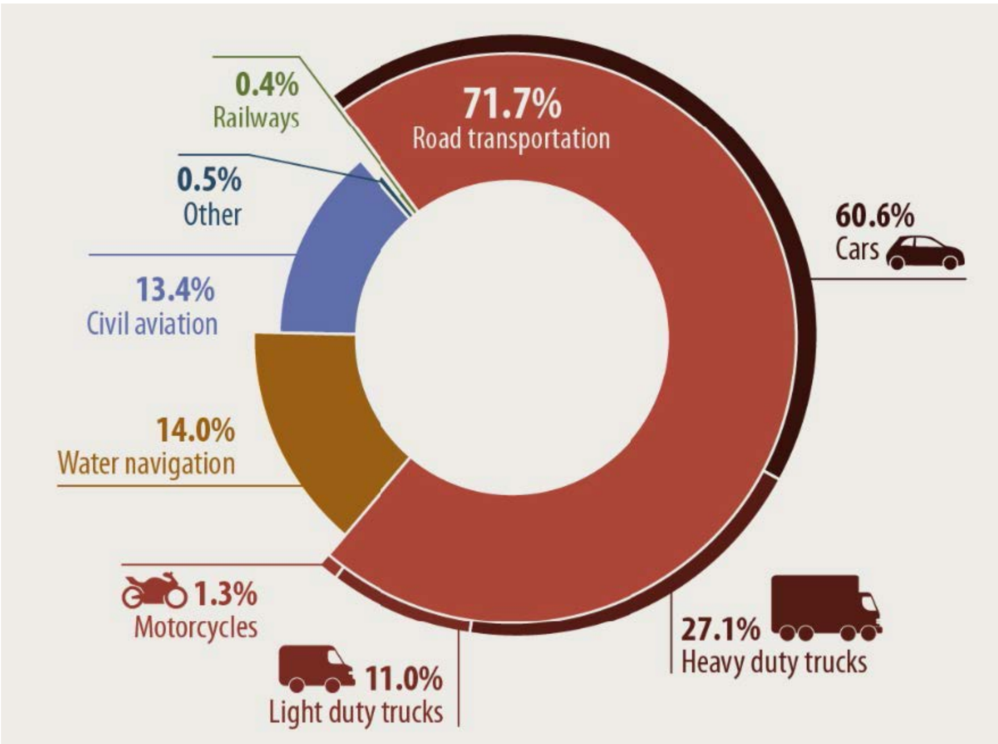

Figure 7. Greenhouse gas emissions breakdown by transport mode in the EU in 2019. Source: [6]

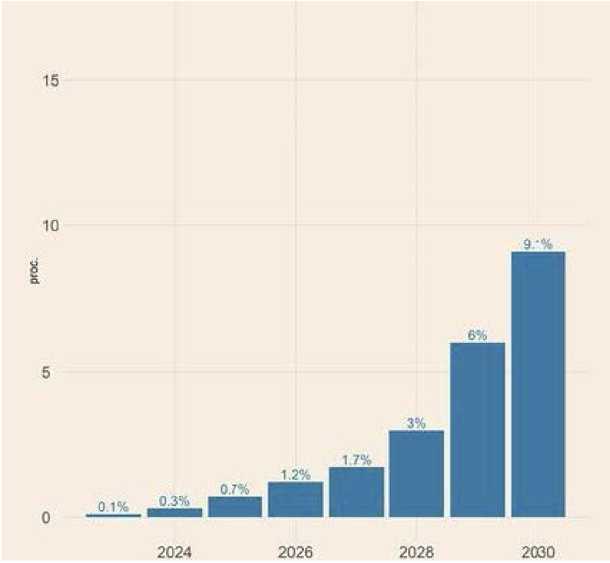

Figure 8. The share of heavy commercial vehicles with electric drive. Source: [16]

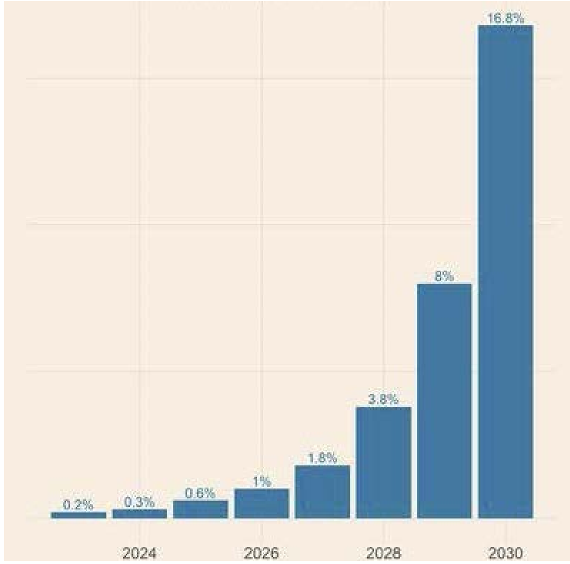

Figure 9. The share of heavy commercial vehicles with hyndrogen drive. Source: [16]

Fit for 55 creates a very large market for producers who will be able to produce electric or hydrogen vehicles. On the other hand, this also means the risk of falling out of the market for companies that will not be able to present such an offer. In this race recently an increasing number of large automotive concerns. Electric trucks already offer, among others Citroën (E-Berlingo and E-Expert models), Peugeot (e-partner), Opel (Combo-E, Vivaro-E), Renault (Kangoo), FIAT (E-Ducato), Ford (E-Transit) and Volvo (FE Electric). The start of the production of such trucks has also recently been announced by Daimler. However, the offer of saddle tractors is limited. These types of vehicles currently offer only Volvo (FH Electric), Iveco (Nikola Tre) and DAF (CF Electric), although several other large manufacturers have already announced that they will soon join this group [16]. Moreover, traditional car companies are increasingly investing (over USD 11 billion since 2015) in autonomous and shared vehicle companies such as Lyft, and setting aggressive electric and autonomous vehicle targets. One of the examples is General Motors that is working towards an “All Electric-future” and also aims to roll-out a fully self-driving ridesharing service [22]. **The consequences of the Fit for 55 package for the automotive industry will be very deep and can significantly undermine the position of companies that will not be able to adapt to the process of rapidly reducing greenhouse gas emissions.**

Electric motors and the associated optimization, lightweight construction and CO2 emission reduction are important issues, however not the only. The car’s interior should be included in analysis and improvements as it is the part of a car most frequently seen by the driver. It must be not only practical, aesthetically pleasing, but also weight saving. The use of natural fibers as alternative materials in the interior plays an important role and is a further step towards greater sustainability. 30.000 tons of natural fibers used in 2005 grew in Europe to 50.000 tons in 2015 [23].

_The concept of sustainability and its elements

Nowadays sustainability is increasingly important for managers across all industries.

Sustainability measurements, especially those regarding environmental pillar, became a **significant topic in the automotive industry.** Significant changes that can currently be observed in the automotive industry suggest that over **30 percent of new car sales are projected to be zero emissions and plug-in hybrid by 2030,** representing a potential USD 1 trillion market [22]. Currently electric cars are already gaining traction, representing 11 percent of all new registered passenger vehicles in 2020. Sales of electric vehicles - battery electric vehicles and plug-in hybrid electric vehicles - have surged since 2017 and tripled in 2020 when the CO2 targets started to apply. Electric vans accounted for 2,3 percent of the market share for new registered vans in 2020 [6].

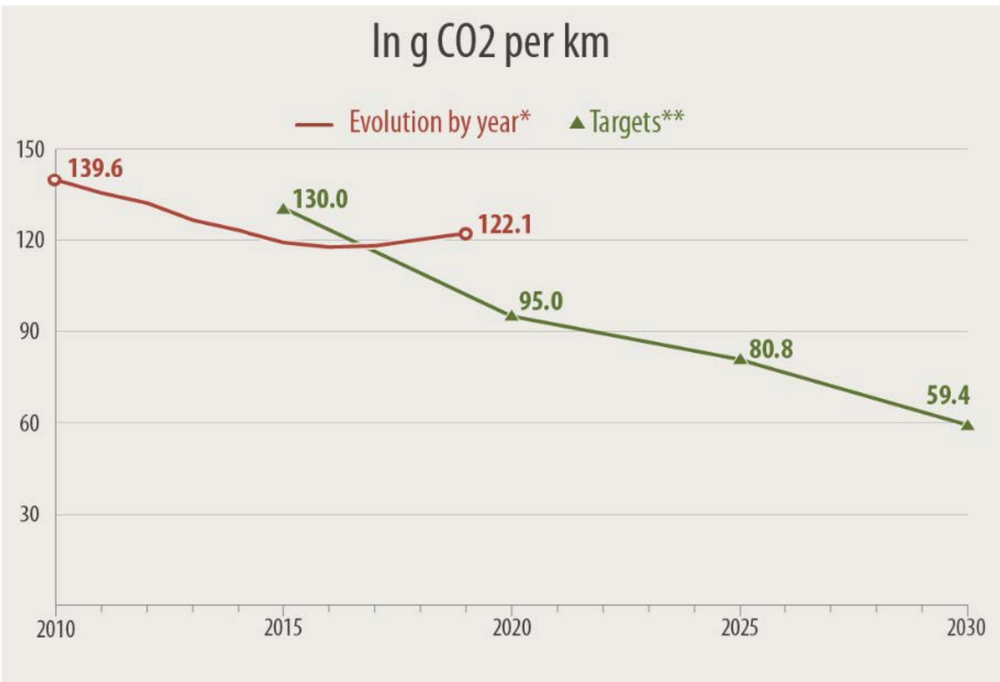

Figure 10. Evolution of CO2 emissions from new passenger cars. Source: [6]

In July 2021, the European Commission revised CO2 emissions standards for new passenger cars and light commercial vehicles. In June 2022 it was agreed to reduce the limit for emissions from cars and vans by a further 15 percent from 2025, followed by a 55 percent reduction for cars and 50 percent for vans by 2030 and to reach zero emissions by 2035 [29, 30].

In the year 2020 The PLM Green Global Alliance was formed "to foster an international community of product lifecycle management (PLM) professionals who collaborate on use of PLM-enabling technologies to address the challenges of sustainability, climate change and energy decarbonization [...]. **PLM lets product developers, marketing personnel and supply chain managers track weights, production costs, nutritional values and component volumes to satisfy compliance regulations and meet environmental goals. Using basic product data management capabilities within PLM, an engineer should be able to simulate expected carbon emissions of a new product design, then calculate and document the actual footprint during production.** Just as early design decisions define the final production cost of an item, these decisions will also determine most GHG emissions. PLM provides the core functionality to roll up the carbon footprint of different design variations, suppliers, production processes, customer uses and recycling scenarios" [31]. One of the aims of establishing the alliance was to study green technologies that can assist with the transition into a sustainable low-carbon circular economy. Some of the emerging new technologies include those that can calculate, manage and track the carbon emission footprint of products, processes and services.

Investment bank Goldman Sachs assesses that the most effective way to achieve the goals of Fit for 55, i.e. 55 percent CO2 emissions by 2030 is electrification on a scale leading to an increase in demand for electricity by half. The bank estimates that the implementation of Fit for 55 should be carried out by increasing electricity consumption by passenger cars, heat pumps, electrolysers and industrial installations. As a result, the share of electricity in primary energy consumption should increase from today's about 20 to 50 percent [32].

Increasing material efficiency is another key opportunity for moving towards the targets set in the Paris Agreement. Materials are vital to economies, but their production is an important source of greenhouse gasses - emissions from producing them increased from 5 gigatons of CO2-equivalent in 1995 to 11 Gt in 2015, with their share of global emissions rising from 15 percent to 23 percent. Most of the material-related emissions stem from the production of bulk materials: iron and steel (32 percent), cement, lime and plaster (25 percent), as well as plastics and rubber (13 percent) [33].

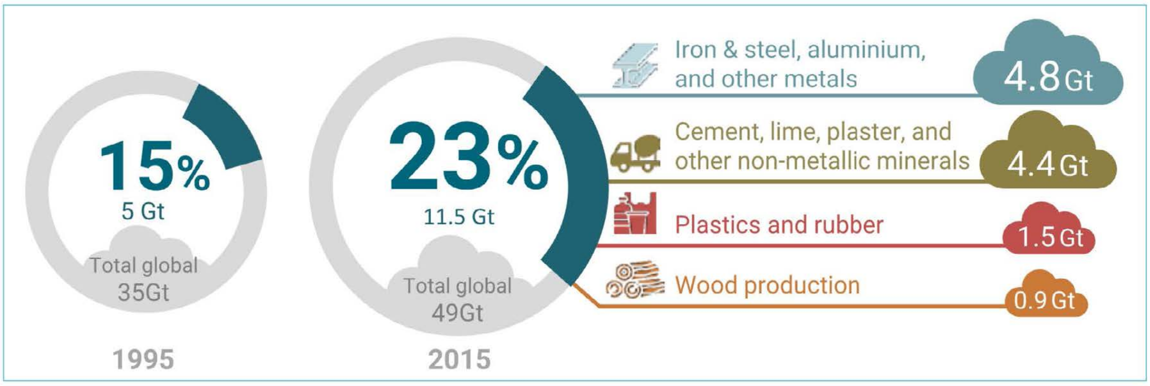

Figure 11. Emissions caused by material production as a share of total global emissions 1995 vs. 2015. Source: [33]

Research on redesigning products and services to minimize the use of materials or using recycled materials has been performed by Bassi and Dias in 2019 [19]. The results of the research have been presented in the figure below.

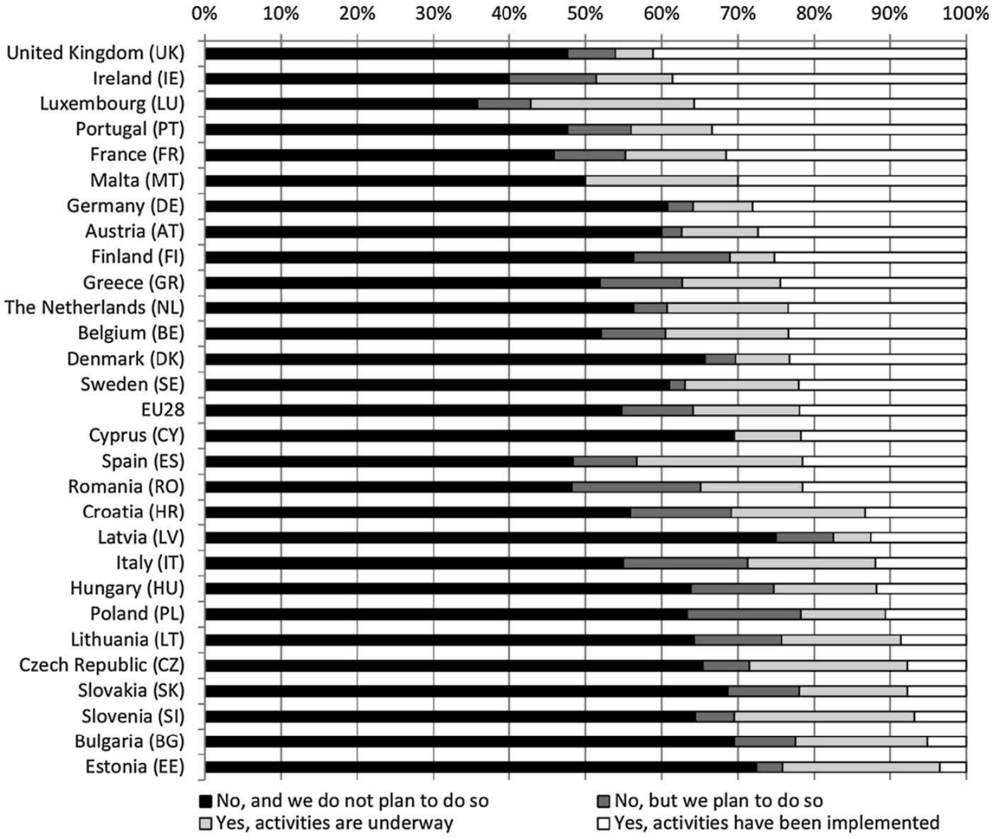

Figure 12. The use of renewable energy in the EU countries in 2016-2019. Source: [19]

Sustainable development, since its appearance in the 1992s, has gained popularity and extensively evolved to integrate the supply chain management field. It is sometimes comprehended as **"an ultimate value system to give orientation for decision making and action in different situations; [...] a framework for companies and their management to transform their responsibility for environmental, economical and social behavior into business practices within the legitimacy of our society"** [34]. Pressures and law regulations have significantly contributed to spread the application of environmental sustainability as a recent management mantra [35, 36]. Not only to fulfill new requirements but also to ensure the success of the company, currently organizations are facing challenges regarding establishing effective governance and internal control of sustainability-related operations. Companies need to conduct several internal assessments to determine the topics in sustainability that are important for them and their environment, including customers and investors. Recently, particularly Original Equipment Manufacturers (OEMs) became more sensible on environmental concerns and complied with some of the standards on presenting sustainability information [37].

Green Supply Chain Management has been defined as "integrating environmental thinking into supply-chain management, including product design, material sourcing and selection, manufacturing processes, delivery of the final product to the consumers as well as end-of-life management of the product after its useful life" [38, 39]. Therefore, Green Supply Chain Management can be considered as a tool to enhance performance of the organization.

In general, due to eco-innovations, eco-efficiency and corporate social responsibility practices define much of the current industrial sustainability agenda and sustainable business models are considered as innovations that change the way the organization creates, delivers and captures value. Sustainable business models consider and engage in operations with a wide range of stakeholder interests, including environment and society toward improvements in reducing energy, resource intensity, and emissions and waste per unit of production. **Business model innovations for sustainability has been defined as "innovations that create significant positive and/or significantly reduced negative impacts for the environment and/or society, through changes in the way the organization and its value-network create, deliver value and capture value (i.e. create economic value) or change their value propositions" [40].**

Important area of activities regards Sustainable Investment - a term that is "inclusive of investment approaches that consider environmental, social and governance (ESG) factors in portfolio selection and management across seven strategies of sustainable or responsible investment" [41]. Aforementioned seven strategies have been presented in the table below.

ESG integration	The systematic and explicit inclusion by investment managers of environmental, social and governance factors into financial analysis.
Corporate engagement & shareholder action	Employing shareholder power to influence corporate behaviour, including through direct corporate engagement (i.e., communicating with senior management and/or boards of companies), filing or co-filing shareholder proposals, and proxy voting that is guided by comprehensive ESG guidelines.
Norms-based screening	Screening of investments against minimum standards of business or issuer practice based on international norms such as those issued by the UN, ILO, OECD and NGOs (e.g. Transparency International).
Negative/exclusionary screening	The exclusion from a fund or portfolio of certain sectors, companies, countries or other issuers based on activities considered not investable. Exclusion criteria (based on norms and values) can refer, for example, to product categories (e.g., weapons, tobacco), company practices (e.g., animal testing, violation of human rights, corruption) or controversies.
Best-in-class/positive screening	Investment in sectors, companies or projects selected for positive ESG performance relative to industry peers, and that achieve a rating above a defined threshold.
Sustainability themed/thematic investing	Investing in themes or assets specifically contributing to sustainable solutions - environmental and social - (e.g., sustainable agriculture, green buildings, lower carbon tilted portfolio, gender equity, diversity).
Impact investing and community investing	**Impact investing** Investing to achieve positive, social and environmental impacts - requires measuring and reporting against these impacts, demonstrating the intentionality of investor and underlying asset/investee, and demonstrating the investor contribution. **Community investing** Where capital is specifically directed to traditionally underserved individuals or communities, as well as financing that is provided to businesses with a clear social or environmental purpose. Some community investing is impact investing, but community investing is broader and considers other forms of investing and targeted lending activities.

Table 1. Strategies of Sustainable or Responsible Investment. Source: [41]

Referring to the research performed by The Global Sustainable Investment Alliance (2020, data covering Europe, the United States, Japan, Canada, Australia and New Zealand) sustainable investment in these markets has reached USD35,3 trillion in assets under management, having grown by 15% in two years (2018-2020). Sustainable investment assets under management make up now a total of 35,9 percent of total assets under management, up from 33,4 percent in 2018. Canada experienced the largest increase in absolute terms over these two years and the growth reached 48 percent. Europe reported a 13% decline in the growth of sustainable investment assets from 2018 to 2020, however the reason is changed measurement methodology. Data has been presented in the Figure 13. below.

REGION	2016	2018	2020
Europe*	12,040	14,075	12,017
United States	8,723	11,995	17,081
Canada	1,086	1,699	2,423
Australasia*	516	734	906
Japan	474	2,180	2,874
Total (USD billions)	**22,839**	**30,683**	**35,301**

Figure 13. Global sustainable investing assets in the following years in billions USD.Source: [41]

The most common sustainable investment strategy is environmental, social and governance integration, followed by negative screening, corporate engagement and shareholder action, norms-based screening and sustainability-themed investment [41]. Details of sustainable investing assets by strategy & region in 2020 has been presented in the figure below.

Figure 14. Sustainable investing assets by strategy & region 2020. Source: [41]

The United Nations Sustainable Development Goals are a call for action by all countries to promote prosperity while protecting the planet. They recognize that ending poverty must go hand-in-hand with strategies that build economic growth and address a range of social needs including education, health, social protection, and job opportunities, while tackling climate change and environmental protection [42]. The 17 goals have been presented in the figure below.

Figure 15. 17 Sustainable development goals. Source: [42]

The Sustainable Development Goals Report is the only United Nations official report that monitors global progress on the 2030 Agenda for Sustainable Development. Recent report has been published in 2022 and highlights the confluence of crises, dominated by COVID-19, climate change, and conflicts, that are creating spin-off impacts on food and nutrition, health, education, the environment, and peace and security, and affecting all the Sustainable Development Goals. Recent report details the reversal of years of progress in eradicating poverty and hunger, improving health and education and providing basic services. It also points out areas that need urgent action in order to rescue the SDGs and deliver meaningful progress for people and the planet by 2030 [43].

In order to help countries and companies account for, report, and mitigate emissions the GHG Protocol has been developed. It was based on a report that identified an action agenda to address climate change that included the need for standardized measurement of GHG emissions [44]. This standard separates emissions into three scopes:

- **Scope 1,** that addresses emissions from directly owned and managed sources. Emissions are released here into the atmosphere as a direct result of a set of activities, at a firm level. It is divided into four categories:
    - stationary combustion (e.g fuels, heating sources) - all fuels that produce GHG emissions,
    - mobile combustion - all vehicles owned or controlled by a firm, burning fuel (e.g. cars, vans, trucks),
    - fugitive emissions - leaks from greenhouse gases (e.g. refrigeration, air conditioning units, noting that refrigerant gases are a thousand times more dangerous than CO2 emissions and companies are encouraged to report these emissions),
    - process emissions - released during industrial processes, and on-site manufacturing (e.g. production of CO2 during cement manufacturing, factory fumes, chemicals) [45].

- **Scope 2,** that addresses purchased energy including electricity, steam, heating and cooling (all energy a company has to acquire to run the business and its facilities),
- **Scope 3,** that addresses indirect emissions upstream and downstream activities (upstream covers the supply chain to acquire materials to produce products, and downstream includes the distribution, usage and end-of-life treatment) [31]. Namely, scope 3 emissions are all indirect emissions - not included in scope 2 - that occur in the value chain of the reporting company. According to GHG protocol, scope 3 emissions are separated into 15 categories (examples include employee commuting, waste generated, transportation and distribution, use of sold products) [45].

Companies reporting their emissions according to GHG Protocol must report Scope 1 and 2 to meet the protocol standards. Namely, Scope 1 and 2 are mandatory to report, whereas scope 3 is voluntary and the hardest to monitor. It is assumed that companies succeeding in reporting all three scopes will gain a sustainable competitive advantage [45]. Although reporting on Scope 3 is voluntary it is often the largest contributor to total emissions - it is estimated that Scope 3 emissions are often five times the amount of the combined Scopes 1 and 2 emissions. Implementing a strategy to provide accurate and verifiable carbon footprint data will require decomposing the emissions down from company and plant-level estimates to product and component-level actuals [31].

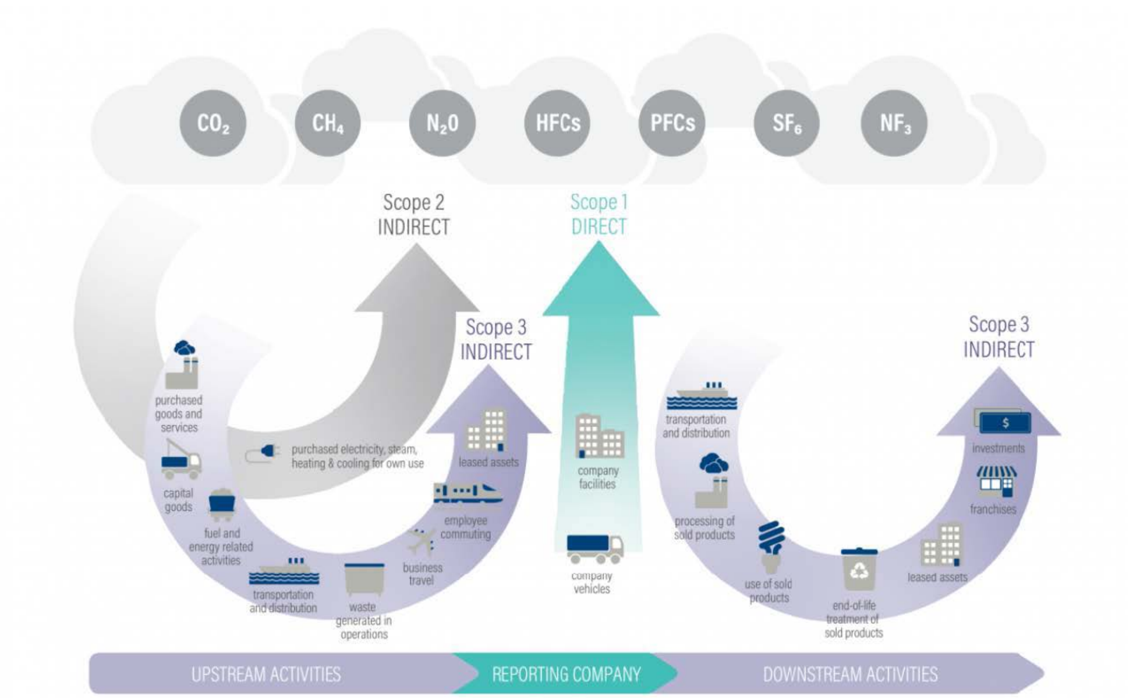

Figure 16. Overview of GHG Protocol scopes and emissions across the value chain. Source: [44]

_Status of implementation of concepts and regulations

EU Green Deal Survey [11] performed by PriceWaterhouseCoopers (March 2022, 300 businesses in 13 European countries) found that **49 percent of businesses are prepared for the EU Green Deal, 66 percent already earmarked capital for sustainability and 51 percent intend to shift their supply chain near term.** Unfortunately, **only fewer than half of organizations surveyed are familiar with the EU Green Deal.** It was found that sustainability initiatives are being undertaken rather on an ad-hoc basis, than as part of an integrated plan. Priorities include consuming more clean energy (78 percent of companies), reducing energy consumption (60 percent), reducing waste and plastic use (59 percent) and cutting carbon emissions (59 percent). For the surveyed companies, manufacturing (44 percent), distribution (27 percent) and procurement (18 percent) generate the highest emissions and are therefore the focus of the biggest sustainability efforts.

The PwC survey found that 70 percent of organizations have investigated ways to refurbish or repurpose products with a finite lifetime or expected obsolescence, including 28 percent doing it to a great extent and 42 percent to some extent. These organizations are more likely to be those who are familiar with and/or prepared for the implementation of the EU Green Deal. Moreover, 50 percent of respondents indicated that they are making efforts to reduce the amount of hazardous waste generated by their production processes and to increase the amount of waste being recycled [11].

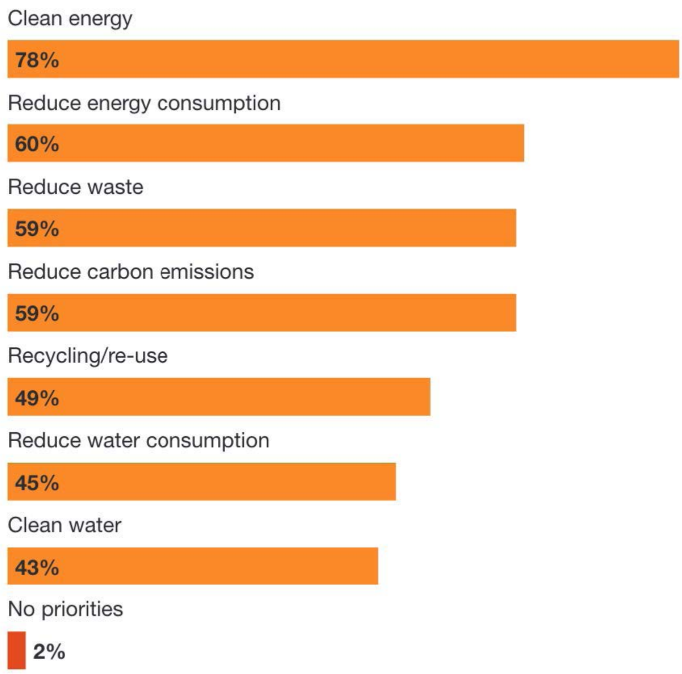

Figure 17. Priorities guided by environmental tax impacts, PwC EU Green Deal Survey. Source: [11]

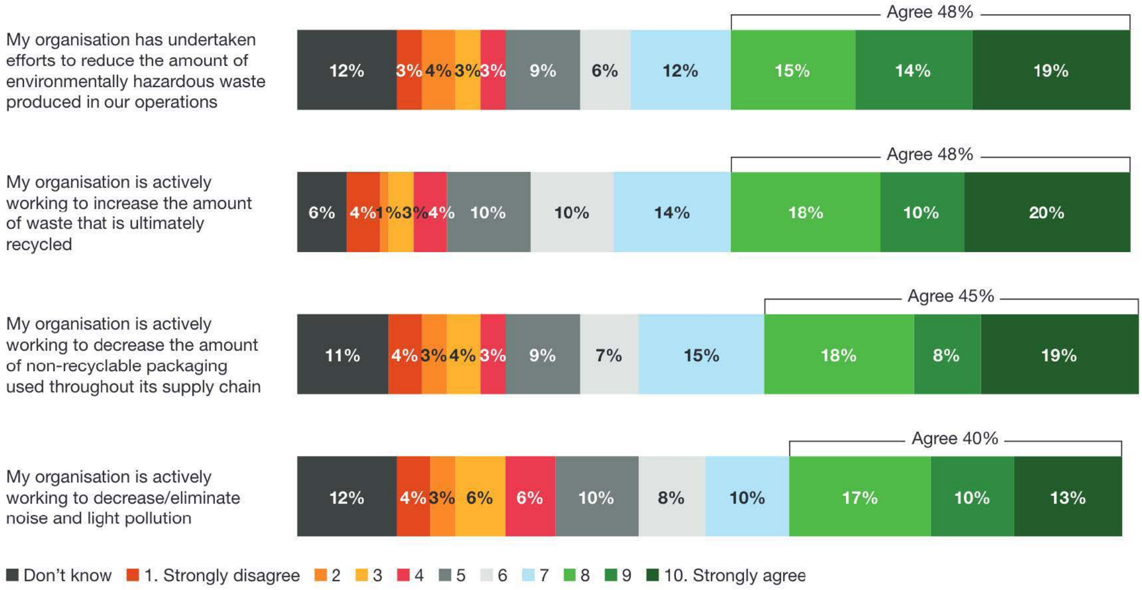

Figure 18. Efforts to reduce the amount of hazardous waste produced and/or increase the amount of waste that is recycled, PwC EU Green Deal Survey. Source: [11]

_Circular economy and its elements

The automotive businesses and operations currently in majority follow a linear approach, meaning that once a vehicle reaches its end-of-life, many of the components of the car will end up in landfills. Eurostat (2021) reported that the end-of-life vehicle weight had reached 5,2 million tonnes by the end of 2015 just in the European Union alone and increased to 6,9 million in 2019. More than 260.000 tonnes of automotive components were disposed of and sent to landfills without any further processing. OECD estimates that following the same trend of mining and using metal, minerals and energy, by 2060 we would require double the amount of resources to meet the global needs. Therefore, the Circular Economy has emerged as an approach addressing the environmental crisis at all levels [20].

In 2015, the European Commission adopted the circular economy action plan. Consisting of concrete and ambitious actions, with measures covering the whole life cycle: from production and consumption to waste management and the market for secondary raw materials and a revised legislative proposal on waste, it was planned to help stimulate Europe's transition towards a circular economy, boost global competitiveness, foster sustainable economic growth and generate new jobs. In 2019 it has been reported that all 54 actions have been adopted or implemented [48]. From a little-known concept from the late 20th century, the circular economy is now recognized by the European Union as an "irreversible, global mega trend" and became the component of the European Green Deal [49]. Over 10 billion EUR in public funding have been allocated to the transition by the Commission in the 2016-2020 period, including:

- "1.4 billion EUR from Horizon 2020 (until 2018), to circular economy projects addressing areas such as sustainable process industries, waste and resource management, closed loop manufacturing systems or the circular bio-economy, with 350 million EUR specifically for making plastics circular,
- at least 7.1 billion EUR from Cohesion Policy, of which 1.8 billion EUR for uptake of eco-innovative technologies among SMEs and 5.3 billion EUR to support the implementation of the EU waste legislation, with additional support being made available through the so-called smart specialization strategies of EU regions and Member States, for market-led innovation and deployment,
- 2.1 billion EUR through financing facilities such as the European Fund for Strategic Investments and Innovfin,

- at least 100 million EUR invested through LIFE in more than 80 projects contributing to a circular economy" [50].

Some of the automotive brands have been recently performing several actions with the purpose to transition to a circular economy. It has been presented in the table below.

Renault	Creation of 'Refactory', the first European factory dedicated to a circular economy mobility. Target to become carbon neutral in Europe by 2040.
Volkswagen	Closed material loop goals. Become carbon neutral by 2050. Battery recycling pilot project. Development of sustainable waste management. Circular Economy KPI's are under development.
Jaguar Land Rover	Net zero carbon emissions across their supply chain, products and operations by 2039. Use of alternative materials such as plant-based textiles and recycled plastic. Recovery of premium grade aluminum from scrapped vehicles to reduce the use of virgin aluminum.
Daimler	In support of the Waste Management Hierarchy, they aim to avoid waste by reusing (with a focus on HV batteries), recycling, and re-manufacturing their materials.
Volvo	To become a circular business with circular products by 2040. Increased use of remanufactured parts.
BMW	Efficient use of raw materials and their reuse and recycling. Use of pilot digital tools that could enable them to trace critical raw materials to improve the flow of goods globally.

Table 2. Automotive brands that have been recently performing actions with the purpose to transition to a circular economy. Source: own elaboration on the basis of [20]

Circular economy is considered as one of the most effective ways for the automotive industry to become more sustainable, covering many key areas of sustainability, from supply chain to recycling, procurement and after-sales. Not only car manufacturers but also suppliers are included in analysis. For example Michelin reuses 85% of old tires by rethreading them at its UK factory, saving 60kg of carbon emissions per tire [51].

_Implementation at organization level

No single person, but business leaders can support efforts of their own organizations' climate transformation, engage employees in actions, advocate for external organizations' taking steps to fight climate change, and collaborate and innovate on sustainability solutions across industries and disciplines. Referring to research performed by Deloitte perception of and concern for climate change among business leaders is increasing from one year to another. Of the **2.083 C-level executives** who responded to the survey in September and October 2021 (polled respondents from 21 countries: 44 percent from Europe/South Africa; 31 percent from the Americas; and 24 percent from Asia Pacific, all major industry sectors), **79 percent see the world at a climate change tipping point** - a number that was 59 percent in a similar Deloitte survey taken 8 months before (in early 2021). **88 percent agreed that with immediate action, the worst impacts of climate change can be limited.** That figure was 63 percent in the previous survey. **Over 66 percent claimed that their organizations are using more sustainable materials and increasing the efficiency of energy use. More than 50% have adopted energy-efficient or climate-friendly machinery, technologies, and equipment. And a majority are intentionally reducing air travel.** 19 percent of the surveyed leaders are implementing at least 4 of the 5 following actions:

- developing new, climate-friendly products or services,
- requiring suppliers and business partners to meet specific sustainability criteria,
- updating or relocating facilities to make them more resistant to climate impacts,
- incorporating climate considerations into lobbying and political donations,
- tying senior leader compensation to sustainability performance [53].

It is worth noting that leaders pointed out obstacles that they face on their way to sustainability. They include as follows:

- difficulty measuring environmental impact (30 percent),
- insufficient supply of sustainable or low-emissions inputs (27 percent),
- too costly (27 percent),
- focus on nearterm business issues/demands from investors/shareholders (25 percent),
- the magnitude of change needed is too large (24 percent) [53].

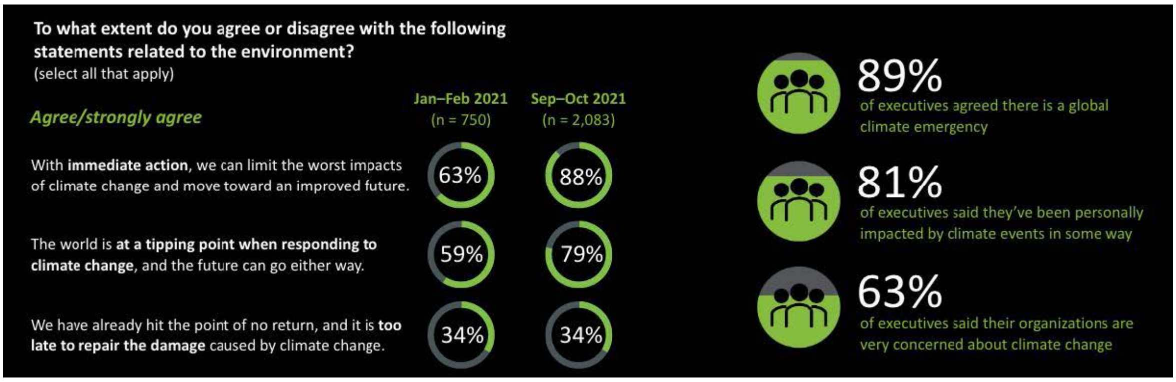

Figure 19. Figure source: [53]

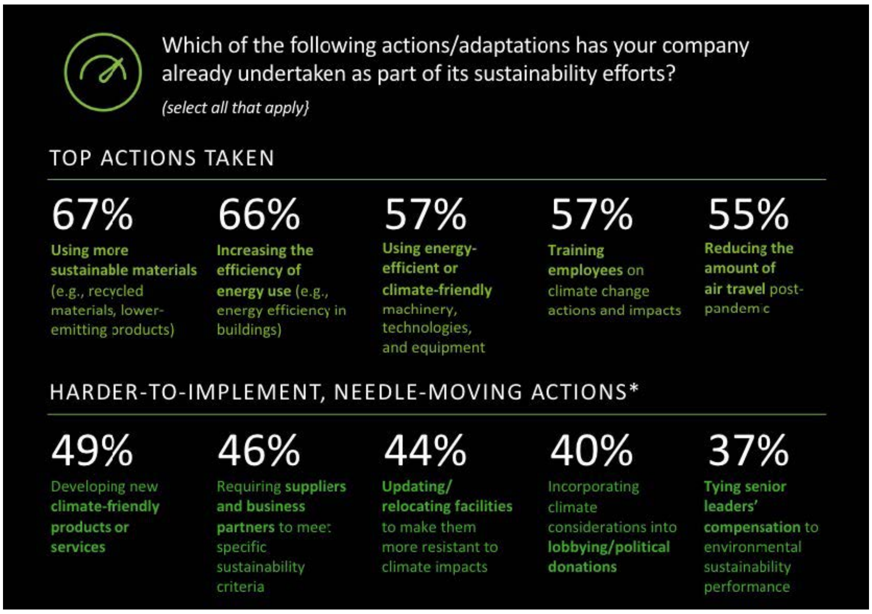

Figure 20. Figure source: [53]

In recent years the automotive industry continues to improve its sustainability, reducing energy use, sourcing more responsibly and increasing recycling. **The environmental performance of the products continues to improve. Huge progress has been made in all areas of the vehicle lifecycle, in terms of product and production decarbonisation, resource preservation and local air quality improvements.** Total energy (gas, electricity and oil) consumed by vehicle manufacturers was down 7,9 percent to 2,8 GWh in 2021, however due to reduced volume of vehicles produced the energy per vehicle rose by 4,5 percent year-on-year to 3.185 kWh. The rise in energy costs have ensured that energy has become an increasingly significant issue for the automotive industry. Energy is typically the second largest 'in-house' manufacturing cost, after labor, and so is critical to competitiveness [54].

The value of used electricity is dropping and in the recent year-to-year performance dropped 39 percent. It influences CO2 emissions that are calculated based on the official conversion factors for each energy stream used by manufacturers. Total CO2 produced (tonnes) from vehicle manufacturing and other operations was down -12,8 percent, while CO2 per vehicle produced dropped -1,2 percent to 0,63 tonnes due to further grid decarbonisation. Overall, it is -42,6 percent lower than in 1999. Green energy value of all the electricity used in 2021 was 44,6 percent [54].

Leaders of the automotive industry admit to using more and more sustainable resources while building healthy ecosystems for future generations. Activities range from small-scale local projects (i.e. investing time and resources in conserving the flora and fauna in their locality), to more extensive collaborations that have a wider significance and are helping to preserve and even improve the local ecosystem [54].

Total water consumed by the signatories was down -17,3 percent in 2021 year-on-year, while water consumed per vehicle dropped by -6,3 percent, due to increased efficiency despite a much reduced volume of vehicles produced. Waste to landfill per vehicle dropped -2,6 percent year on year to 1,3 kg per unit. In 2021 83,1 percent of waste was recycled, while 15,2 percent was reused or recovered [54].

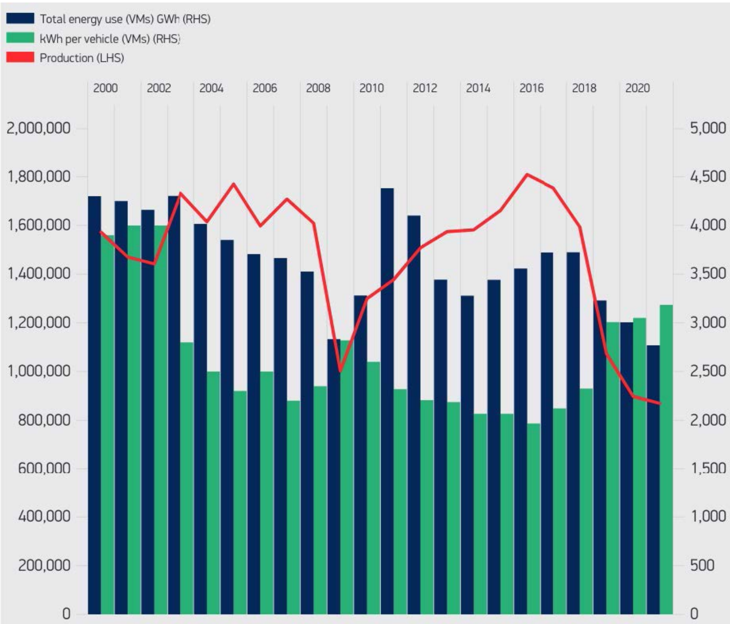

Figure 21. Energy usage vs production. Source: [54]

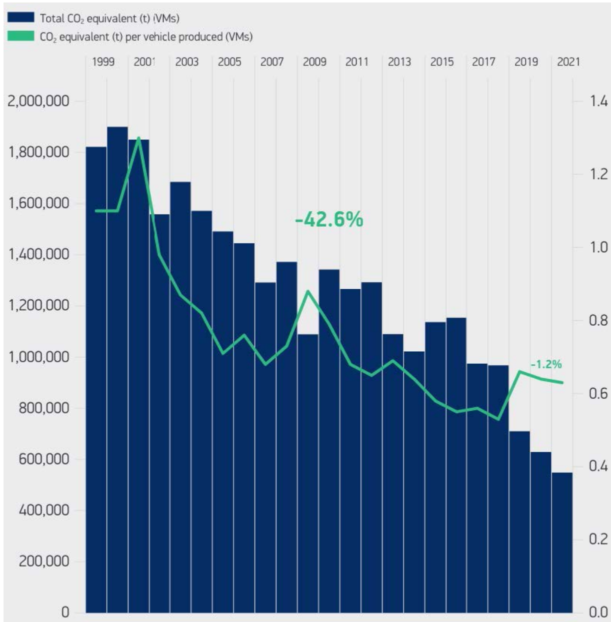

Figure 22. Total VM per vehicle CO2. Source: [54]

_Assessment of the possibility of using existing databases -

a report containing an assessment of the identified indicators

_Industrial sectors ready for Green PLM on the example of automotive industry (automobiles, parts, services)

Sustainable industrial development has been one of the main issues of interest for all countries since the 50th of the XX century [56]. According to Vaz et al. sustainable measures, including corresponding indicators, require certain investments in research and development as well as a certain time frame until they can be adopted as a new paradigm of production [57]. Javaid et al. underline that "sustainable manufacturing seeks to integrate into the industrial sector the fundamental values of sustainable development. It contributes to increased environmental, social, and economic efficiency. (...) Worldwide, manufacturers are pressurised to reduce their environmental effects. It involves learning the incoming requests, identifying and applying environmentally-friendly activities that are most appropriate, and tailoring them to meet the industry needs"[58]. The Product Environmental Footprint (PEF) has a profound impact on the environmental sustainability, however most of the existing PEF models fail for product life cycle [59]. In 2018 the European Commission launched Single Market for Green Products Initiative and in 2021 proposed the Product Environmental Footprint (PEF) and Organisation Environmental Footprint (OEF) methods as a common way of measuring environmental performance [60]. PEF method for modelling the environmental impacts of the flows of material/energy and resulting emissions and waste streams associated with a product from a supply chain perspective (from extraction of raw materials, through use, to final waste management) [61]. OEF is calculated using aggregate data representing the flows of resources and wastes that cross the defined organisational boundary [62]. The final Product Environmental Footprint Category Rules (PEFCRs) and Organisation Environmental Footprint Sector Rules (OEFSRs) can be used for calculating the Environmental Footprint profile for products and organisations in scope. According to European Commission, within the Environmental Footprint impact categories groups of indicators were selected:

- **Climate change**
    - Ozone depletion56
    - Human toxicity - cancer effects
    - Human toxicity - non-cancer effects

- **Particulate matter**
    - Ionizing radiation HH
    - Photochemical ozone formation
- **Acidification**
    - Eutrophication - terrestrial
    - Eutrophication - freshwater
    - Eutrophication - marine
    - Ecotoxicity - freshwater
    - Land use
    - Water scarcity
    - Resource use, mineral
    - Resource use, energy carriers

PEF Life cycle stages assessment should cover (as a minimum) stages:

1. Raw material acquisition and pre-processing (including production of parts and components);
2. Manufacturing (production of the main product);
3. Distribution (product distribution and storage);
4. Use;
5. End of life (including product recovery or recycling).

Marcon et al. indicate that among products having sustainable attributes - apart from food, clothing, and housing, - **automobiles** have been investigated most often [63]. Analysis of different sectors shows that the automotive industry is crucial from an environmental point of view - according to the publication of the United Nations Environment Programme (UNEP) referring to the "Resource Efficiency and Climate Change: Material Efficiency Strategies for a Low-Carbon Future" report: "producing and using materials more efficiently to build passenger cars and residential homes could cut CO2 equivalent emissions between 2016 and 2060 by up to 25 gigatons across the Group of Seven (G7) member states" [64]. According to [65] road transport contributes heavily to the overall environmental impact as it causes approximately 20% of greenhouse gas (GHG) emissions. The European Commission in the "sustainable and smart" mobility strategy is expecting to have at least 30 million zero-emission cars on European roads by 2030 [66]. Hannon et al. notice that although powertrains electrify to meet these expectations, in fact, the largest contributor of automotive carbon emissions will come from vehicles' material production - at least 30% by 2030 [66]. The analysis focused on the automotive industry shows that the implementation of changes related to material efficiency may positively affect reductions of greenhouse gas emissions in light-duty vehicles - according to research presented in [67] emissions from the production of materials for the manufacture of cars could be reduced by 30% to 70% in 2050. Thus it is crucial for the automotive industry and the Original Equipment Manufacturers (OEMs) in particular to radically redesign their products and processes. Car producers facing strong regulatory pressure for sustainability will have to reduce resource consumption in production, improve the recyclability of materials, and reduce tailpipe emissions during operation [65]. Therefore, what is expected in the first place is transparency: **"manufacturers must create transparency on the emissions embedded in their upstream activities"**[66]. Moreover, automotive companies will have to shift toward sustainable design, investment in clean technologies, and value creation for local and global communities [65].

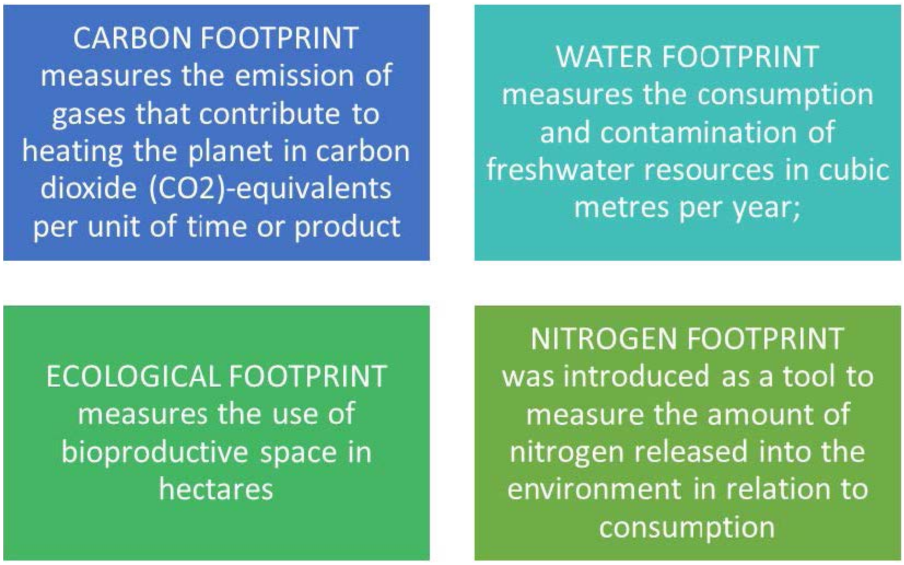

Figure 23. Footprints definitions; source: [66]

In order to ensure the transparency about the greenhouse gas (GHG) emissions of products, a number of methodologies have been developed. In general they can be divided in two main groups (all listed standards are based on the principles of ISO 14040 and ISO 14044) [68]:

- Single-issue methodologies, covering only emissions and impacts related to climate change:
  - The ISO 14067 standard - the international reference standard for conducting PCF,
  - National standards (e.g. PAS 2050 developed by the British Standards Institute - considered the first carbon footprint standard used internationally),
  - The GHG Protocol Product Standard;
- Methodologies that have a broader scope, covering environmental issues beyond climate change:
  - The Product Environmental Footprint (PEF) - EU-recommended method to perform LCA,
  - National standards (e.g. BP X30-323-0),
  - EN 15804 - the European standard providing core product category rules for all construction products and services.

The concept of "water footprint" was initially introduced by Hoekstra. The water footprint is divided into three main categories [67]:

- **blue water footprint** - "the volume of surface and groundwater consumed (evaporated) as a result of the production of a good",
- **green water footprint** - "the rain water consumed",
- **grey water footprint** - "the volume of freshwater that is required to assimilate the load of pollutants based on existing ambient water quality standards".

Hirz and Brunner point out that **eco-design** in the **automotive industry** requires a comprehensive consideration of numerous influencing factors [68]. According to Javaid et al. implementation of new manufacturing technologies (e.g. additive manufacturing) that enable the production of parts that can replace complicated assemblies saves material [58] and makes vehicles lighter parts for better fuel economy. Thus, manufacturing processes become less difficult than for example stamping and welding. Similarly, different lightweight materials (e.g. aluminium) are used to replace steel [68]. In consequence, manufacturers can become more sustainable by finding ways to use fewer resources and content [58]. From the PLM point of view, there is an urgent need to define corresponding indicators that will be able to measure, track, monitor and assess these changes in order to appropriately follow guidelines of sustainable manufacturing. One of the key aspects in terms of energy consumption reduction in the automotive industry is reducing the weight of a car [70]. Apart from lightweight, the most common approaches implemented by OMEs in terms of designing are [65]:

- manufacturing processes/technologies optimization,
- vehicle assemblies/components redesign,
- more efficient materials usage.

Results of the study performed by Vaz et al. show that the automotive industry in order to reduce the environmental impact associated with production has focused on [57]:

- outsourcing renewable and recycled materials,
- implementing clean technology and environmental management systems in individual manufacturing sites and throughout the supply chain,
- reducing material inputs,
- changing manufacturing processes to reuse byproducts and, where possible, alternative, less toxic materials,
- seeking technological alternatives to the internal combustion engine (ICE).

Similarly, the analyses presented in the above-mentioned report on "Resource Efficiency and Climate Change: Material Efficiency Strategies for a Low-Carbon Future" show that the following material cycle improvements should be implemented in the automotive industry to reduce negative environmental impact [67]:

- increased fabrication yields and fabrication scrap diversion,
- light-weighting of vehicles through a shift from steel to aluminium,
- lifetime extension and increasing the reuse of parts and recycling of materials from end-of-life vehicles.

According to Ciceri et al., the above assumptions can be met by implementation of the Sustainable Engineering concept, which is understood as **"as a layer of engineering oriented approaches, methods and tools crossing the four pillars of Society, Economy, Environment and Technology for achieving sustainability oriented results."** In practice, it means applying scientific knowledge to the design and implementation of products, materials, technologies and processes, taking into account the specifics of each of the 4 pillars of sustainable development in order to create solutions for design, operational and organizational activities related to products, processes, services and culture in the manufacturing sector [71].

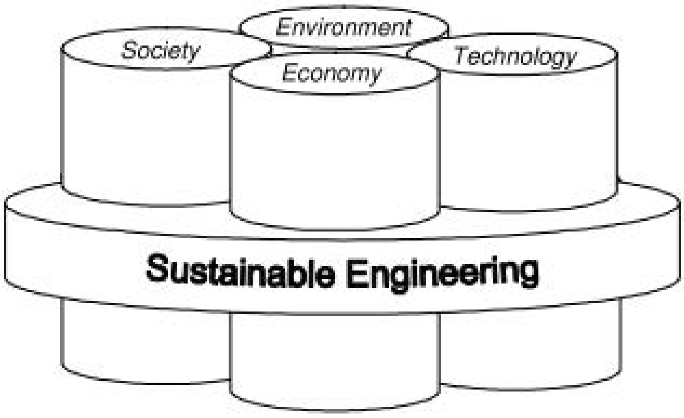

Figure 24. Pillars of sustainable development; source: [71]

Nowadays, without a doubt, **sustainable development is becoming to play a critical role in the automotive industry.** Apart from merely an economic point of view, also ecological and societal aspects are taken into account by customers and regulations, and thus have to be deeply considered by car producers [70]

- Ecology-related factors focus on:
  - the consumption of energy,
  - the consumption of resources,
  - the effects of produced substances and influences on the environment;
- Society-related factors take into account:
  - the involvement of staff,
  - the influences on the general society.

The above-mentioned need to be considered during the entire life cycle of an automobile [70]:

- conception phase,
- development phase,
- production engineering phase,
- manufacturing phase,
- in-use-phase,
- recycling and disposal phase.

The figure below presents the key steps in the lifecycle of a car clustered in main phases. Moreover, the influences from society, ecology and economy are highlighted [70].

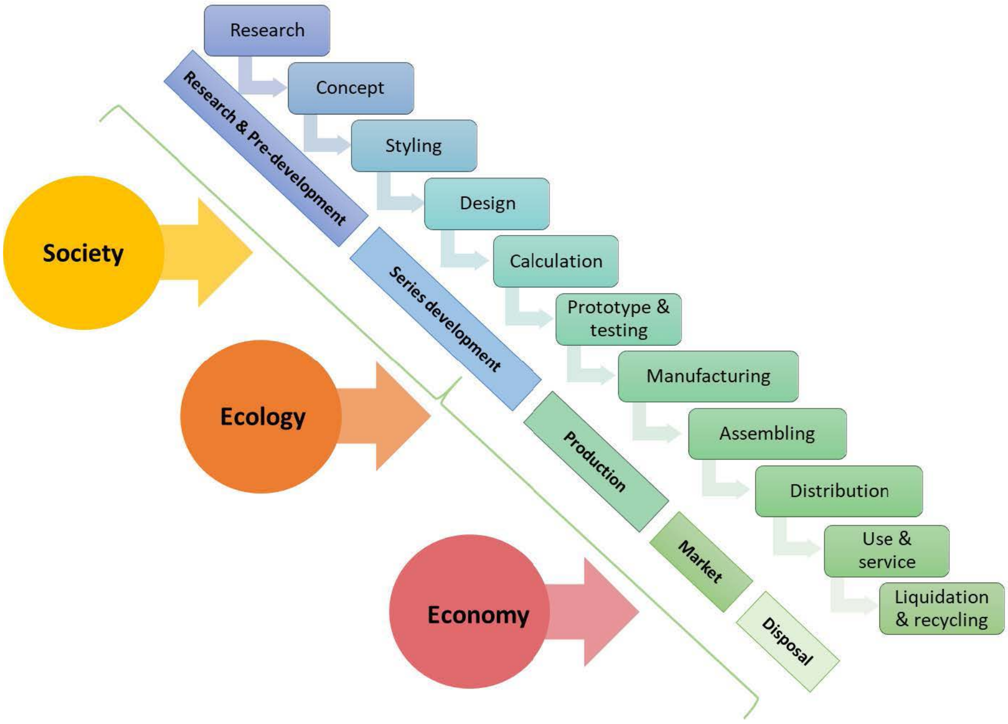

Figure 25. Lifecycle of a car and influencing factors; source: [70]

The first phases during which the design of new products and related production and organizational processes takes place are of particular importance. Decisions made at this stage affect all the above-mentioned phases. **Sustainable product design** means designing products and processes that meet the following requirements [72]:

- The raw material obtained meets the environmental and social criteria.
- In the supply chain, all parties involved ensure that distances are kept as short as possible and arrange only absolutely necessary transport.
- The products are designed to have a maximum service life.
- The products are also designed to be easy to repair ("refurbishing") and reusable in the aftermarket.
- They can be repaired and upgraded, for example by replacing components.

Development of the **new digital factories** and pressure from the legislators require **adjustment of existing PLM systems.** They need to support the companies in terms of collaborative processes and workflows to enhance sustainable information sharing. According to Belkadi et al., the **key challenge** in this context is not only **the definition of information flow between all involved entities in the sustainability process** but also the **mapping of information between different production lifecycle phases** [73]. In the investigated area a number of definitions have been developed to better precise the emerging area, including:

- Sustainable products [74],
- Closed Loop Lifecycle Management (CL2M)[75]
- Green Information Systems [75],
- Sustainable PLM [75],
- Intelligent Products [75].

A figure below presents the above-mentioned terms with corresponding definitions:

TERM	DEFINITION
Sustainable products	products with positive social and/or environmental attributes
Closed Loop Lifecycle Management (CL2M)	attempts to extend PLM also to the usage, refurbishing, disposal and other lifecycle phases that product instances go through.
Green Information Systems	studies how to reduce the production of CO2 and other greenhouse gases through new combinations of people, processes, and technologies that enable the processing of digitized information
Sustainable PLM	a type of Closed Loop Lifecycle Management (CL2M) for the purpose of improving environmental sustainability during all phases of the lifecycle
Intelligent products	provide a model for how an information system can integrate supply and demand data to increase energy efficiency; Intelligent Products and messaging interfaces are the technological basis for introducing instance based architectures for Sustainable PLM

Figure 26. Definitions related to Green PLM; source: [74], [75]

In terms of sustainable products a number of indicators can be considered in order to provide the customers with the appropriate assurance and information about their sustainability performance, for example [74]:

- Sustainability labels:
  - organic,
  - fair-trade,
  - non-GMO;
- Narrative claims and physical appearance:
  - bio-degradable packaging,
  - less packaging.

According to Främling et al. **Sustainable PLM** can be defined as a type of **Closed Loop Lifecycle Management (CL2M).** The key feature is the possibility to connect Intelligent Products with each other and at the same time with other information systems. The systems that are called **Green Information Systems** (Green IS) aim at reducing environmental impacts [75]. Their focus is to reduce ”the production of CO2 and other greenhouse gases through new combinations of people, processes, and technologies that enable the processing of digitized information”[75]. Främling et al. underline that the main purpose of CL2M is to constantly improve design, manufacturing, use and end-of-life handling of products, in order to obtain “improved quality, less breakdowns, reduced need for spare parts and ensuring an operation that is continuously maintained at the most energy- and resource-efficient level”[75]. According to Främling et al. Sustainable PLM should be understood as CL2M for the purpose of improving environmental sustainability during all phases of the lifecycle. A key issue in terms of Sustainable PLM is related to measurement of environmental sustainability and ways to improve it. Therefore, it is crucial to measure, gather, and analyse data and corresponding indicators which can be a firm basis and a trigger for companies in their shift towards green production. A helpful approach in this process is LCA, which stands for **Life Cycle Assessment or Life Cycle Analysis** defined a methodological framework for estimating and assessing the environmental impacts attributable to the life cycle of a product [75]. According to Främling et al., it is hard to extend and / or adapt existing ERP systems to the requirements of Sustainable PLM. Främling et al. state that “it is likely that an easier, safer, and more scalable approach is to develop and increase the use of Intelligent Product-based information systems separately and communicate with stock-based information systems using their own external interfaces. The multi-organizational, multi-manufacturer, etc., reality and requirements of Sustainable PLM can only be met in a scalable way if ad hoc, loosely coupled interoperability between devices and other information systems is technically easy and economically feasible enough. Failing to recognize the importance of loosely coupled integration can delay the speed of evolution and adoption of Sustainable PLM” [75].

According to Vila et al. a **Green PLM strategy** should be composed of Mission, Vision and Objective as presented in the Figure below:

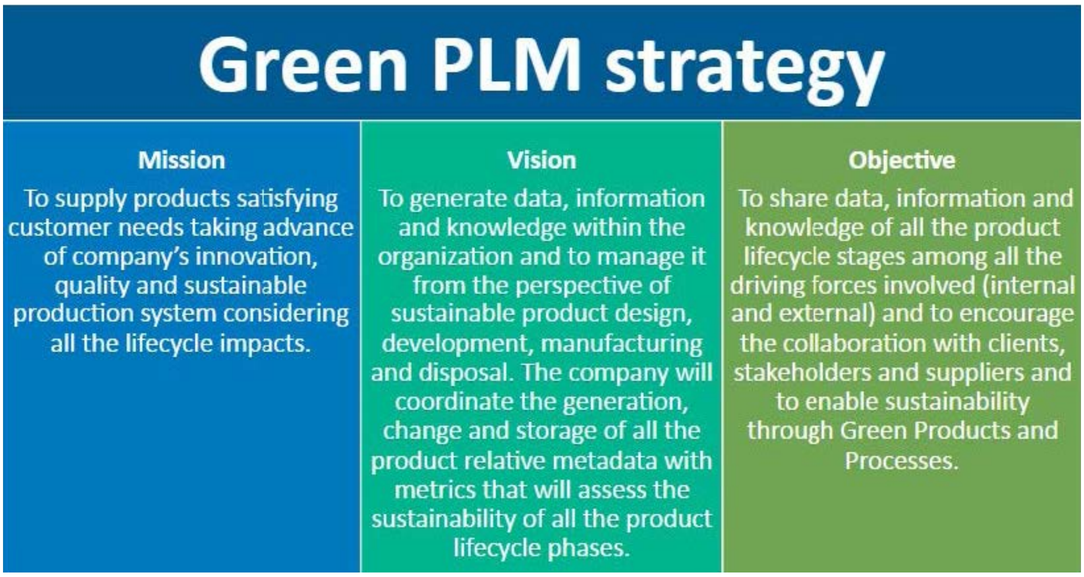

Figure 27. Figure **Green PLM strategy**; source: [56]

The figures below represent approaches (56) to product lifecycle with green competencies [56], (57) Green Product Lifecycle Framework [56], and (58) a framework of green product attributes' groups divided into product life cycle phases [63].

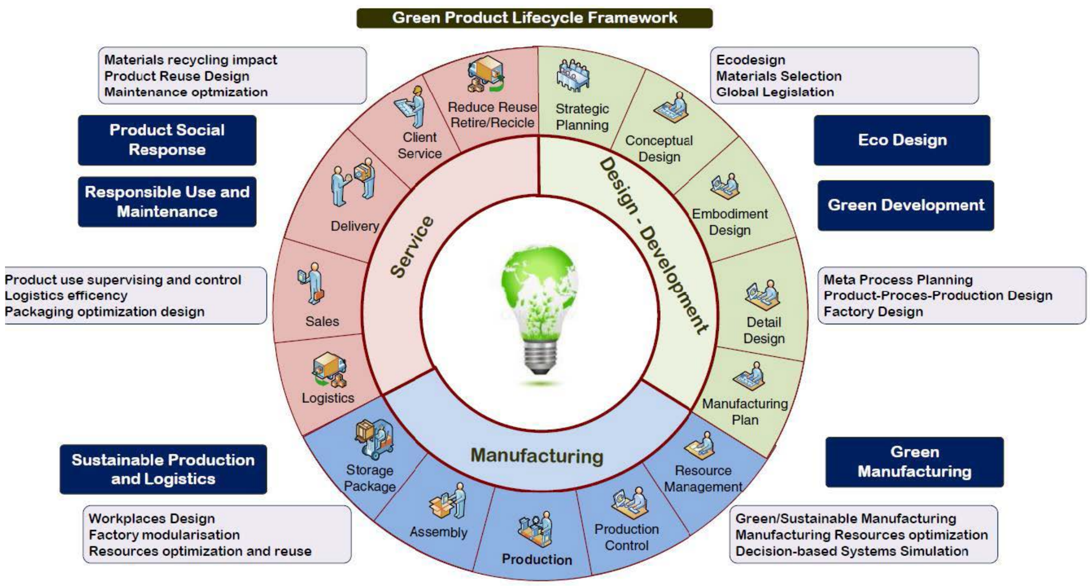

Figure 28. An approach to product lifecycle with green competencies proposed by Vila et al.; source: [56]

According to Vila et al. **Green Product Lifecycle Framework** should be composed of 3 main phases [56]:

1. **Design-Development phase,** focused on Eco Design and Green Development, composed of:
   - Strategic Planning,
   - Conceptual Design,
   - Embodiment Design,

- Detail Design,
- Manufacturing Plan;

2. **Manufacturing phase,** focused on Green Manufacturing and Sustainable Production, composed of:
   - Storage Package,
   - Assembly,
   - Production,
   - Production Control,
   - Resource Management;
3. **Service phase,** focused on Sustainable Logistics, Product Special Response and Respon-sible Use and Maintenance, composed of:
   - Logistics,
   - Sales,
   - Delivery,
   - Client Service,
   - Reduce/ Reuse / Retire / Recycle;

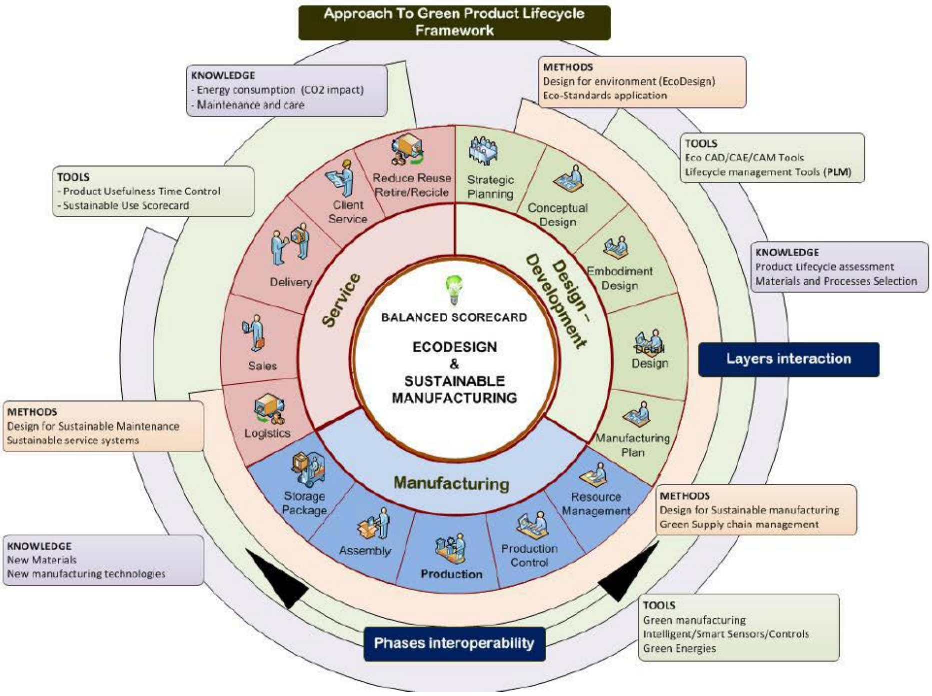

Figure 29. An approach to Green Product Lifecycle Framework proposed by Vila et al.; source: [56]

For each of the 3 above-mentioned phases, Vila et al. propose an approach based on dedicated methods, tools and knowledge, as follows [56]:

1. **Design-Development phase:**
    - **Methods:**
        - Design for environment (Eco Design)
        - Eco-standards application
    - **Tools:**
        - Eco CAD/ CAE/ CAM tools
        - Lifecycle management tools (PLM)
    - **Knowledge:**
        - Product lifecycle assessment
        - Materials and process selection
2. **Manufacturing phase:**
    - **Methods:**
        - Design for sustainable manufacturing
        - Green Supply chain management
    - **Tools:**
        - Green manufacturing
        - Intellignet/ smart sensors/ controls
        - Green energies
    - **Knowledge:**
        - New materials
        - New manufacturing technologies
3. **Service phase:**
    - **Methods:**
        - Design fo Sustainable Maintenance
        - Sustainable service system
    - **Tools:**
        - Product Usefulness Time Control
        - Sustainable Use Scorecard
    - **Knowledge**:
        - Energy consumption (CO2 impact)
        - Maintenance and care.

Marcon et al. propose another framework for a green product (figure below). They divided green product attributes' groups into 3 main product life cycle phases, namely - (56) Production, (57) Use and (58) End-of-life [63].

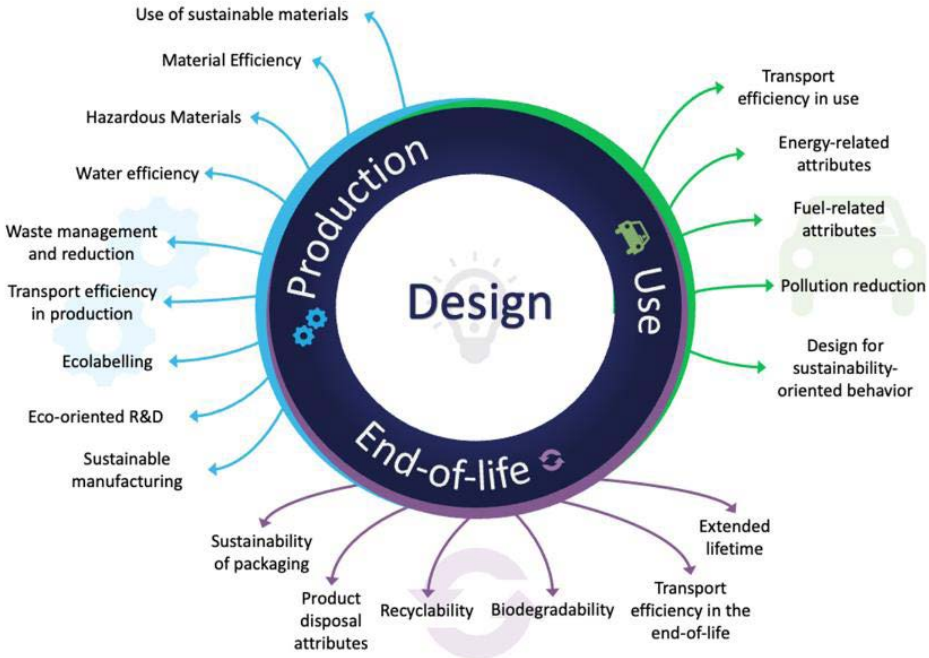

Figure 30. A framework of green product attributes' groups divided into product life cycle phases proposed by Marcon et al.; source: [63]

Importance of intrinsic and extrinsic attributes for the purchase decision of cars and furniture.

	Importance level frequency					Avg.
	1	2	3	4	5	
Car attributes						
Economy	0	3	13	28	56	4.37
Design	2	1	16	50	31	4.07
Engine	1	1	19	38	41	4.17
New technologies for reducing emissions	3	8	22	27	40	3.93
Materials used for finishing	5	11	17	38	39	3.75

Respondents' preferences for green product attributes included in the experiment.

		Frequency
Car attributes		
Engine	Flexible-fuel	63%
	Hybrid	37%
New technologies	Emission reduction	61%
	Use of biomass for fuel	39%
Finishing materials	Natural fibers	43%
	Recycled materials	57%

Table 3. Importance of intrinsic and extrinsic attributes for the purchase decision of cars and furniture; Source: [72]

_Identification and analysis of indicators

The literature research shows that in many studies, indicators and concepts for sustainable development have been explored and defined based on five dimensions: economics, ecology, society, technology and performance management. Many organizations are making some efforts in this regard. The result of the work carried out by the United Nations Environment Program (UNEP) and the US NGO is the Global Reporting Initiative (GRI), which defined more than 100 indicators and focused on the first three dimensions. Another effort of the National Institute of Standards and Technology (NIST) is the Repository of Sustainable Production Indicators (SMIR), which defined widely available sets of indicators and focused on five dimensions.

Also, academia and research centres have carried out and are carrying out a lot of research on this subject. Based on the analysis of the results of the above-mentioned activities, it is possible to define an initial general division of indicators that determine the sustainability of the product [77].

Dimensions	Sustainability indicators	Dimensions	Sustainability indicators
Economy	Investment	Society	Labor Practices
	Economic performance		Human Rights
	Product Presence in the market		Social influence
	Green Process Design		Product Responsibility
	Green Manufacturing		Eco-design Responsibility
Ecology	Energy emissions		Innovative new materials care
	Carbon Foot Print	Technology	Life Cycle Assessment
	Waste Reduction		Design for Environment tools
	Water Usage		Zero Emissions &Waste
	Compliance		

Table 4.c. Successful sustainability indicators.

Regarding ecology, in 2012, the European Commission proposed a multi-standard indicator, named as product environmental footprint (PEF), to measure the environmental performance of a product throughout life cycle [78]. PEF assessment system contains 14 impact types: climate change, ozone depletion, ecotoxicity - freshwater, human toxicity - cancer effects, human toxicity - non-cancer effects, inhalable inorganics, ionizing radiation, photochemical ozone synthesis, acidification, eutrophication - land, eutrophication - water body, water consumption, minerals and fossils consumption, as well as land transfer. He et al. developed a method to evaluate these impacts on product lifecycle that can be applied in product development in various industries [59].

Khan et al. proposed a life cycle indexing system — LInX, which facilitates the LCA application in process and product evaluation and decision-making [79]. It covers four main groups of indicators: environment, health and safety (EHS), cost, technical feasibility, and socio-political factors. Each of the group was divided into more specific attributes:

1. **Environment, health and safety:**
    - Resource depletion;
    - Greenhouse effect;
    - Ozone depletion;
    - Acidification potential;
    - Oxidation potential;
    - Mass of air pollutants released;
    - Mass of water pollutant released;
    - Mass of solid waste disposed;
    - Human health risk;
    - Ecological risk;
    - Safety risk;
2. **Technology**
    - Technical Feasibility;
    - Process conditions;
    - Energy efficiency;
    - Human–machine interaction;
3. **Cost house**
    - Fixed cost;
    - Operation and maintenance cost;
    - Health, safety, and environment cost;
4. **Socio-political house**
    - Socio-political acceptance;
    - Vulnerability of area;
    - Social impacts.

According to Hirz and Brunner four main groups of influencing factors on a car's life cycle performance can be distinguished [70]:

1. **Technical specifications:**
    a. Vehicle type, size and weight,
    b. Propulsion technology,
    c. Vehicle technology,
    d. Materials,
2. **Supply of resources and energy:**
    a. Type and amount of energy for production and use,
    b. High-/low impact materials,
3. **Raw-materials:**
    a. Production and recycling technology
    b. Efficient production, supplier and logistics processes,
    c. Design for recycling,
    d. Recycling technologies,
4. **In-use phase:**
    a. Transportation demands,
    b. User profiles, driving behaviour,
    c. Fuel- and energy consumption,
    d. Maintenance and service effort.

The following table comprises measures for Eco-design divided into phases proposed by Staniszewska et al. [80].

Area	Measures	Current state	Potential improvement	Impact on environment
Design	Weight of the product and its parts	Mass of products has been increasing steadily	Lighter product means less material	Medium
	Consumption of fuel	Products use fuel and gas, bigger and bigger engines are produced	Using hybrid, biofuels, electric cars and lightweight constructions	High
	Number of parts	Complicated designs with a lot of features	Simplifying the design	Medium
Raw materials	Resources used	Use of coal plants and nuclear plants	Increased use of renewable energy	High
	Hazardous materials	Use of toxic paint	Use of eco and natural paint	High
	Use of materials from recycling	Use of newly produced materials	Reuse of materials from old cars (aluminium,plastics,etc.)	Medium
Manufacturing and distribution	Use of media (energy, water)	Use of coal plants and nuclear plants, use of fresh water	Increased use of renewable energy and wastewater treatment plant	High
	Amount of waste	Big amounts of waste from manufacturing, documentation, packaging	Use of multiuse products, electronical communication, lean manufacturing etc.	Medium
	Use of hazardous materials	Use of harsh and toxic	Use of eco and natural substances	High
	Pollution	Pollution from electricity and fuels	Use of filters and modern ecological machines	High
	Type of packaging	Single use packaging, multi packaging	Single, recyclable packaging	Medium
	Mode of transport	Use of trucks	Use of rail and multimodal	High
	Size and weight	Products are heavy	Producing lightweight vehicles	Low
	Documentation	Paper documentation	Electronical documentation	Low
	Stock	High stock of materials and products	Lean management	Low
	Intensity	Delivery of few vehicles at once, depending on mode of transport and customer order	More rare but higher quantity deliveries	Medium
End of life	Reuse of parts	Landfilling the parts due to difficult reprocessing	Use of new technologies that help with reprocessing	High
	Hazardous waste	Inappropriate handling due to high cost	Raising the knowledge about handling and its consequences	High

Figure 31. Measures for Eco-design divided into phases proposed by Staniszewska et al.; source: [80]

Zhao et al. focused on the following sustainability-related indicators [81]:

- “GRI **(Global Reporting Initiative)** Sustainability Indicator - In 1997, the United Nations Environment Programme (UNEP) together with the United States nongovernmental organization, Coalition for Environmentally Responsible Economics (CERES) launched the GRI with the goal of “enhancing the quality, rigour and utility of sustainability reporting”[82]. Reporting is therefore the strong focal point of the guidelines. The GRI uses a hierarchical framework in three focus areas, namely social, economic, and environmental. The hierarchy consists of categories, aspects, and indicators. The guideline contains more than 100 indicators. However, not all the indicators are easy to evaluate and no guidance is given on how to choose between the indicators[83]. The guideline does, however, indicate what should be considered at a lower level, i.e. operational or project level within the company, especially if the company reports on sustainability using the GRI principles”[84].

- **“The Institution of Chemical Engineers** (IChemE) published a set of sustainability indicators in 2002 to measure the sustainability of operations within the process industry. The IChemE provides standard reporting forms and conversion tables [85]. This framework is less complex and impact-oriented. However, the framework strongly favours environmental aspects, as well as quantifiable indicators that may not be practical in all operational practices, e.g. in the early phases of a project’s life cycle [86]”.

Zhao et al. based elements associated with sustainable development on GRI reports and IChemE reports [87]. According to figure below, the elements of sustainable development for sustainable PLM are divided into **environmental, economic,** and **social indicators.**

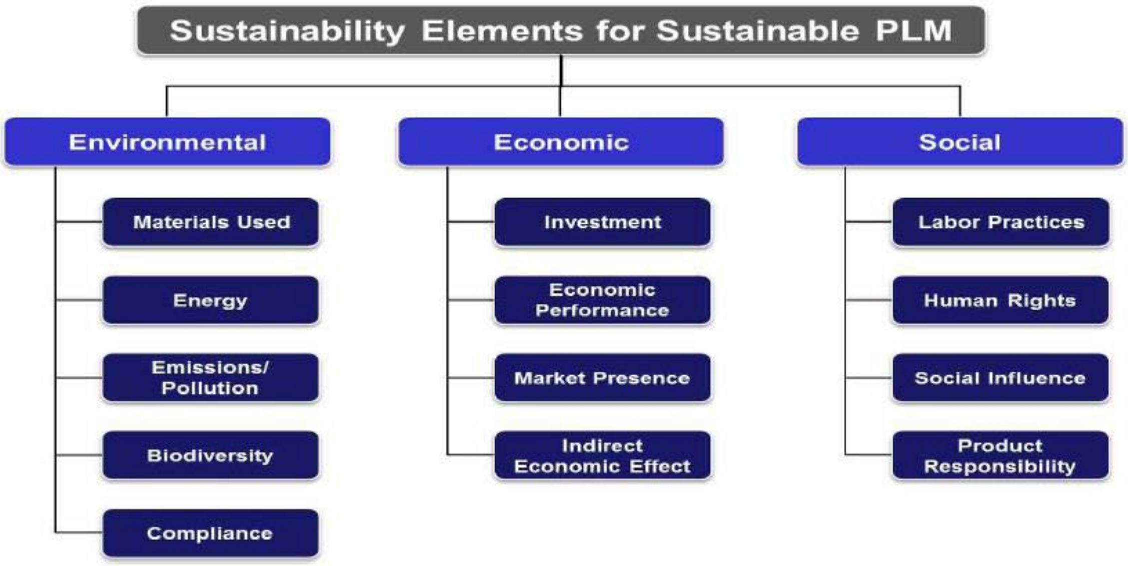

Figure 32. Sustainability indicators for sustainable PLM; source: [81]

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_References:

1. Schlacke, S., Wentzien, H., Thierjung, E.-M., Köster, M.: Implementing the EU Climate Law via the 'Fit for 55' package. Oxf. Open Energy. 1, oiab002 (2022). https://doi.org/10.1093/ooenergy/oiab002.

2. EU responses to climate change | News | European Parliament, https://www.europarl.europa.eu/news/en/headlines society/20180703STO07129/eu-res ponses-to-climate-change, last accessed 2022/09/02.

3. Climate change in Europe: facts and figures | News | European Parliament, https://www.europarl.europa.eu/news/en/headlines/society/20180703STO07123/climate-change-in-europe-facts-and-figures, last accessed 2022/09/12.

4. A European Green Deal. Striving to be the first climate-neutral continent, https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en, last accessed 2022/09/02.

5. New research study on Green Deal, https://frontex.europa.eu/future-of-border-control/eu-research/news-and-events/new-research-study-on-green-deal-Y3EKx6, last accessed 2022/09/02.

6. CO2 emissions from cars: facts and figures (infographics) | News | European Parliament, https://www.europarl.europa.eu/news/en/headlines/society/20190313STO31218/co2-emissions-from-cars-facts-and-figures-infographics, last accessed 2022/09/12.

7. McKinsey & Company: This surprising change can help the auto industry tackle emissions goals, https://www.mckinsey.com/business-functions/sustainability/our-insights/sustainabilityblog/this-surprising-change-can-help-the-auto-industry-tackle-emissions-goals, last accessed 2022/08/30.

8. The automotive industry and climate change Framework and dynamics of the CO2 (r)evolution (PWC), https://www.pwc.com/th/en/automotive/assets/co2.pdf?fbclid=IwAR22KpDBJ4y0kAOEmLQKNFYyogN5UfY9dOibavAsTb-Eqbl8ONZDzqm55aA.

9. Paris Agreement, https://ec.europa.eu/clima/eu-action/international-action-climate-change/climate-negotiations/paris-agreement_en, last accessed 2022/09/06.

10. The European Green Deal & Fit for 55 - KPMG Global, https://home.kpmg/xx/en/home/insights/2021/11/the-european-green-deal-and-fit-for-55.html, last accessed 2022/09/06.

11. PricewaterhouseCoopers: EU Green Deal Survey, https://www.pwc.com/gx/en/services/tax/publications/are-europes-businesses-ready-for-the-eu-green-deal.html, last accessed 2022/09/07.

12. Fit for 55: A major step towards a decarbonized EU by 2050. | EIRIE, https://ses.jrc.ec.europa.eu/eirie/en/news-and-events/news/fit-55-major-step-towards-decarbonized-eu-2050, last accessed 2022/09/07.

13. Fetting, C.: The European Green Deal. ESDN Report, December 2020, ESDN Office, Vienna. 22.

14. Industry and the Green Deal, https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal/industry-and-green-deal_en, last accessed 2022/09/06.

15. The EU Emissions Trading Scheme (ETS) and its reform in brief | News | European Parliament, https://www.europarl.europa.eu/news/en/headlines/society/20170213STO62208/the-eu-emissions-trading-scheme-ets-and-its-reform-in-brief, last accessed 2022/09/12.

16. Fit for 55 będzie rewolucją dla transportu drogowego (Puls Biznesu), http://pb.pl/fit-for-55-bedzie-rewolucja-dla-transportu-drogowego-1129041, last accessed 2022/09/06.

17. Carbon Border Adjustment Mechanism, https://taxation-customs.ec.europa.eu/green-taxation-0/carbon-border-adjustment-mechanism_en, last accessed 2022/09/07.

18. European Council on Foreign Relations, Leonard, M., Pisani-Ferry, J., Bruegel European Think Tank, Peterson Institute, European University, Shapiro, J., European Council on Foreign Relations, Tagliapietra, S., Bruegel European Think Tank, Wolf, G., Bruegel European Think Tank: The geopolitics of the European Green Deal. Int. Organ. Res. J. 16, 204–235 (2021). https://doi.org/10.17323/1996-7845-2021-02-10.

19. Bassi, F., Dias, J.G.: The use of circular economy practices in SMEs across the EU. Resour. Conserv. Recycl. 146, 523–533 (2019). https://doi.org/10.1016/j.resconrec.2019.03.019.

20. Hernandez, M.D.A., Bakthavatchaalam, V.: Circular economy as a strategy in European automotive industries to achieve Sustainable Development: A qualitative study. 5 (2022).

21. PIE: Fit for 55 wpłynie na redukcję emisji z transportu pasażerskiego w Polsce nawet o 70 proc. (Puls Biznesu), http://pb.pl/pie-fit-for-55-wplynie-na-redukcje-emisji-z-transportu-pasazerskiego-w-polsce-nawet-o-70-proc-1162767, last accessed 2022/09/06.

22. Global Car Industry Must Shift to Low Carbon to Survive - CDP | UNFCCC, https://unfccc.int/news/global-car-industry-must-shift-to-low-carbon-to-survive-cdp, last accessed 2022/09/07.

23. Wellbrock, W., Ludin, D., Röhrle, L., Gerstlberger, W.: Sustainability in the automotive industry, importance of and impact on automobile interior – insights from an empirical survey. Int. J. Corp. Soc. Responsib. 5, 10 (2020). https://doi.org/10.1186/s40991-020-00057-z.

24. Salvado, M., Azevedo, S., Matias, J., Ferreira, L.: Proposal of a Sustainability Index for the Automotive Industry. Sustainability. 7, 2113–2144 (2015). https://doi.org/10.3390/su7022113.

25. Meuer, J., Koelbel, J., Hoffmann, V.H.: On the Nature of Corporate Sustainability. Organ. Environ. 33, 319–341 (2020). https://doi.org/10.1177/1086026619850180.

26. Upward, A., Jones, P.: An Ontology for Strongly Sustainable Business Models: Defining an Enterprise Framework Compatible With Natural and Social Science. Organ. Environ. 29, 97–123 (2016). https://doi.org/10.1177/1086026615592933.

27. Purvis, B., Mao, Y., Robinson, D.: Three pillars of sustainability: in search of conceptual origins. Sustain. Sci. 14, 681–695 (2019). https://doi.org/10.1007/s11625-018-0627-5.

28. Winter, M., Knemeyer, A.M.: Exploring the integration of sustainability and supply chain management: Current state and opportunities for future inquiry. Int. J. Phys. Distrib. Logist. Manag. 43, 18–38 (2013). https://doi.org/10.1108/09600031311293237.

29. Fit for 55: MEPs back objective of zero emissions for cars and vans in 2035 | News | European Parliament, https://www.europarl.europa.eu/news/en/press-room/20220603IPR32129/fit-for-55-meps-back-objective-of-zero-emissions-for-cars-and-vans-in-2035, last accessed 2022/09/12.

30. Reducing car emissions: new CO2 targets for cars and vans explained, https://www.europarl.europa.eu/news/en/headlines/society/20180920STO14027/reducing-car-emissions-new-co2-targets-for-cars-and-vans-explained, last accessed 2022/09/02.

31. PLM Plays Part Tracking Carbon Footprint in DE, https://plmgreenalliance.com/plm-green-examples/plm-plays-part-tracking-carbon-foot print-in-de/, last accessed 2022/09/13.

32. Goldman Sachs: najlepsza droga do Fit for 55 to masowa elektryfikacja (Puls Biznesu), http://pb.pl/goldman-sachs-najlepsza-droga-do-fit-for-55-to-masowa-elektryfikacja-1139688, last accessed 2022/09/06.

33. Hertwich, Edgar, Lifset, Reid, Pauliuk, Stefan, Heeren, Niko, Ali, Saleem, Tu, Qingshi, Ardente, Fulvio, Berrill, Peter, Fishman, Tomer, Kanaoka, Koichi, Kulczycka, Joanna, Makov, Tamar, Masanet, Eric, Wolfram, Paul: Resource Efficiency and Climate Change: Material Efficiency Strategies for a Low-Carbon Future. Zenodo (2019). https://doi.org/10.5281/ZENODO.3542680.

34. Koplin, J., Seuring, S., Mesterharm, M.: Incorporating sustainability into supply management in the automotive industry – the case of the Volkswagen AG. J. Clean. Prod. 15, 1053–1062 (2007). https://doi.org/10.1016/j.jclepro.2006.05.024.

35. Jasiński, D., Meredith, J., Kirwan, K.: Sustainable development model for measuring and managing sustainability in the automotive sector. Sustain. Dev. 29, 1123–1137 (2021). https://doi.org/10.1002/sd.2207.

36. Sharma, M.: The Role of Employees' Engagement in the Adoption of Green Supply Chain Practices as Moderated by Environment Attitude: An Empirical Study of the Indian Automobile Industry. Glob. Bus. Rev. 15, 25S-38S (2014). https://doi.org/10.1177/0972150914550545.

37. Toth Arpad, Suta Alex: Global Sustainability Reporting in the Automotive Industry via the eXtensible Business Reporting Language. Chem. Eng. Trans. 88, 1087–1092 (2021). https://doi.org/10.3303/CET2188181.

38. Srivastava, S.K.: Green supply-chain management: A state-of-the-art literature review. Int. J. Manag. Rev. 9, 53–80 (2007). https://doi.org/10.1111/j.1468-2370.2007.00202.x.

39. El Baz, J., Iddik, S.: Green supply chain management and organizational culture: a bibliometric analysis based on Scopus data (2001-2020). Int. J. Organ. Anal. 30, 156–179 (2022). https://doi.org/10.1108/IJOA-07-2020-2307.

40. Bocken, N.M.P., Short, S.W., Rana, P., Evans, S.: A literature and practice review to develop sustainable business model archetypes. J. Clean. Prod. 65, 42–56 (2014). https://doi.org/10.1016/j.jclepro.2013.11.039.

41. Global Sustainable Investment Review 2020, http://www.gsi-alliance.org/, last accessed 2022/09/02.

42. United Nations Sustainable Development Goals, https://www.un.org/sustainabledevelopment/, last accessed 2022/09/13.

43. The Sustainable Development Goals Report 2022, https://unstats.un.org/sdgs/report/2022/, last accessed 2022/09/13.

44. Greenhouse Gas Protocol, https://www.wri.org/initiatives/greenhouse-gas-protocol, last accessed 2022/09/13.

45. What are Scopes 1, 2 and 3 of Carbon Emissions?, https://plana.earth/academy/what-are-scope-1-2-3-emissions, last accessed 2022/09/13.

46. Kirchherr, J., Reike, D., Hekkert, M.: Conceptualizing the circular economy: An analysis of 114 definitions. Resour. Conserv. Recycl. 127, 221–232 (2017). https://doi.org/10.1016/j.resconrec.2017.09.005.

47. Kirchherr, J., Piscicelli, L., Bour, R., Kostense-Smit, E., Muller, J., Huibrechtse-Truijens, A., Hekkert, M.: Barriers to the Circular Economy: Evidence From the European Union (EU). Ecol. Econ. 150, 264–272 (2018). https://doi.org/10.1016/j.ecolecon.2018.04.028.

48. First circular economy action plan, https://environment.ec.europa.eu/topics/circular-economy/first-circular-economy-action-plan_en, last accessed 2022/09/06.

49. Calisto Friant, M., Vermeulen, W.J.V., Salomone, R.: Analysing European Union circular economy policies: words versus actions. Sustain. Prod. Consum. 27, 337–353 (2021). https://doi.org/10.1016/j.spc.2020.11.001.

50. Circular Economy Action Plan I, https://www.switchtogreen.eu/circular-economy-strategy/, last accessed 2022/09/06.

51. The Automotive Industry in the Era of Sustainability report, https://www.capgemini.com/news/press-releases/the-automotive-industry-in-the-era-ofsustainability-report/, last accessed 2022/09/02.

52. Shannon, M.A., Bohn, P.W., Elimelech, M., Georgiadis, J.G., Marinas, B.J., Mayes, A.M.: Science and technology for water purification in the coming decades. 10 (2008).

53. 2022 Deloitte CxO Sustainability Report, https://www2.deloitte.com/global/en/pages/operations/articles/deloitte-cxo-sustainability-report.html, last accessed 2022/09/02.

54. Automotive Sustainability Report 2022, https://www.smmt.co.uk/industry-topics/sustainability/, last accessed 2022/09/02.

55. #GetOutInFront. Global Research Report, December 2020 (Deloitte), https://www2.deloitte.com/content/dam/Deloitte/global/Documents/Risk/gx-get-out-infront-final.pdf.

56. Vila, C., Abellán-Nebot, J.V., Albiñana, J.C., Hernández, G.: An Approach to Sustainable Product Lifecycle Management (Green PLM). Procedia Engineering. 132, 585–592 (2015). https://doi.org/10.1016/j.proeng.2015.12.608.

57. Vaz, C.R., Rauen, T.R.S., Lezana, Á.G.R.: Sustainability and Innovation in the Automotive Sector: A Structured Content Analysis. Sustainability. 9, 880 (2017). https://doi.org/10.3390/su9060880.

58. Javaid, M., Haleem, A., Singh, R.P., Suman, R., Gonzalez, E.S.: Understanding the adoption of Industry 4.0 technologies in improving environmental sustainability. Sustainable Operations and Computers. 3, 203–217 (2022). https://doi.org/10.1016/j.susoc.2022.01.008.

59. He, B., Shao, Y., Wang, S., Gu, Z., Bai, K.: Product environmental footprints assessment for product life cycle. Journal of Cleaner Production. 233, 446–460 (2019). https://doi.org/10.1016/j.jclepro.2019.06.078.

60. European Commision: Recommendation on the use of Environmental Footprint methods, https://environment.ec.europa.eu/publications/recommendation-use-environmental-footprint-methods_en, last accessed 2022/08/26.

61. Product Environmental Footprint Guide.

62. Organisation Environmental Footprint Guide.

63. Marcon, A., Ribeiro, J.L.D., Dangelico, R.M., de Medeiros, J.F., Marcon, É.: Exploring green product attributes and their effect on consumer behaviour: A systematic review. Sustainable Production and Consumption. 32, 76–91 (2022). https://doi.org/10.1016/j.spc.2022.04.012.

64. Materials used to build cars and homes key to tackling global warming, http://www.unep.org/news-and-stories/press-release/materials-used-build-cars-and-homes-key-tackling-global-warming, last accessed 2022/08/09.

65. Antonacci, A., Del Pero, F., Baldanzini, N., Delogu, M.: Holistic eco-design tool within automotive field. IOP Conf. Ser.: Mater. Sci. Eng. 1214, 012045 (2022). https://doi.org/10.1088/1757-899X/1214/1/012045.

66. Ercin, A.E., Hoekstra, A.Y.: Carbon and water footprints: concepts, methodologies and policy responses$nElektronische Ressource. UNESCO, Paris (2012).

67. SimaPro database manual, https://simapro.com/wp-content/uploads/2020/10/DatabaseManualMethods.pdf, last accessed 2022/10/07.

68. Product Carbon Footprint standards: which one to choose?, https://pre-sustainability.com/articles/product-carbon-footprint-standards-which-standard-to-choose/, last accessed 2022/10/07.

69. Mekonnen, M., Hoekstra, A.: The Green, Blue and Grey Water Footprint of Crops and Derived Crop Products. Hydrology and Earth System Sciences Discussions. 15, (2011). https://doi.org/10.5194/hess-15-1577-2011.

70. Hirz, M., Brunner, H.: ECO-Design in the Automotive Industry – Potentials and Challenges. (2015).

71. Ciceri, N.D., Garetti, M., Terzi, S.: Product Lifecycle Management Approach for Sustainability. 8.

72. The Circular Economy as a Model for the Future.

73. Belkadi, F., Bernard, A., Laroche, F.: Knowledge Based and PLM Facilities for Sustainability Perspective in Manufacturing: A Global Approach. (2015). https://doi.org/10.1016/j.procir.2015.01.065.

74. Bangsa, A.B., Schlegelmilch, B.B.: Linking sustainable product attributes and consumer decision-making: Insights from a systematic review. Journal of Cleaner Production. 245, 118902 (2020). https://doi.org/10.1016/j.jclepro.2019.118902.

75. Främling, K., Holmström, J., Loukkola, J., Nyman, J., Kaustell, A.: Sustainable PLM through Intelligent Products. Engineering Applications of Artificial Intelligence. 26, 789–799 (2013). https://doi.org/10.1016/j.engappai.2012.08.012.

76. de Medeiros, J.F., Ribeiro, J.L.D., Cortimiglia, M.N.: Influence of perceived value on purchasing decisions of green products in Brazil. Journal of Cleaner Production. 110, 158–169 (2016). https://doi.org/10.1016/j.jclepro.2015.07.100.

77. Zhang, H., Ouzrout, Y., Bouras, A., Savino, M.M.: Sustainability consideration within product lifecycle management through maturity models analysis. IJSOM. 19, 151 (2014). https://doi.org/10.1504/IJSOM.2014.065330.

78. Lehmann, A., Bach, V., Finkbeiner, M.: EU Product Environmental Footprint—Mid-Term Review of the Pilot Phase. Sustainability. 8, 92 (2016). https://doi.org/10.3390/su8010092.

79. Khan, F.I., Sadiq, R., Veitch, B.: Life cycle iNdeX (LInX): a new indexing procedure for process and product design and decision-making. Journal of Cleaner Production. 12, 59–76 (2004). https://doi.org/10.1016/S0959-6526(02)00194-4.

80. Staniszewska, E., Klimecka-Tatar, D., Obrecht, M.: Eco-design processes in the automotive industry. Production Engineering Archives. 26, 131–137 (2020). https://doi.org/10.30657/pea.2020.26.25.

81. Zhao, W.-B., Park, Y.H., Lee, H.Y., Jun, C.M., Do Noh, S.: Design and Implementation of a PLM System for Sustainable Manufacturing. In: Rivest, L., Bouras, A., and Louhichi, B. (eds.) Product Lifecycle Management. Towards Knowledge-Rich Enterprises. pp. 202–212. Springer, Berlin, Heidelberg (2012). https://doi.org/10.1007/978-3-642-35758-9_18.

82. GRI - Home, https://www.globalreporting.org/, last accessed 2022/08/05.

83. Veleva, V., Ellenbecker, M.: A Proposal for Measuring Business Sustainability: Addressing Shortcomings in Existing Frameworks. Greener Management International. 101–120 (2000).

84. Labuschagne, C., Brent, A.C., van Erck, R.P.G.: Assessing the sustainability performances of industries. Journal of Cleaner Production. 13, 373–385 (2005). https://doi.org/10.1016/j.jclepro.2003.10.007.

85. Institution of Chemical Engineers - IChemE, https://www.icheme.org/, last accessed 2022/08/05.

86. Labuschagne, C.: Sustainable project life cycle management: Criteria for the South African process industry, (2003).

87. Zhao, W.B.: A study on concept design of a PLM system for sustainable engineering. In: Annual Conference of CAD/CAM, PyeongChang (2012).

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