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Carbon Footprint

Definition, regulations and methodology

volum 1

Support of higher education system in a context of climate change mitigation through regional level of carbon footprint caused by a product, building and organization.

Hi-EduCarbon

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Content

Preface

It is well known that CO_2 concentrations in the atmosphere are at high levels. So, we have an impact not only on human health but the real danger to the environment. We have to take into consideration CO_2 emissions per capita in each country. In Spain, CO_2 emissions per capita are equivalent to 5.4 tons per person, in Romania – 4.0, in Slovakia - 6.5 and in Ukraine - 4.8. Buildings consume an excessive amount of energy and produce too much waste. Their operation is also linked with consumption about 25 % of the world's water and 40 % of its resources, while creating one-third waste and 40 % of global carbon emissions. Despite these statistics related to buildings unsustainability, buildings have huge untapped potential to become a key part of the solution to urgent sustainability challenges. Promoting energy efficient building is considered as the most successful strategy for CO_2 emission reduction and energy saving during the life cycle of the building, while applying for suitable green building products plays an important role in facilitating energy efficient building promotion. New eco-friendly designs of buildings based on the construction of environmentally friendly materials can give improving human health, safety, comfort, and productivity in the current conditions of climate change. Environmentally friendly materials must become part of a sustainable world buildings design because their production and use could offer minimization of the negative environmental impacts. These impacts are representing by climate change, ozone layer depletion, acidification of soil and water, resources exhaustion or human toxicity in connection to indoor and outdoor air pollution. Therefore, it is very important to include sustainability ideas into products, operations, and research and development to apply best technologies, produce materials/products and increase waste construction materials by recycling/reusing them leaving a smaller negative environmental footprint. This situation requires clear steps to be taken to reduce the impact of climate change as a result of human activity. One of the first steps is to increase awareness, knowledge and opportunities to achieve "Carbon neutrality".

Chapter 01

Introduction to Carbon Footprint

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The European Green Deal aims to transform the EU into a fair and prosperous society, with a modern, resource-efficient and competitive economy where there are no net emissions of greenhouse gases in 2050 and where economic growth is decoupled from resource use. It aims to protect, conserve and enhance the EU's natural capital, and protect the health and well-being of citizens from environment-related risks and impacts. It put people first, and pay attention to the regions, industries and workers who will face the greatest challenges.

The Delegated Acts (Commission Delegated Regulations (EU) 2020/1816, 2020/1817 and 2020/1818) required by the Low Carbon Benchmark Regulation (Regulation (EU) 2019/2089) have been published in the Official Journal of the European Union on 3 December 2020 and entered into force on 23 December 2020. They set out:

- the environmental, social and governance disclosure requirements for benchmarks provided in accordance with the EU Benchmark Regulation (Regulation (EU) 2016/1011)
- the minimum standards for EU Climate Transition Benchmarks ("EU CTB") and Paris-Aligned Benchmarks ("EU PAB").

Regulation (EU) 2020/1818 requires implementation of common methodologies for:

(1) calculation of greenhouse gas (GHG) intensity or absolute emissions and changes in those indicators,

(2) overweighting of companies setting and publishing GHG emission targets, and

(3) setting a decarbonization trajectory for both EU CTB and EU PAB..

GHG intensity is defined as absolute GHG emissions (tonnes of CO_2 equivalent) divided by millions of euros in enterprise value including cash. It should be the main parameter to calculate the decarbonization strategy and performed on a yearly basis and use the same currency for all underlying assets.

The ISO 14060 series of standards provides organizations with concrete support for the following activities within the scope of greenhouse gas emission management:

- Development and implementation of strategies and plans for GHG management;
- Development and implementation of mitigation measures through emission reductions and improvements in the removal of GHG emissions;
- Instruments to determine performance and progress in reducing GHG emissions and/or improving GHG abatement;
- Improving the credibility, consistency and transparency of GHG quantification, monitoring, reporting and uniform requirements for validation (ex ante) and verification (ex post).

ISO 14064-1: 2018 Greenhouse gases – Part 1: Specification with guidance at the organization level for quantification and reporting of greenhouse gas emissions and removals

- This document specifies principles and requirements at the organization level for the quantification and reporting of GHG emissions and removals.
- It includes requirements for the design, development, management, reporting and verification of an organization's GHG inventory.

ISO 14064-2: 2019 Greenhouse gases - Part 2: Specification with guidance at the project level for quantification, monitoring and reporting of greenhouse gas emission reductions or removal enhancements

- This document specifies principles and requirements and provides guidance *at the project level* for the quantification, monitoring and reporting of activities intended to cause GHG emission reductions or removal enhancements.

- It includes requirements for planning a GHG project, identifying and selecting GHG sources, sinks and reservoirs (SSRs) relevant to the project and baseline scenario, monitoring, quantifying, documenting and reporting GHG project performance and managing data quality.

ISO 14064-3: 2019 Greenhouse gases – Part 3: Specification with guidance for the verification and validation of greenhouse gas statements

- This document specifies principles and requirements and provides guidance for verifying and validating GHG statements.
- It is applicable to organization, project and product GHG statements.

ISO 14065: 2020 General principles and requirements for bodies validating and verifying environmental information

- This document specifies principles and requirements for bodies performing validation and verification of environmental information statements.
- This document is a sector application of ISO/IEC 17029:2019, which contains general principles and requirements for the competence, consistent operation and impartiality of bodies performing validation/verification as conformity assessment activities.

ISO 14066: 2011 Greenhouse gases – Competence requirements for greenhouse gas validation teams and verification teams

- It specifies competence requirements for validation teams and verification teams.
- This standard complements the implementation of ISO 14065.

ISO 14067: 2018 Greenhouse gases – Carbon footprint of products – Requirements and guidelines for quantification

- This document specifies principles, requirements and guidelines for the quantification and reporting of the carbon footprint of a product (CFP), in a manner consistent with International Standards on life cycle assessment (LCA) (ISO 14040 and ISO 14044).
- Requirements and guidelines for the quantification of a partial CFP are also specified.
- This document addresses only a single impact category: climate change.

ISO/TR 14069:2013 Greenhouse gases – Quantification and reporting of greenhouse gas emissions for organizations – Guidance for the application of ISO 14064-1

- This document describes the principles, concepts and methods relating to the quantification and reporting of direct and indirect GHG emissions for an organization.
- It provides guidance for the application of ISO 14064-1 to GHG inventories at the organization level, for the quantification and reporting of direct emissions, energy indirect emissions and other indirect emissions.

1.1 Carbon Footprint of Product
EN ISO 14067:2018

Standards that address the carbon footprint of product:

- EN ISO 14044:2007 Environmental management – Life cycle assessment – Requirements and guidelines.
- EN ISO 14026:2019 Environmental labels and declarations - Principles, requirements and guidelines for communication of footprint information.
- EN ISO 14027:2017 Environmental labels and declarations - Development of product category rules
- STN EN ISO 14067: 2018 Greenhouse gases – Carbon footprint of products – Requirements and guidelines for quantification.
- ISO/TS 14071: 2014 Environmental management – Life cycle assessment – Critical review processes and reviewer competencies: Additional requirements and guidelines to ISO 14044:2006

According to EN ISO 14067, *Carbon footprint of a product (CFP)* is sum of GHG emissions and GHG removals in a product system, expressed as CO2 equivalents and based on a life cycle assessment using the single impact category of climate change.

Partial carbon footprint of a product (partial CFP) is sum of GHG emissions and GHG removals of one or more selected process(es) in a product system, expressed as CO2 equivalents and based on the selected stages or processes within the life cycle.

The quantification of a CFP takes into consideration the entire life cycle of a product, including

- acquisition of raw material,
- design,
- production,
- transportation/delivery,
- use and
- the end-of-life treatment

The CFP study is structured around a functional unit (CFP) or a declared unit (partial CFP) and the results are calculated relative to this functional unit or declared unit.

A CFP study shall include the four phases of LCA (Figure 1.1).

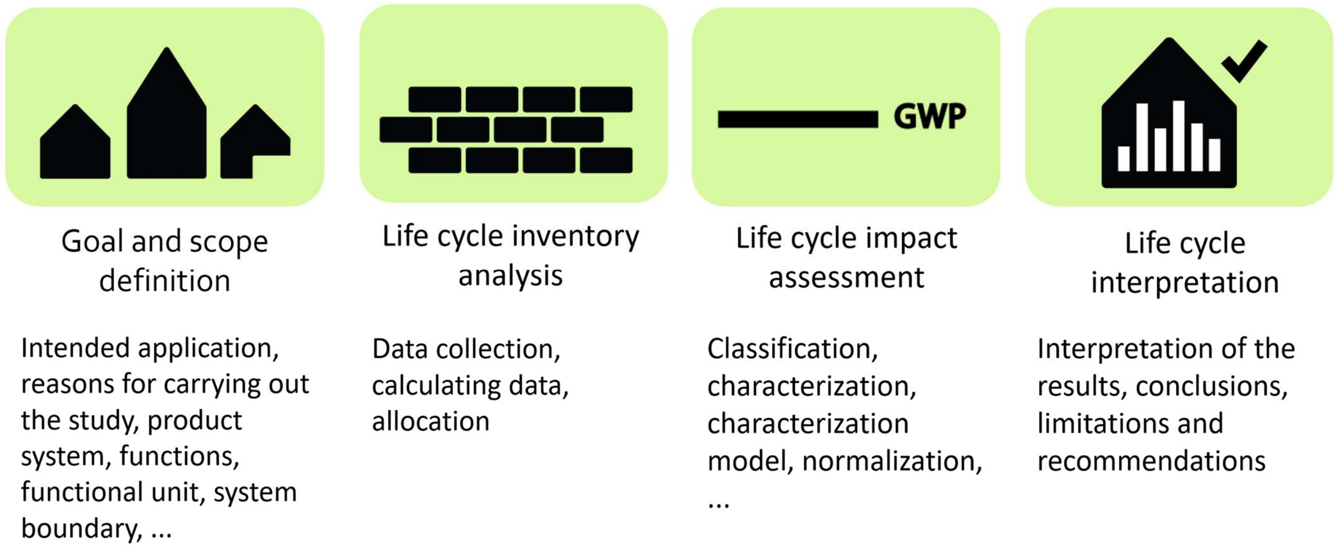

Figure 1.1. LCA phases

The unit processes comprising the product system shall be grouped into life cycle stages. GHG emissions and removals from the product's life cycle shall be assigned to the life cycle stage in which the GHG emissions and removals occur. Partial CFPs may be added together to quantify the CFP, provided that they are performed according to the same methodology for the same timeframe and that no gaps or overlaps exist. As an example from the construction sector, it is possible to have a partial CFP for:

- a substance or preparation (e.g. cement),
- a bulk product (e.g. gravel),

- a service (e.g. maintenance of a building) or
- an assembled system (e.g. masonry wall)

1. Goal and scope of a CFP study

- to calculate the potential contribution of a product to global warming expressed as CO2e by quantifying all significant GHG emissions and removals over the product's life cycle or selected processes, in line with cut-off criteria

In defining the goal of a CFP study, the following items shall be stated:

- the intended application
- the reasons for carrying out the CFP study
- the intended audience
- the intended communication

In defining the scope of the CFP study, the following items shall be considered and clearly described:

- the system under study and its functions
- the functional or declared unit
- the system boundary, including the geographical scope of the system under study
- data and data quality requirements
- the time boundary for data
- assumptions, especially for the use stage and the end-of-life stage
- allocation procedures
- specific GHG emissions and removals, e.g. due to LUC
- methods to address issues occurring with specific product categories
- the CFP study report
- the type of critical review, if any
- limitations of the CFP study

Functional or declared unit FU/DU:

- consistent with the goal and scope of the CFP study;
- to provide a reference to which the inputs and outputs are related - shall be clearly defined and measurable;
- DU shall only be used in a partial CFP;
- FU/DU shall be defined in the CFP-PCR;
- a comparison between product systems shall be made on the basis of the same functional unit(s);
- comparisons based on partial CFP(declared unit) are permitted if the omitted life cycle stages are identical;
- comparison based on the DU may be used for business-to-business purposes.

System boundary

- shall be the basis used to determine which unit processes are included within the CFP study;
- the selection of the system boundary shall be consistent with the goal of the CFP study;
- cut-off criteria shall be identified and explained;
- decisions shall be made regarding which unit processes to include in the CFP study;
- the exclusion of life cycle stages, processes, inputs or outputs is only permitted if they do not significantly change the overall conclusions of the CFP study.

Life cycle phases and modules are illustrated in figure 1.2.

Product stage			Assembly stage		Use stage							End of life stage				Beyond the system boundaries		
A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D		
x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		
Raw materials	Transport	Manufacturing	Transport	Assembly	Use	Maintenance	Repair	Replacement	Refurbishment	Operational energy use	Operational water use	Deconstr./demol.	Transport	Waste processing	Disposal	Reuse	Recovery	Recycling

Figure 1.2 Life cycle phases and modules

Quantification shall include all GHG emissions and removals of those unit processes that have the potential to make a significant contribution to the CFP or the partial CFP.

Within the goal and scope definition phase, consistent criteria shall be defined:

- for which unit processes a detailed assessment is needed due to an expected significant contribution to the CFP or the partial CFP
- for which unit processes the quantification of GHG emissions may be based on secondary data if the collection of primary data are not possible or practicable
- which unit processes may be merged, e.g. all transport processes within a plant

Cut-off criteria

In general, all processes and flows that are attributable to the system shall be included. If individual material or energy flows are found to be insignificant for the CFP of a particular unit process, these may be excluded for practical reasons and shall be reported as data exclusions. The effect of the selected cut-off criteria on the outcome of the study shall also be assessed and described in the CFP study report. All inputs and outputs of the unit processes, for which data is available for, are included in the calculation. There is no neglected unit process more than 1% of total mass or energy flows. The module specific total neglected input and output flows also do not exceed 5% of energy usage or mass.

Data and data quality – Site-specific data

- shall be collected for individual processes where the organization undertaking the CFP study has financial or operational control
- should be used for those unit processes that are most important and not under financial or operational control
- the most important processes are those which together contribute at least 80 % to the CFP

- refer to either direct GHG emissions (determined through direct monitoring, stoichiometry, mass balance or similar methods), activity data (inputs and outputs of processes that result in GHG emissions or removals) or emission factors
- can be collected from a specific site, or can be averaged across all sites that contain the process within the system under study
- can be measured or modelled as long as the result is specific to the process in the product's life cycle

Data and data quality – Primary data, Secondary data

Primary data

- that are not site-specific data, and which have undergone third-party review, should be used when the collection of site-specific data is not practicable

Secondary data

- shall only be used for inputs and outputs where the collection of primary data is not practicable, or for processes of minor importance
- shall be justified and documented with references in the CFP study report

A CFP study should use data that reduce bias and uncertainty as far as practical by using the best quality data available. Data quality shall be characterized by both quantitative and qualitative aspects. Characterization of data quality should address the following:

- time-related coverage: age of data and the minimum length of time over which data should be collected;
- geographical coverage: geographical area from which data for unit processes should be collected;
- technology coverage: specific technology or technology mix;
- precision: measure of the variability of each data value expressed (e.g. variance);
- completeness: percentage of total flow that is measured or estimated;
- representativeness: qualitative assessment of the degree to which the data set reflects the true population of interest (i.e. geographical coverage, time period and technology coverage);
- consistency: qualitative assessment of whether or not the study methodology is applied uniformly to the various components of the sensitivity analysis;

- reproducibility: qualitative assessment of the extent to which information about the methodology and data values would allow an independent practitioner to reproduce the results reported in the CFP study;
- sources of the data;
- uncertainty of the information.

Use stage and use profile

The user of the product and the use profile of the product shall be specified in the CFP study. Service life information shall be verifiable. It shall refer to the intended use conditions and to the related functions of the product. The use profile should seek to represent the actual usage pattern in the selected market. Where not otherwise justified, the determination of the use profile shall be based on published technical information, such as:

a) CFP-PCR;
b) published International standards
c) published National guidelines
d) published Industry guidelines

→ that specify guidance and requirements for development of scenarios and service life for the use stage for the product being assessed

e) use profiles based on documented usage patterns for the product in the selected market.

End-of-life stage

End-of-life processes may include:

a) collection, packaging and transport of end-of-life products;
b) preparation for recycling and reuse;
c) dismantling of components from end-of-life products;
d) shredding and sorting;
e) material recycling;
f) organic recovery (e.g. composting and anaerobic digestion);
g) energy recovery or other recovery processes;
h) incineration and sorting of bottom ash;
i) landfilling.

2. Life cycle inventory analysis for the CFP

LCI is the phase of LCA involving the compilation and quantification of inputs and outputs for a product throughout its life cycle. This consists of the following steps, which shall apply when relevant:

- data collection;
- validation of data;
- relating data to unit process and functional / declared unit;
- refining the system boundary;
- allocation.

Biogenic carbon in products

Biomass-derived carbon contained in a product is referred to as the biogenic carbon content of the product. Information on biogenic carbon content shall be provided when performing cradle to gate studies, as this information may be relevant for the remaining value chain. In the case of products containing biomass, the ***biogenic carbon content*** is equal to the ***carbon removal during plant growth***. This biogenic carbon can be ***released in the end-of-life stage***.

3. Impact assessment for CFP or partial CFP

In the LCIA phase of a CFP study, the ***potential climate change impact*** of ***each GHG emitted and removed by the product system*** shall be calculated by ***multiplying the mass of GHG released or removed by the 100-year GWP*** given by the IPCC in units of ***kg CO2e per kg emission*** (according to IPCC). The CFP is the sum of these calculated impacts. Where GWP values are amended by the IPCC, the latest values shall be used in the CFP calculations.

100-year global warming potential (GWP 100) is used to represent **shorter-term impacts of climate change**, reflecting **the rate of warming**.

100-year global temperature potential (GTP 100) is used as an **indicator for the longer-term impacts of climate change**, reflecting the **long-term temperature rise**.

There is no scientific basis for choosing a 100-year time horizon compared to other time horizons. The time horizon is a value judgement of international convention that weighs the effects that are likely to occur over different time horizons.

Impact assessment of biogenic carbon

Removals of CO_2 into biomass shall be characterized as - 1 kg CO_2e/kg CO_2 in the calculation of the CFP when entering the product system. Emissions of biogenic CO_2 shall be characterized as +1 kg CO_2e/kg CO_2 of biogenic carbon in the calculation of the CFP. The amount of CO_2 taken up in biomass and the equivalent amount of CO_2 emissions from the biomass at the point of complete oxidation results in zero net CO_2 emissions integrated over time, except when biomass carbon is not converted into methane, non-methane volatile organic compounds (NMVOC) or other precursor gases. For fossil and biogenic methane, the characterization factors in accordance with the most recent IPCC report shall be used.

4. Interpretation of CFP or partial CFP

The life cycle interpretation phase of a CFP study shall comprise the following steps:

a) identification of the significant issues based on the results of the quantification of the CFP and partial CFP in accordance with LCI and LCIA phases;
b) an evaluation that considers completeness, consistency and sensitivity analysis;
c) the formulation of conclusions, limitations and recommendations.

- The results of the quantification of the CFP and partial CFP according to the LCI or LCIA phases shall be interpreted according to the goal and scope of the CFP study. The interpretation shall:
    - include an assessment of uncertainty, including the application of rounding rules or ranges;
    - identify and document the selected allocation procedures in the CFP study report in detail;
    - identify the limitations of the CFP study.

CFP study report

Results reported in the CFP study report may be used in footprint communications (ISO 14026). "CFP study report" is a specific term relating to the carbon footprint of products. Other standards use different terminology for the same type of document (e.g. "third-party report" used in ISO 14044:2006 and "footprint study report" used in ISO 14026). The results and conclusions of the CFP study shall be documented in the CFP study report without bias. The results, data, methods, assumptions and the life cycle interpretation shall be transparent and

Chapter 02

Regulations and plans to reduce climate change

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This chapter offers a general framework on regulations at European and national level, as well as plans to decrease the discharge of greenhouse gases, energy consumption and step up the proportion of energy derived from renewable sources to meet European Union climate neutrality target before 2050.

2.1 International and European Regulations

The challenge of climate change is tackled worldwide by the main international treaty – the United Nations Framework Convention on Climate Change. Often abbreviated as UNFCCC, this significant treaty was launched in 1992 with the primary goal of addressing the pressing issue of environmental changes, setting the groundwork for international action to prevent these modifications. The aim is to limit the amount of greenhouse gases in the air to forestall them from disrupting the Earth's climate in a harmful way. It states that this target must be accomplished within a timeframe that allows nature to evolve without human intervention, guarantees the security of food supply, and allow economies keep growing in a way that protects the environment [1].

The Kyoto Protocol (1997), the UNFCCC Protocol, was the first step toward achieving this objective. Measures, targets, and periods to reduce greenhouse gas (GHG) emissions have been established under this Protocol: first for 2008-2012 and second for 2013-2020 period.

Later, in 2015, all counties involved in the UNFCCC came together to sign the Paris Agreement. It represents an enforceable global accord to fight climate challenge, their general purpose being to maintain global warming significantly below 2 0C compared to before the Industrial Revolution, ideally even closer to 1.5 0C [2].

The European Union (EU), along with all its member states are counted among the parties to the UNFCCC. They also given their formal consent to the Kyoto Protocol and subsequently agreed to the terms of the Paris Agreement.

The main European directives and regulations regarding warming planet, alterations in climate patterns, pollution problems and building sector are listed below:

- Directive 2010/31/EU on the energy performance of buildings (recast);
- Directive 2011/92/EU on the assessment of the effects of certain public and private projects on the environment;
- Regulation (EU) No 305/2011 laying down harmonized conditions for the marketing of construction products and repealing Council Directive 89/106/EEC;
- Directive (EU) 2016/2284 on the reduction of national emissions of certain atmospheric pollutants, amending Directive 2003/35/EC and repealing Directive 2001/81/EC;
- Regulation (EU) 2018/1999 on the Governance of the Energy Union and Climate Action, amending Regulations (EC) No 663/2009 and (EC) No 715/2009, Directives 94/22/EC, 98/70/EC, 2009/31/EC, 2009/73/EC, 2010/31/EU, 2012/27/EU and 2013/30/EU, 2009/119/EC and (EU) 2015/652 and repealing Regulation (EU) No 525/2013;
- Regulation (EU) 2021/1119 establishing the framework for achieving climate neutrality and amending regulations (EC) No 401/2009 and (EU) 2018/1999 ('European Climate Law');
- Directive (EU) 2023/1791 on energy efficiency and amending Regulation (EU) 2023/955 (recast);
- Regulation (EU) 2023/956 establishing a carbon border adjustment mechanism.

Regarding climate and energetic context, EU established targets for 2020, 2030 and 2050.

For 2020, European Union established three climate and energy targets (20-20-20 objectives): cutting emissions from GHG with 20% compared to the levels of 1990, while securing a 20% shift to a more efficient and renewable energy mix.

The 2021 report from the European Environment Agency confirm that EU successfully met its key targets set for 2020 [3]. Based on the report from 2023, in 2022 EU has made significant progress in reducing its GHG footprint by 31% compared to 1990 and since 2005 the contribution of renewables to the energy supply reached 22.5% within the EU, while primary and final energy consumption have fallen by 16%, respectively 8% [4].

Although greenhouse gas emissions in EU decreased by 1.9% in 2022, compared to those recorded in 2021, the amount of energy delivered to end users and the total energy used throughout the supply chain rose with 1.5%, respectively 4%, and also the renewable energy share rose with 0.7%. To accomplish the set goals for diminishing emissions by the year 2030, faster annual reductions are needed in particular from road transport, buildings, agriculture and small industries, while the annual growth for the renewable energy share and the annual reductions for energy consumption must accelerate even further [4] (see Figure 2. 1, Figure 2. 2 and Figure 2. 3).

Since the vast majority of global greenhouse gas emissions are due to the energetic sector, to transition this sector from reliance on fossil fuels to a zero-carbon footprint before 2050, comprehensive measures will be necessary across various domains, including industrial energy consumption, building energy use, and transportation [8, 9]. As a result, to achieve a balance in which the net amount of carbon dioxide emissions is zero by the year 2050, governments around the world, from national to international levels, are prioritizing strategies to clean up the power sector. But to fulfil this goal, effective measures will be required in every sector.

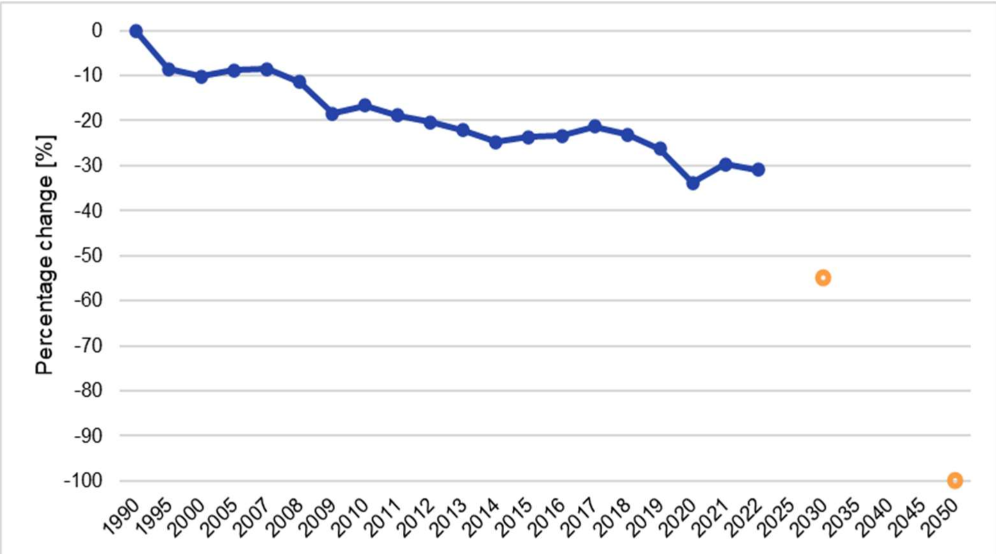

Figure 2. 1. EU historical trends and projections of GHG emissions [4, 5]

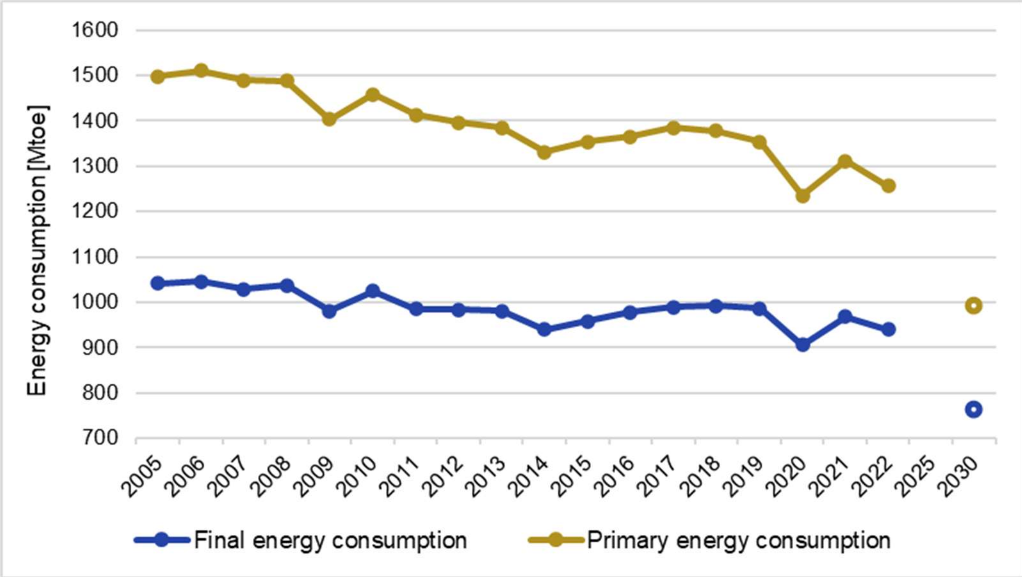

Figure 2. 2. Historical energy consumption patterns and projections within EU [4, 6]

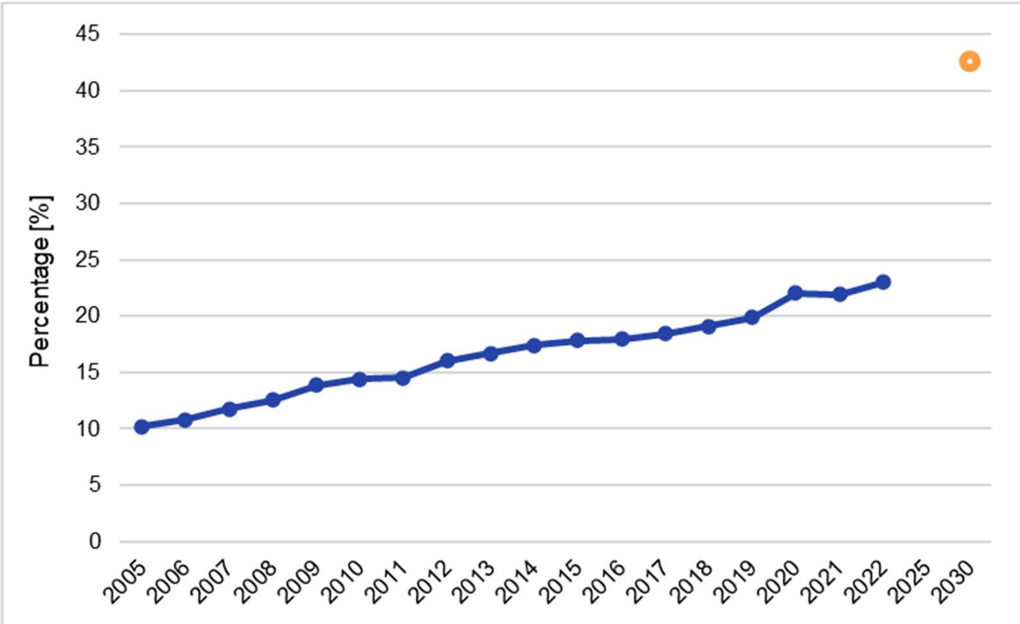

Figure 2. 3. The evolution and future prospects on the share of renewable energy [4, 7]

By 2050, EU wants to achieve climate neutrality, having an economic system that attain a net balance of zero emissions from GHG. The European Climate Law has made this commitment, which represents the main part of the European Green Deal, aligning with the global climate endeavors under the Paris Agreement [10,11].

Based on the legislative package "Fit for 55", presented in 2021, to achieve the EU's ambition target of reaching carbon neutrality by mid-century it was set a more ambition target for 2030 namely, to slash greenhouse gases by more than a half (minimum 55%) from 1990 levels [12].

In 2022, in response to the instability generated in the international energy market following Russia's incursion into Ukraine, REPowerEU plan was launched to boost energy security in EU. Based on this plan, in view of energy saving, diversification of energy sources, enhancing the share of RES and so stimulating the green transition, the European Commission proposed greater ambition: to heighten the contribution of RES to minimum 42.5%, aiming for 45% and to reduce the consumptions of energy by a minimum of 11.7% with reference to the projection made in 2020 for 2030. This translates to targets of nearly 993 million tonnes of oil equivalent (Mtoe) for overall energy use and 763 Mtoe for final energy [12–14].

In order to support the shift to a clean environment and accelerate the passing to climate neutrality, through a carbon neutral industry, the Green Deal Industrial Plan for Europe was proposed in 2023. This plan aims to ensure: a simplified regulatory environment, faster access to finance, increasing the level of expertise, and unrestricted commerce for robust supply networks [15].

Despite the estimated full achievements of 2020 targets at EU level [3], not every country has achieved their individual goals. To fulfill the obligations of the Paris Agreement and the European targets imposed, each member submitted National Energy and Climate Plans (NECPs) outlining their contribution from 2021 to 2030 in areas like energy conservation, use of renewable energy, and greenhouse gas diminution.

Regarding the EU's target of carbon neutrality by 2050, long-term national plans have been established by each country outlining how they intend to reduce GHG emissions to fulfill their obligations complying with the international commitments and the European ones.

2.2 Regulations and plans to reduce climate change in Romania, Slovakia, Spain and Ukraine

Romania has formally committed to the UNFCCC and the Kyoto Protocol by incorporating them into its national legislation through Law no. 24/1994 and Law no. 3/2001. From 2006, greenhouse gas emission allowances (CO2 allowances) are traded in Romania through governmental decisions (no. 780/2006 and no. 204/2013).

Below is a list of the main Romanian laws on climate change, GHG emissions, environment, and the building sector.:

- Law No 24/1994 for ratifying the UNFCCC;
- Law No 3/2001 for ratifying the Kyoto Protocol to UNFCCC;
- Government Emergency Ordinance No 195/2005 on environmental protection;
    - Decision No 1474/2007 for the approval of the Regulation on the management and operation of the national greenhouse gas emissions register;
- Government Decision No 60/2008 approving the national allocation Plan on emission allowances for greenhouse gases for 2007 and 2008-2012 periods;
- Government Emergency Ordinance No 69/2010 regarding the thermal rehabilitation of residential buildings through government guaranteed loans;
- Government Emergency Ordinance 115/2011 regarding institutional framework and Governmental authorization, to auction greenhouse gas emissions certificates attributed to Romania at the level of EU;
- Law No 104/2011 on ambient air quality;
- Government Decision No 668/2012 for amending and supplementing of Government Decision No 1570/2007 on the setting up of the national System for estimating the level of anthropogenic greenhouse gas emissions resulting from sources or the sequestration of carbon dioxide, regulated by the Kyoto Protocol;
- Decision no. 3420/2012 approving the procedure for issuing and reviewing the greenhouse gas emissions permit for 2013 – 2020 period;
- Government Emergency Ordinance 63/2012 for modifying and completing Government Emergency Ordinance 18/2009 regarding increased energy performance of blocks of flats;

- Governmental Decision No 204/2013 amending and supplementing the Governmental Decision No 780/2006 on the establishment of the greenhouse gas emission allowance trading scheme;
- Law No 70/2013 on the approval of Government Emergency Ordinance No 114/2007 amending and supplementing Government Emergency Ordinance No 195/2005 on environmental protection;
- Decision No 870/2013 regarding the approval of national waste management Strategy 2014-2020;
- Emergency Decree No 57/2013 regarding the amendment of the Law 220/2008 for establishing the promotion system of power from renewable sources production;
- Government Decision No 1026/2014 on re-organize of the National Commission of Climate Change;
- Law No 121/2014 on energy efficiency;
- Law No 177/2015 for modifying and completing Law No 10/1995 regarding the quality in construction;
- Government Decision no. 122/2015 approving the national action Plan for energy efficiency;
- Government Decision no. 739/2016 for approving the national Strategy on climate change and low carbon economic growth for the period 2016-2020 and of the national action Plan for the implementation of the national Strategy on climate change and growth low carbon economy for 2016-2020;
- Order No 13/2016 for modifying and completing Law no. 372/2005 regarding energy performance of buildings;
- Decision No 1076/2021 for the approval of the Integrated National energy and climate plan 2021-2030;
- Emergency Ordinance No 108/2022 on decarbonization of the energy sector;
- Government Decision No 1215/2023 regarding the approval of the Long-Term Strategy of Romania for reducing greenhouse gas emissions - Romania Neutral in 2050.

Romania aligns with the EU's vision for a climate-neutral Europe before 2050. This shared goal is reflected in their support for the European Green Deal, which strive to evolve EU into a sustainable and ambitious economy through the following measures: achieving net-zero

GHG emissions by 2050, increasing the proportion of renewable energy and strengthened energy efficiency, promoting economic growth without exhausting resources, refurbishing buildings for a more eco-friendly life, and enhancing the holistic well-being for European citizens [16].

The primary energy and environmental goals set for Romania, for the decade 2021-2030, by the Integrated National Energy and Climate Plan (NECP), focuses on curbing emissions from GHG (with reference to 2005), significantly increasing reliance on clean energy sources, and achieving substantial energy savings before 2030 (regarding the projections from 2007). The plan underscores the following targets:

- A nearly 44%, respectively 2% lowering for sectors covered by the Emissions Trading Systems (ETS), respectively for non-ETS sectors;
- Around 30% of energy consumption to come from renewable sources (RES);
- About 49% of electricity generation to be powered by renewables;
- About 14% of energy used in transportation to be from renewable sources;
- 33% of heating and cooling needs to be met by renewables;
- About 45% reduction in primary energy, translated to a projected consumption of over 32 Mtoe;
- About 40% reduction in final energy, meaning the consumption is expected to reach over 25 Mtoe.

In terms of emissions that contribute to global warming, Romania has met its target for 2020, cutting greenhouse gas pollution by 65% from 1990. Romania was contributing with less than 3% of the overall emissions at the level of the European Union and decreased them at a rate quicker than the European medium from 2005 until 2019, toward almost 26% [18].

Romania's contribution to the EU decarbonization target is translated into compliance with the emission reduction commitments related to the ETS sector by almost 44% (emissions are expected to reach 39 mill CO2 eq in 2030) and strive to achieve a 2% decrease in emissions from non-ETS sector until 2030, measured against 2005.

The main initiatives to bring down greenhouse gas pollution are [17]:

- Encouraging investments in modern, environmentally friendly power generation infrastructure. This state-of-the-art power plants, fueled by gas, nuclear energy, and renewable sources, will replace high-emission facilities;

- Leveraging funds to support projects that promote energy efficiency and a greener energy mix, both domestically and internationally;
- Deploying state-of-the-art technologies to achieve significant reductions in emissions and boost energy efficiency in the realm of industrial production;
- Promoting transition in the direction of a circular economy with the aid of waste control guidelines and measures (raising the rate of municipal waste reuse and recycling, lowering biodegradable waste, expanding separate gathering programs for a wider range of recyclables, scaling up sorting infrastructure to handle increased recycling volumes);
- Fostering electromobility in road transport, biofuels apply and alternative mobility;
- Promoting cost-effective energy-saving measures in EU-ETS industries;
- Implementing advanced cogeneration initiatives;
- Encouraging new technologies in the energy sector;
- Roll-out a long-term building upgrade plan to diminish building consumptions and GHG emissions;
- Subsequent implementation of the Green House+ Program;
- Advancement of "smart cities" and "green cities";
- Expansion of the wooden areas and their resilience to climate change.

Conform Eurostat, Romania has accomplished its target for 2020 with 24.48% of renewables in overall energy mix and the following contribution across key consumption sectors: 43.37% in electricity (RES-E), 25.32% in heating and cooling (RES-H&C) and 8.54% in transport (RES-T) [6] (see Figure 2. 4).

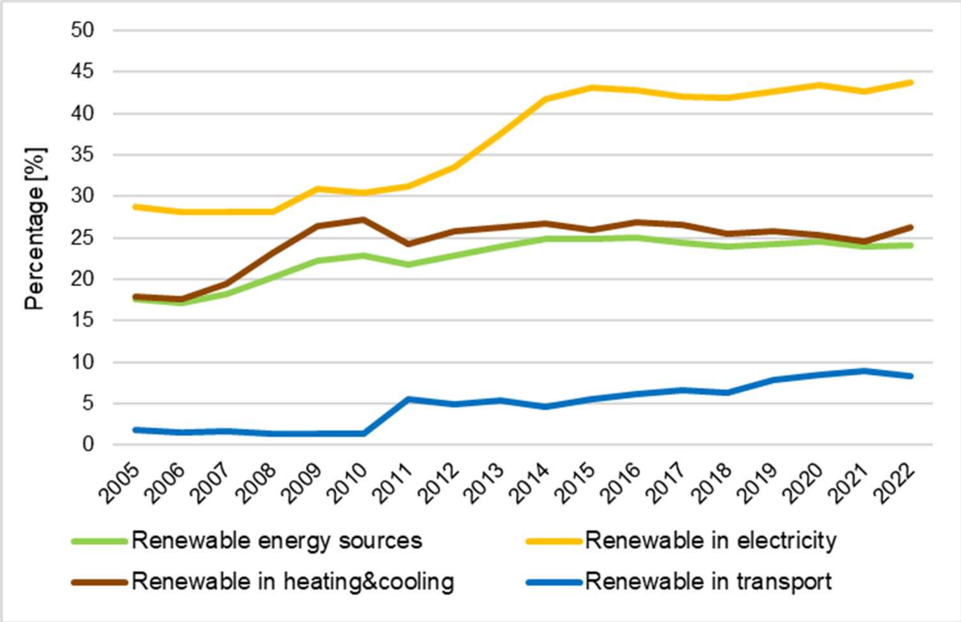

Figure 2. 4. Romania's progress in renewable energy use, in 2005-2022 [6]

Fulfilling our renewable energy goals for 2030 necessitates polices that accelerate renewable energy production [17]:

- Transition to electromobility and biofuels;
- Driving investments in new renewable energy generation;
- Boosting energy savings in Europe's regulated industries;
- Investing in ways to store excess renewable power;
- Digitalization of the Romanian energy system;
- Integrating advanced solutions to power our future with renewables for electricity, transportation, and heating and cooling;
- Investing in clean energy manufacturing and electric vehicles;
- Expanding capacities of wind and photovoltaic systems considering the growing electricity need;
- Developing the heating based on electricity in Romania;
- Implementation of heat pumps and solar panels to provide thermal energy;
- Continuing long-term operation of the Green House+ Program;
- Support performant heating installations rely on biomass with full combustion and zero pollutants;

- Launching the national plan to upgrade buildings for better energy performance, using clean sources for heating and cooling, with a focus on solar panels and heat pumps.

As for energy efficiency Romania reached its target for 2020, both final and primary energy consumption decreased with more than 20% compared to 1990 level (see Figure 2. 5).

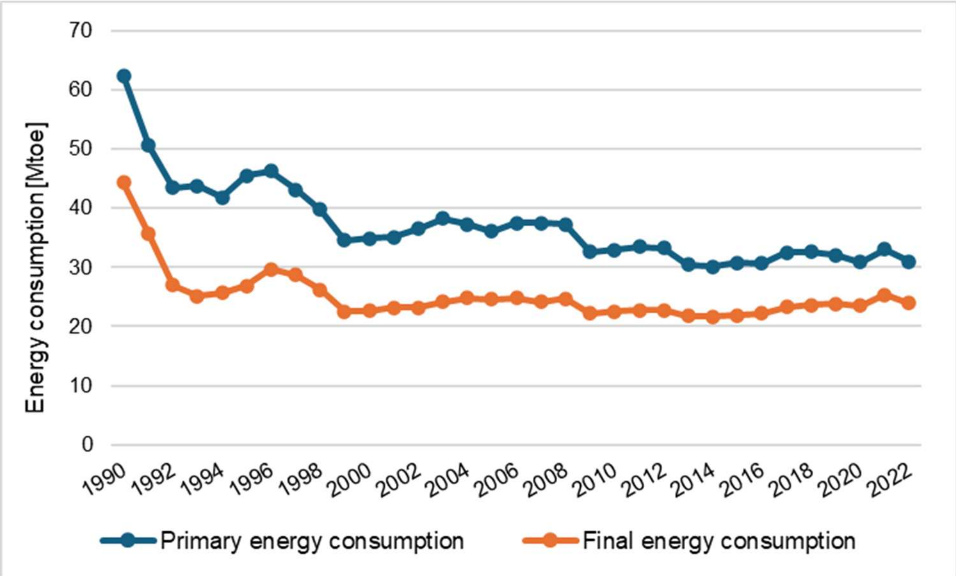

Figure 2. 5. Saving energy in Romania, in 1990-2022 [6]

As the economy grows by 2030, we expect to use more energy overall. This increase will be primarily driven growth in the transportation, industry, and businesses sectors, while homes are expected to use less energy thanks to efficiency improvements.

To cut back on energy use as planned, we need to take some big steps in the energy sector, such as [17]:

- Putting our long-term plan into action to make buildings more efficient and use less carbon. This will involve:
    - inventorying the existing residential buildings and evaluating the potential to improve energy efficiency;
    - enhancing thermal insulation for public buildings (including government offices, schools, and hospitals), commercial and residential buildings (both apartments and homes);

  - upgrading buildings with a focus on cost-effective solutions that combine renewable sources and ventilation systems to ensure optima thermal comfort;
  - developing efficient standards for enhancing energy efficiency in buildings with the help of better insulation and upgraded heating and cooling systems.
- Digital transformation of the energy system;
- Boosting energy-saving measures in EU industries covered by ETS;
- Exploring new transportation options and modernizing older vehicles with cleaner options.

On the path to a carbon-neutral Europe before 2050, the Long-Term Strategy of Romania set up the country roadmap for achieving the global goals, considering three feasible scenarios: the Reference Scenario (REF) based on the 2021-2030 NECP and considering a boom from 30.7% to 34.3% in the global proportion of renewable energy resources; the Romania Neutral Scenario (Romania Neutral) under which Romania aims to become climate neutral by 2050, requiring a massive 99% cut in GHG; and a moderate scenario that falls between the first two (Middle) [19].

Although in 2020, emissions were reduced by 65% compared to 1990 level, securing carbon neutrality by 2050 demands ongoing efforts, with a focus on accomplishing the critical 2030 emission reduction goals of 78% emission discount, in accordance with Romania Neutral, while for REF target was set to 67% for 2030 and 85% for 2050 and for Middle scenario 77% for 2030 and 94% for 2050 [19] (see Figure 2. 6).

Achieving the ambitious targets in line with Romania Neutral will only be possible by implementing policies and measures that are appropriate for each sector, for some sectors (transport, building sector and waste) first with the need to stop the increasing trend in emissions, followed only then by the process of reducing emissions.

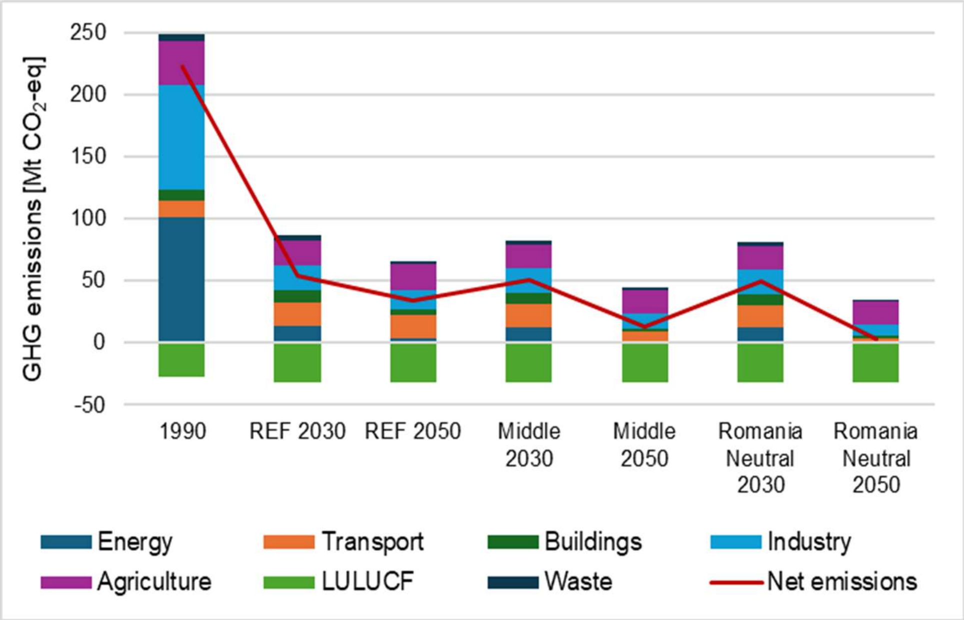

Figure 2. 6. Evolution of Romania GHG emissions across different sectors, as reported by all three scenarios [19]

Regarding the RES, their percentage in overall energy use must hit 36.2% in 2030, respectively 86.1% in 2050, while the 2030 energy efficiency goals call for a 45% decrease in final energy consumption and 48% in primary energy. By 2050 these consumptions should be further decreased by 26%, respectively by 13% for overall energy use, respectively for energy used before it reaches consumers.

In conclusion, it's imperative that we persistently address the challenge of global climate and its far-reaching impacts on surroundings, human well-being, and economic stability. To achieve this, concerted efforts must be sustained at multiple levels, including national, European, and global scales. These efforts should be directed toward curbing emissions from GHG across all sectors, with particular emphasis on the energy sector, which significantly influences the overall environmental footprint.

By prioritizing emissions decreasing strategies, we can collectively work toward a more sustainable and resilient future. There will also be a lot of opportunities as we move toward climate neutrality, including the possibility of economic expansion, creation of new market and business models, new jobs, the advancement of technology, so the future research, development and innovation policies will play crucial role [20].

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Chapter 03

Global Warming and Greenhouse Gas Emissions

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This chapter provides first and foremost the worldwide context of global warming and climate change, highlighting their causes and effects. Additionally, it emphasizes the critical necessity to mitigate greenhouse gas emissions to ensure a sustainable future for the entire planet, focusing on the main polluting sector, namely the building sector.

3.1 Worldwide global warming and greenhouse gases

Global warming

Since the pre-industrial period (1850-1900), there has been a persistent rise in the planet's overall temperature, a phenomenon known as global warming. The term is frequently used interchangeably with the term climate change. However, they have different meanings. While global warming is a specific aspect of climate change focusing on the average increase in Earth's global surface temperature of the planet resulting primarily from human activities, climate change encompasses more than just global warming, referring to a comprehensive spectrum of transformations unfolding across our planet [1].

Formed in 1988 by the World Meteorological Organization (WMO) and the United Nations Environment Program (UNEP), The Intergovernmental Panel on Climate Change (IPCC) is the United Nations body that plays a crucial role in assessing the science regarding climate change [2]. Scientists, experts, and policymakers collaborate to prepare comprehensive assessment reports about climate change knowledge, its causes, impacts, and potential solutions, fostering collaboration and informed decision-making to tackle climate change on a global scale.

Based on the Synthesis Report of the IPCC Sixth Assessment Report [3], the significant changes that have taken place across the Earth systems, including the atmosphere, ocean, ice covered regions and living ecosystems, are primarily driven by human activities and their impact is leading to adverse consequences for both the environment and human population. The impact of climate change can be seen through extreme weather events like rising temperatures, record floods, raging storms, drought, forest fires, rising sea and ocean levels, lowering of the ice caps but also by poverty, food insecurity, physical and mental health risks, losing species, obstructing the efforts to achieve a more equitable and sustainable world [1, 3, 4]. This underscores the urgent need for global efforts to mitigate, adapt to these challenges and protect our planet.

Since 1970, global surface temperature has witnessed the fastest temperature increase over any 50-year span in at least the last 2000 years. Globally, the warmest ten years period recorded was the past 10 years (2014 –2023), with a global mean temperature of 1.20 0C above the average temperature recorded during the historical period from 1850 to 1900, based on the analysis of six distinct datasets [5]. Was confirmed that 2023 year stands as the warmest year ever recorded, the annual average global temperature soared to approximately 1.45 0C above pre-industrial level, approaching the critical threshold of 1.5 0C – the symbolic target set by the Paris Agreement on climate change [5–7]. Besides, in 2023 every single day surpassed 1 0C above the pre-industrial baseline, nearly half of the days witnessed temperatures soaring beyond 1.5 0C above the pre-industrial benchmark, and two specific days in November defied historical norms by breaching the 2 0C warmer threshold [6], as shown in Figure 3. 1.

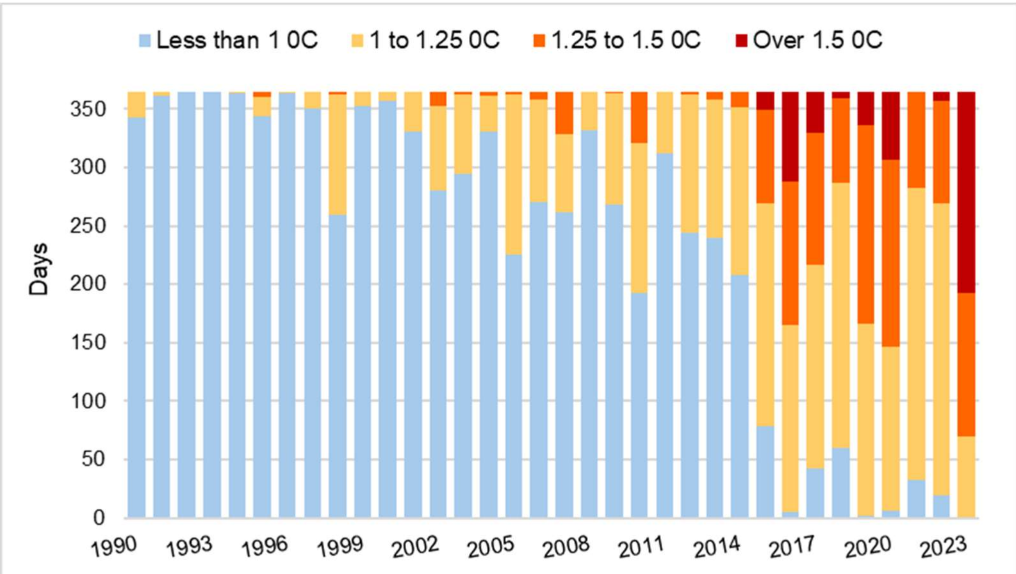

Figure 3. 1. The annual number of days with increased temperatures above the average for 1850-1900 covering the period 1990 – 2023 [6]

Long-term monitoring of global temperatures serves as key indicator for understanding climate dynamics and its transformations, but several others contribute to our comprehensive assessment of climate change: greenhouse gas concentrations, ocean heat and acidification, sea level, extend of ice, balance of glacier mass, and according to the report "Provisional State of the Global Climate 2023" [8], multiple records were broken across various climate indicators. All these serve as a stark reminder of the urgency to address climate change and adhere to the goals set forth by the Paris Agreement. To slow down, with the eventual aim of stopping rising global temperature, the world's countries need to stabilize and reduce the concentrations of greenhouse gases in Earth's atmosphere.

3.2 Greenhouse gases

Global warming is primarily attributed to the human enhancement of the greenhouse effect, which happens when gases in the atmosphere capture heat from the sun that would otherwise escape into space and causes the Earth to warm naturally [1, 9]. Greenhouse gases (GHG) are gases that absorb and re-emit infrared energy from the atmosphere down to the Earth's surface, leading to the heating of the planet.

Besides the greenhouse gases that occur naturally, the human activities, through their actions to provide energy like burning fossil fuels, deforestation, farming livestock, the use of fertilizers in agriculture, decomposition of organic fabric in landfills [10, 11] have greatly influenced the increase of anthropogenic GHG emissions. According to the Kyoto Protocol, there are six types of greenhouse gases: carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF6) [12]. Anthropogenic GHG include [13]:

- carbon dioxide from burning fossil fuels for energy production, transport or industrial activities, deforestation;
- methane from agricultural activities, waste management, energy use and biomass burning;
- nitrous oxide from agricultural fertilizers;
- fluorinated gases from industrial processes and refrigeration.

Since pre-industrial times, climate change has been largely caused by the rising levels of these greenhouse gases [14]. Of all greenhouse gases emitted by human activities, those that have the greatest impact on the climate are carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). As can be seen from figures below: Figure 3. 2, Figure 3. 3 and Figure 3. 4, these emissions are on a continuous and alarming rise. Greenhouse gases concentrations reached new highs by the end of 2023:

- world annual average for CO_2 - 419.25 parts per million (ppm);
- world annual average for CH_4 – 1922.52 parts per billion (ppb);
- world annual average for N_2O - 336.66 parts per billion (ppb).

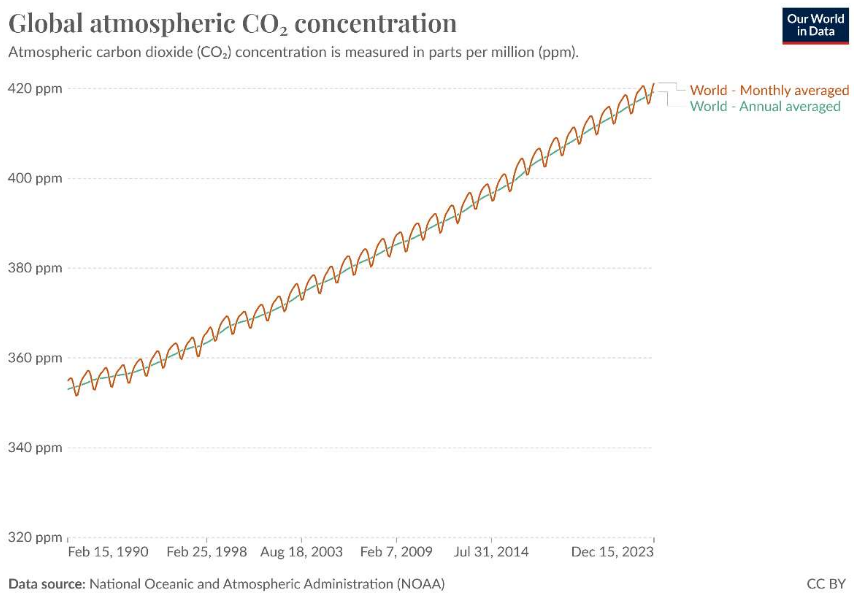

Figure 3. 2. Global atmospheric CO2 concentration [15]

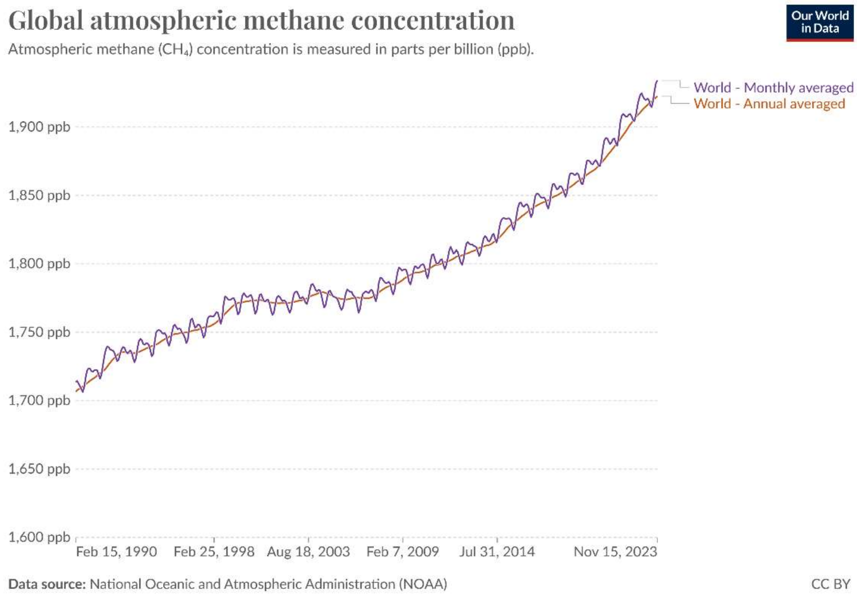

Figure 3. 3. Global atmospheric CH4 concentration [15]

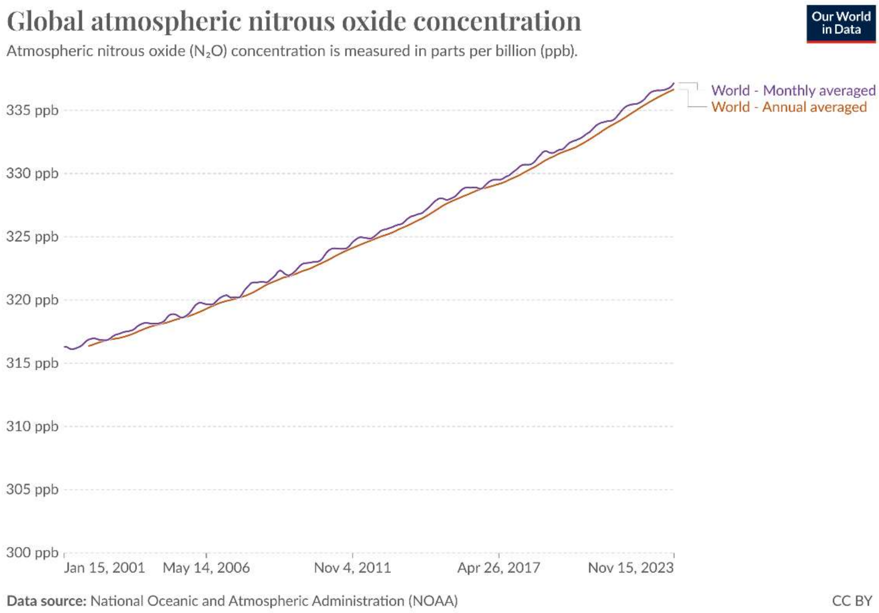

Figure 3. 4. Global atmospheric N2O concentration [15]

From the GHG emitted by human activities, carbon dioxide continues to be the greatest contributor to global warming. In 2021, emissions from CO2 covered 75.32% from the global greenhouse gas emissions, while CH4 emissions covered 19.25% and N2O 5.44% [16]. A similar distribution of greenhouse emissions is found at the level of the four countries involved in the project: Slovakia, Spain, Romania, and Ukraine, as seen in Figure 3. 5.

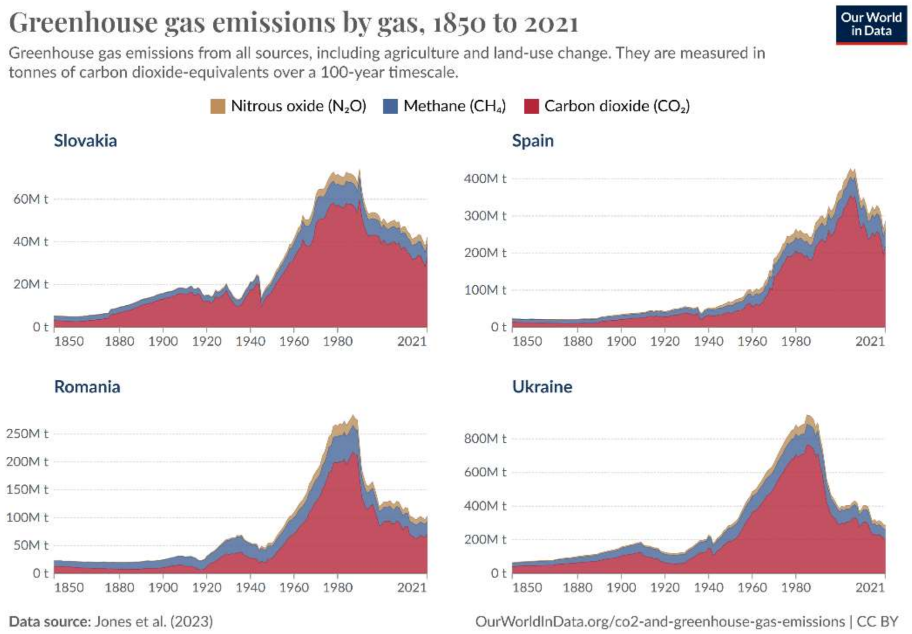

Figure 3. 5. Trend in CO2, CH4 and N2O emissions since 1850 to 2021 for Slovakia, Spain, Romania, and Ukraine [16]

In Slovakia and Spain, emissions from CO2 encompasses for over 75%, while in Ukraine and Romania the contribution of CO2 is lower (71.49% for Ukraine, 68.03% for Romania) but the percentage of methane emissions is higher (19.69% for Ukraine and 22.84% for Romania), due to heating systems predominantly based on gas and biomass.

The greenhouse effect is determined by two characteristics of GHG: their ability to absorb energy and radiate it and their atmospheric lifetime, meaning the time the gas stays in the atmosphere before natural processes remove it (chemical reactions) [9]. These two characteristics are included in the Global Warming Potential (GWP). GWP is calculated over 100 years, carbon dioxide is taken as reference gas with 100-year and GWP=1. GWP for a specific gas represents the amount of energy the emissions of 1 ton of gas will absorb over a given time (100 years) compared with the emissions of 1 ton of CO2 [17].

Carbon dioxide is a long-lived greenhouse gas that accumulates in the atmosphere for hundreds of years. Methane, even if it has a larger equivalent greenhouse effect than carbon dioxide, has a shorter atmospheric life (up to a decade). Nitrous oxide, like carbon dioxide, is a long-lived greenhouse gas that accumulates in the atmosphere.

Global Warming Potential for greenhouse gases over 100 years, relative to CO2, are represented in Figure 3. 6. These values play an important role in blending various GHG into a unified measurement known as carbon dioxide equivalent (CO2e). This metric allows us to comprehensively assess the overall impact of these gases on the environment.

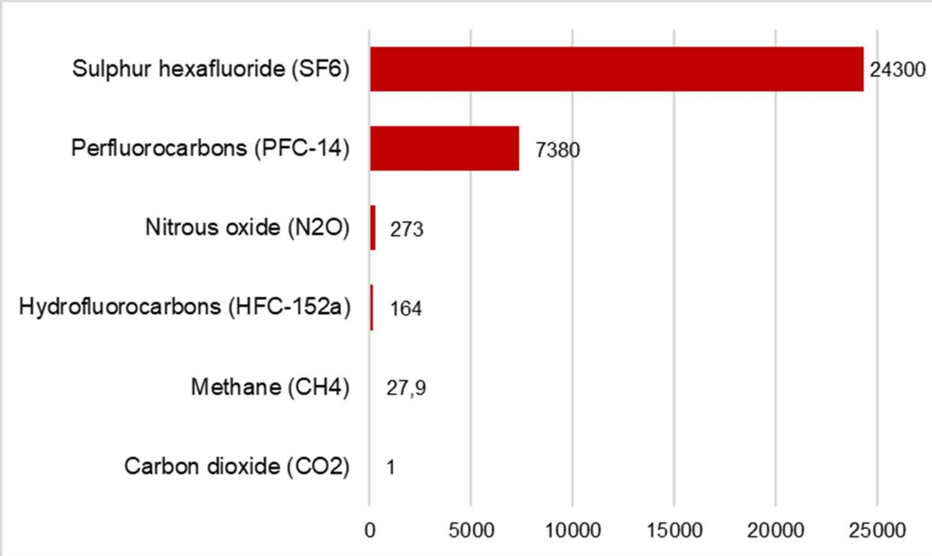

Figure 3. 6. Global Warming Potential for greenhouse gases relative to CO2 [16]

In 2021, global greenhouse gas emissions rose by 44% from 1990 levels, to 54.59 billion tones CO2e. The long-term progression of relative changes in greenhouse gas emissions, both globally and within the context of Slovakia, Romania, Spain, and Ukraine, during the period from 1990 to 2021, is visually depicted in Figure 3. 7.

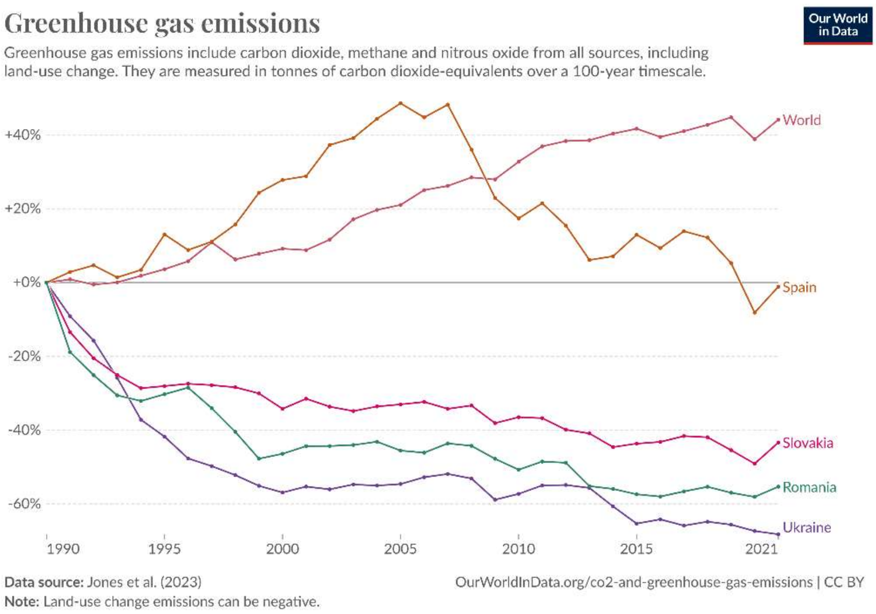

Figure 3. 7. GHG emissions for 1990-2021 period [16]

In 2021, GHG emissions in Slovakia accounted for 1.2% of total GHG emissions in the 27 countries of the European Union (EU), those in Romania 3%, while in Spain and Ukraine 8.4%.

Given that greenhouse gas emissions are considered the main cause of global warming/climate change and continue to rise at global level, the world's countries have committed to fight the effects of climate change and to limit the greenhouse gas (GHG) emissions.

An increase of 2 0C compared to the pre-industrial mean temperature is associated with negative impacts on the environment, human health, society, and economy. By adopting the Paris Agreement on climate change, the international community agreed to limit the increase in the global average temperature. To emphasize the importance of limiting global warming and the impact of the GHG's reduction, in Figure 3. 8. are highlighted several future climate scenarios (2020-2100) for GHG emissions. If no climate policies were put in place, we could experience a significant increase in global temperatures of 4.1 0C – 4.8 0C. If the current policies continue, this trajectory could lead to a warming of 2.5 – 2.9 0C, while if all countries successfully achieve their current future targets, the global temperature might fall to 2.1 0C.

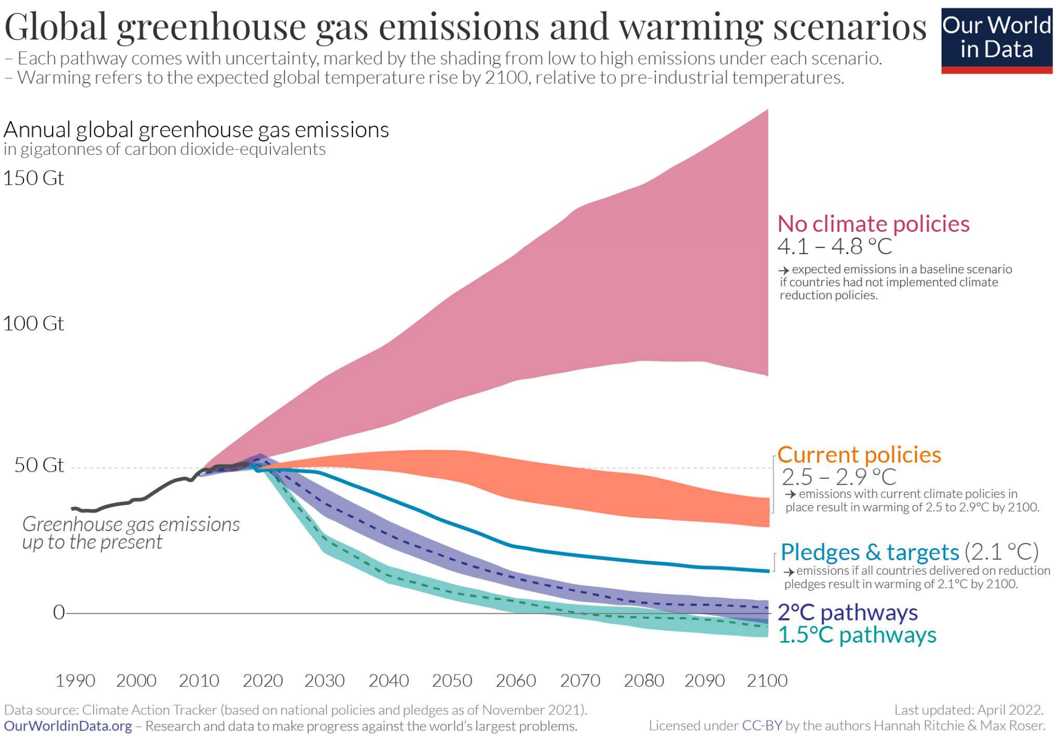

Figure 3. 8. Climate scenarios and policies on GHG emissions [16]

But to achieve the Paris Agreement's targets (well below 20C, preferable 1.5 0C), countries will need to take action to adapt to both the current effects of climate change and the expected impacts in the future, increasing their commitments and align their policies accordingly, to urgently reduce the GHG emissions by shifting to green energy, promoting sustainability and energy efficiency.

3.3 Impact of the buildings and construction sector
Global context

In the global climate context, where GHG emissions continue to rise, although they should be reduced rapidly, to find effective strategies to reduce them, we first need to know which sectors are most contributing to the increase in GHG emissions.

The building sector (buildings and construction) represents a key driver of energy demand and emissions, being responsible for over one third of global final energy consumption and CO2 emissions. According to the 2022 Global Status Report for Buildings and Construction [18], in 2021 this sector accounted for 34% of global final energy consumption, followed by industry and transport (Figure 3. 9). The operational energy demand in buildings surged to an unprecedented 135 exajoules (EJ). This remarkable increase represents a 4% growth compared to the previous year (2020) and surpassed the pre-pandemic peak recorded in 2019 by more than 3%.

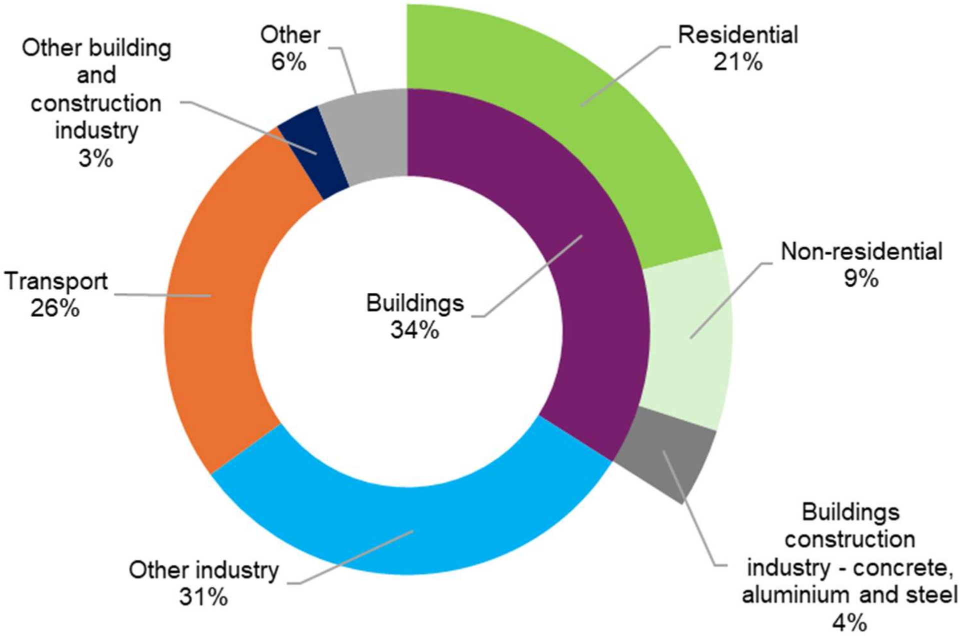

Figure 3. 9. Buildings and construction's share in global final energy in 2021 [18]

Operational energy required for various purposes within buildings like space heating and cooling, water heating, lighting, cooking, and other uses accounted for approximately 30% of the total final energy demand. Additionally, building construction industry of materials, like concrete, steel, and aluminum, added another 4% in final energy demand. So, combining the operational energy demand with the energy used for material production, the share of buildings reached 34%. Of the 3 percent of other building and construction industry, materials such as bricks and glass make up about 1%.

According to the International Energy Agency, the energy consumption associated with buildings has been on a steady upward trajectory. In 2022, there was a rise of almost 1% compared with the previous year, the proportion of electricity reached approximately 35%, making an outstanding increase from 2010 (Figure 3. 10). But despite the gradual transition from fossil fuels towards electricity and renewable sources, the use of fossil fuels within the building sector hasn't diminished, in fact it has been growing with an average rate of 0.5% annually since 2010, indicating that despite the shift towards cleaner energy fossil fuels remain a significant component in the energy mix [19].

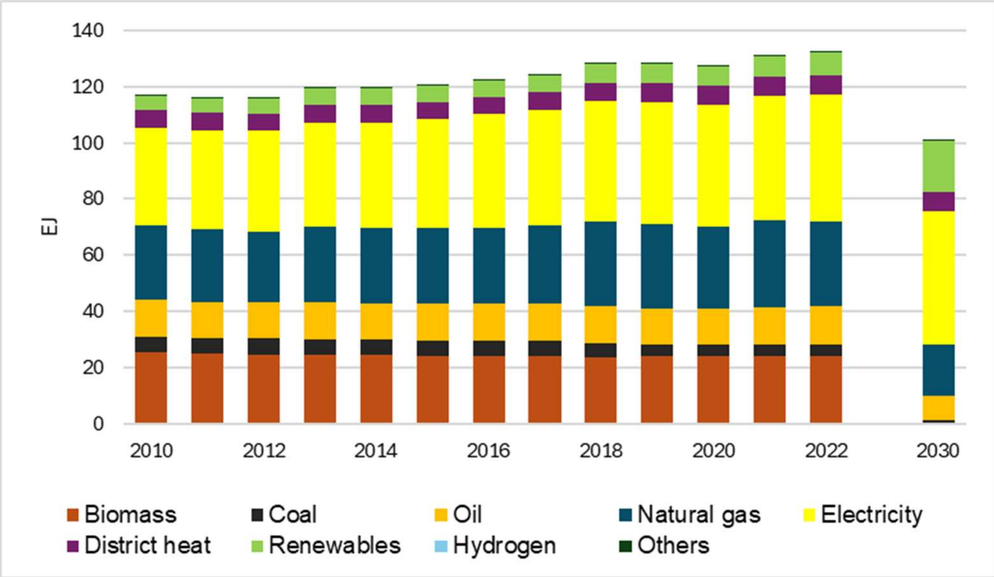

Figure 3. 10. CO2 emissions from building worldwide under the Net Zero Scenario, from 2010 to 2030 [19]

Simultaneously, in 2021, the building sector accounted for 37% of global CO2 emissions, followed by industry and transport (Figure 3. 11).

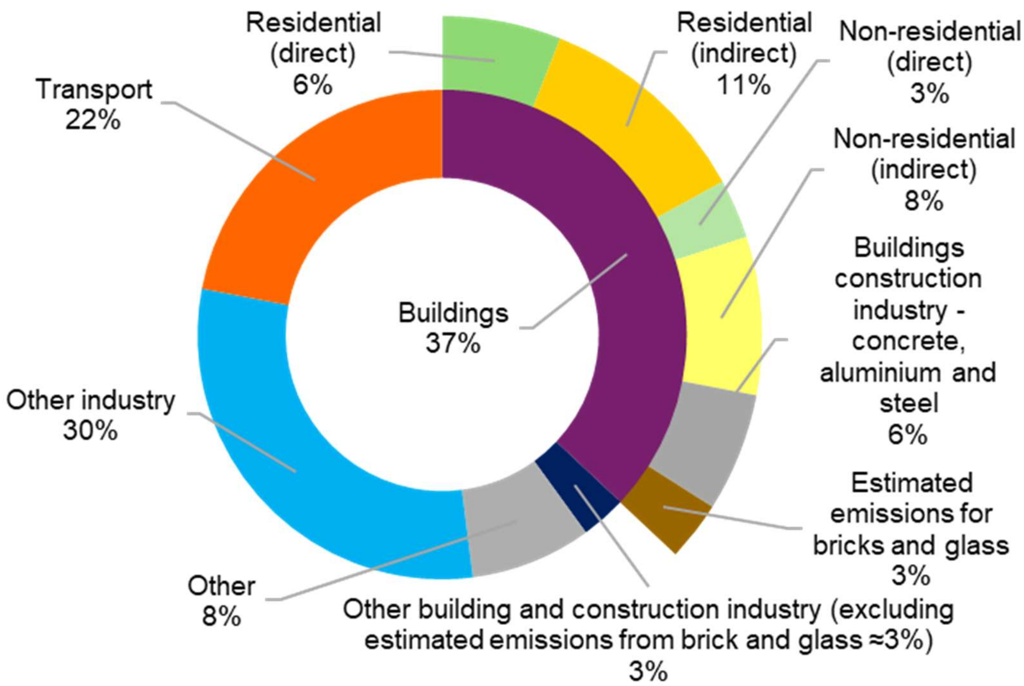

Figure 3. 11. Buildings and construction's share of global operational and process CO2 emissions in 2021 [18]

This sector witnessed a record high in operational energy-related CO_2 emissions, reaching approximately 10 gigatons (Gt CO_2), which means a significant environmental impact. This increase exceeds the 2020 emission levels by around 5%. Furthermore, it even surpasses the previous peak observed in 2019 by 2%.

When considering the environmental impact of buildings, it's important to account for the emissions produced throughout the whole lifecycle, not only during their operation. From the global energy-related CO_2 emissions in buildings, approximately 27% arise from the operational aspects of buildings, about 9% result from the direct use of fossil fuels within buildings and an additional 19% of emissions arise due to electricity consumption in buildings. Although these emissions are considered indirect, they play a crucial role in the overall environmental impact of buildings. The rise in direct CO_2 emissions is related to the enhanced fossil fuels operation, especially from the use of fossil fuel gas in emerging economies. By adding around 9% emissions from the manufacturing of construction materials (concrete, steel, aluminum, bricks, glass), for the entire lifecycle a building is responsible for 37% of global energy-related CO_2 emissions. This significant percentage underscores the critical need for strategies and practices aimed at reducing emissions across the entire lifecycle of buildings, from construction to demolition, to mitigate their environmental footprint and struggle against climate change.

According to the International Energy Agency, in 2022 emissions from building operation (direct and indirect emissions) were like the previous year, recording 9.8 Gt CO_2 (Figure 3. 12). Direct CO_2 emissions attributable to the operational activities of buildings saw a reduction, coming down to 3 Gt CO_2, a slight decrease compared to the previous year, unlike the average annual growth of nearly 1% from 2015 to 2021. Conversely, the indirect CO_2 emissions from buildings, which primarily arise from the consumption of electricity, experienced a significant increase by 1.4% compared to 2021, reaching 6.8 Gt CO_2. This reflects the growing demand for electrical energy, underscoring the importance of addressing efficient sources of electricity generation to mitigate the environmental impacts of buildings. To align with the objectives set forth in the Net Zero Scenario, it's imperative that emissions decrease annually by 9% leading up to the year 2030 [19]. In addition to direct and indirect emissions produced by building operations, in 2022, a further 2.5 Gt CO_2 emissions were linked to the construction of buildings.

Decarbonizing the global building sector is of utmost importance in our fight against severe climate change. To align with the goals set forth in the Paris Agreement, the transition of the entire global buildings and construction industry to a net zero carbon footprint by the year 2050 is imperative. Furthermore, starting from 2030, all new buildings must adhere to the same net zero carbon standard [19].

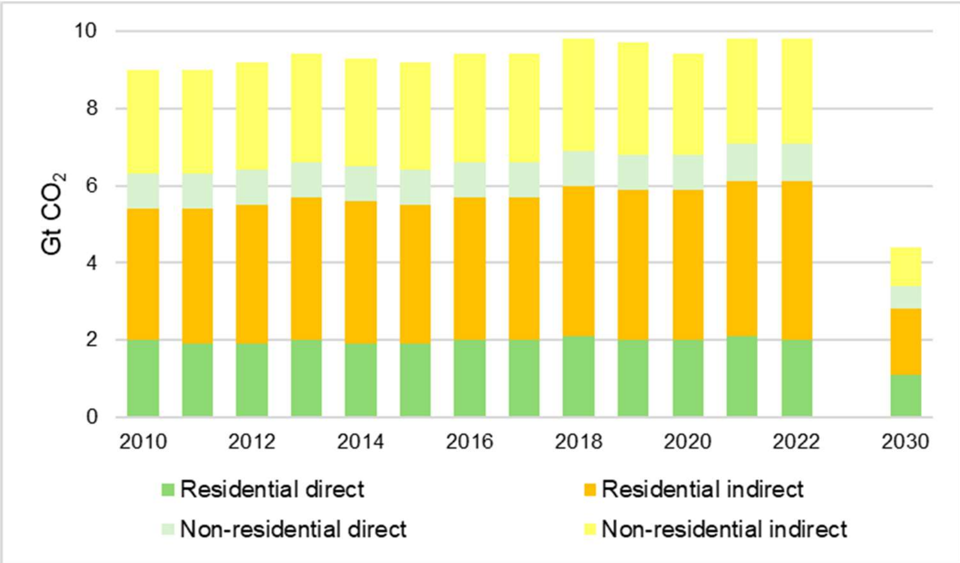

Figure 3. 12. Global CO2 emissions from building operations in the Net Zero Scenario, 2010-2030 [19]

In the context of demographic growth, increasing energy demand and the rapid growth of the number of buildings and the floor area in the coming years, achieving full decarbonization in the building sector will require several essential measures: implementing improvements to enhance energy efficiency, adopting better practice during the design and construction phase, using environmental friendly materials, transition to electric or district heating systems powered by renewable energy from carbon-free sources, ensuring the generation or procurement of carbon-free renewable energy [20].

Whole life carbon (WLC) emissions represent the aggregate of all GHG emissions and removals associated with a building, including both operational and embodied emissions, throughout its entire life cycle up to disposal. The comprehensive assessment of building's whole life carbon performance also accounts for separately detailing the possible advantages or burdens arising from the eventual recovery, reuse, and recycling of energy or materials, as well as from utilities that are exported [21].

Operational carbon emissions are the term for GHG emissions generated from the energy used by a building throughout its life cycle [21]. These emissions can be mitigated over time by implementing energy efficiency, adopting renewable sources of energy, and optimizing energy use. On the other hand, embodied carbon emissions encompass all GHG emissions and absorptions linked to the materials and construction processes over the building's entire life cycle [21]. Unlike operational emissions, which can be gradually reduced, embodied carbon emissions remain fixed throughout the building's lifespan and encompass a wide range of emissions starting with the production of building materials, extraction of raw materials and transport to manufacturing facilities, then manufacturing, transport to the construction site, construction practices, maintenance, operation, and ending with demolition, waste management and recycling [20, 22]. While the global building stock is projected to double by 2060, is estimated that almost 50% of the overall carbon footprint from new buildings from now until 2050 will be attributed to embodied carbon. In response to this challenge, the aim is to eliminate embodied carbon emissions from buildings by 2050. But to achieve zero embodied emissions in the building sector we must embrace a comprehensive approach that encompasses several key principles such as: reuse by renovating existing buildings, using recycled materials, and designing structures with deconstruction in mind; reduce by minimizing emissions through carefully selecting materials with low to zero carbon; sequester by designing sites and structures that capture and store carbon [20].

Approaches to reduce both the embodied and the operational carbon emissions can be organized into three main strategies: "avoid", "shift", and "improve" [18]:

- "Avoid" strategy includes measures such as minimizing construction, adopting circular methods that use fewer or low-carbon materials, and designing buildings that emit less carbon during their use;
- "Shift" strategy refers to expanding the use of alternative construction materials that are local, low in carbon, and based on hybrid or biological source;
- "Improve" strategy aims on cutting down the emissions from traditional construction materials.

Integrating these principles and strategies into building practices will contribute to building decarbonization, ensuring a sustainable future for our planet.

With the aim of decarbonizing the building materials industry, it's crucial for all stakeholders involved in the construction process to comprehend the consequences of the material choices throughout the entire life cycle. The intricate nature of the supply chains for materials and systems requests the use of advanced tools. These tools are imperative for empowering those who make decisions to evaluate various materials based on their environmental impact during the whole life cycle: production, use, and disposal.

The publicly available documents which transparently certify the environmental performance or impact of a whole building over its lifetime are The Environmental Product Declarations (EPD). Theses have been established as credible instruments that report on the environmental impact of products through life cycle assessments. However, their effectiveness for guiding is limited from several factors: variability in the quality of data provided, variations in the methodologies relied, discrepancies in the functional equivalences between different products, and their diverse rules that define product categories. All these issues make challenges in using EPDs to make reliable decisions regarding materials supply. But providing standardization remains a key objective and practical solutions like implementing logbooks and materials passports must be consistently adopted worldwide [18].

3.4 European and National Framework from Romania, Slovakia, Spain, and Ukraine

According to Eurostat [23], in 2022, the building sector in European Union accounted for 40% of final energy consumption. Similar percentages were recorded in Slovakia and Romania, in Spain the share of buildings was around 31%, while in Ukraine the last data recorded was almost 42% in 2020 (Figure 3. 13). Comparing with the previous year, the final energy consumption fell by nearly 4% in EU, 5.66% in Slovakia, approximately 1% in Spain, 5.4% in Romania. Regarding the final energy consumption from buildings, the annual decrease from 2021 to 2022 was even more marked: 6.5% in EU, 9.4% in Slovakia, around 2% in Spain.

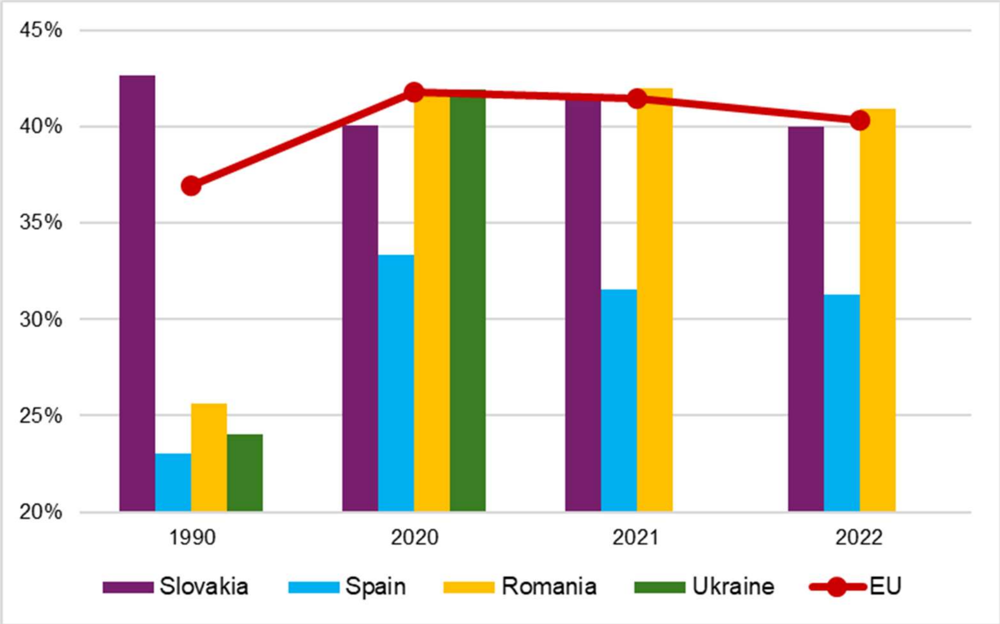

Figure 3. 13. Share of buildings in final energy consumption in EU, Slovakia, Spain, Romania, and Ukraine [23]

At EU-level, the emissions from building sector represent 35% of energy related emissions within the EU in 2021. This is due to both the direct consumption of fossil fuels within buildings and the generation of electricity and heat that buildings use. Eu greenhouse gas emissions from buildings saw a 31% reduction since 2005 (Figure 3. 14).

This reduction was influenced by the implementation of energy efficiency regulations for newly constructed buildings, an increase in energy efficiency for older structures, the growing renovation rate of building stocks, the shift towards less carbon-intensive electricity and heating, and an increase in average temperatures.

While GHG emissions from energy consumption decreased between 2005 and 2021 in EU, Slovakia, Spain, and Romania, regarding the change in GHG emissions from energy use in buildings things differ from one country to another (Figure 3. 15). Slovakia and Spain experienced a decline in emissions between 2005 and 2021 (21%, respectively nearly 16%), in Romania emissions revealed an upward trajectory of almost 8% (Ukraine wasn't included in the comparison due to lack of data).

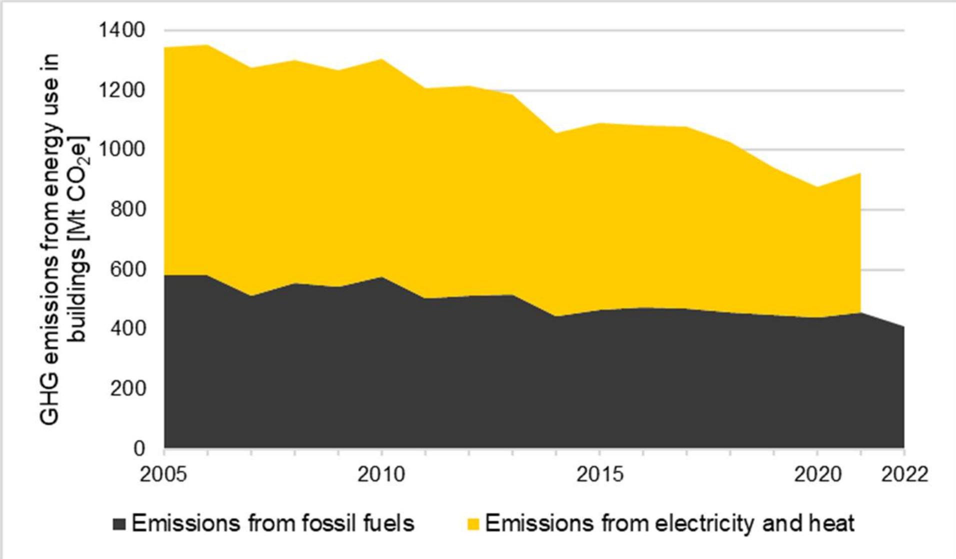

Figure 3. 14. GHG emissions from energy use in buildings in EU, between 2005-2022 [24]

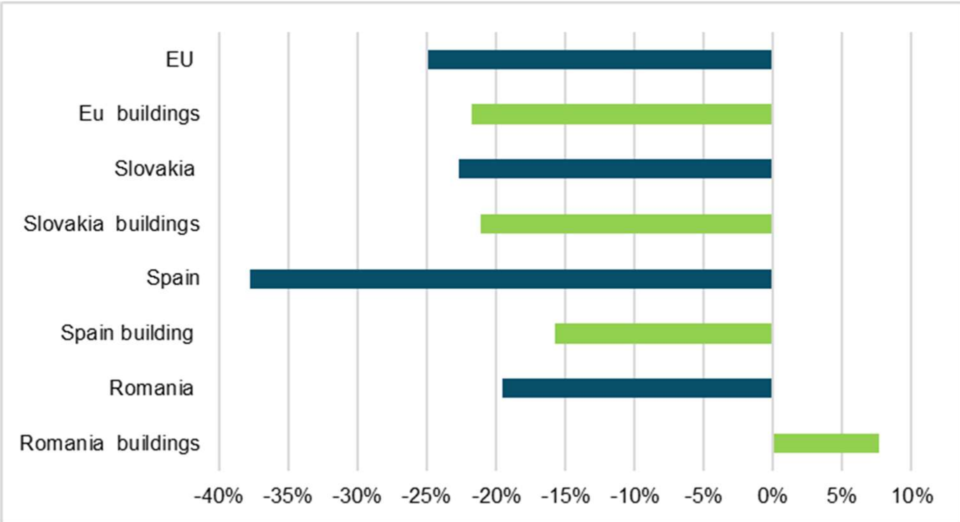

Figure 3. 15. Rate of change in GHG emissions from energy consumption and energy use in buildings in EU, Slovakia, Spain, and Romania, in 2005-2021 [23]

Country wide projections of emissions from buildings indicate a continued decline by 2030 compared to 2005 in nearly all Member States with two exceptions, one being Romania due to expected higher income levels (Figure 3. 16).

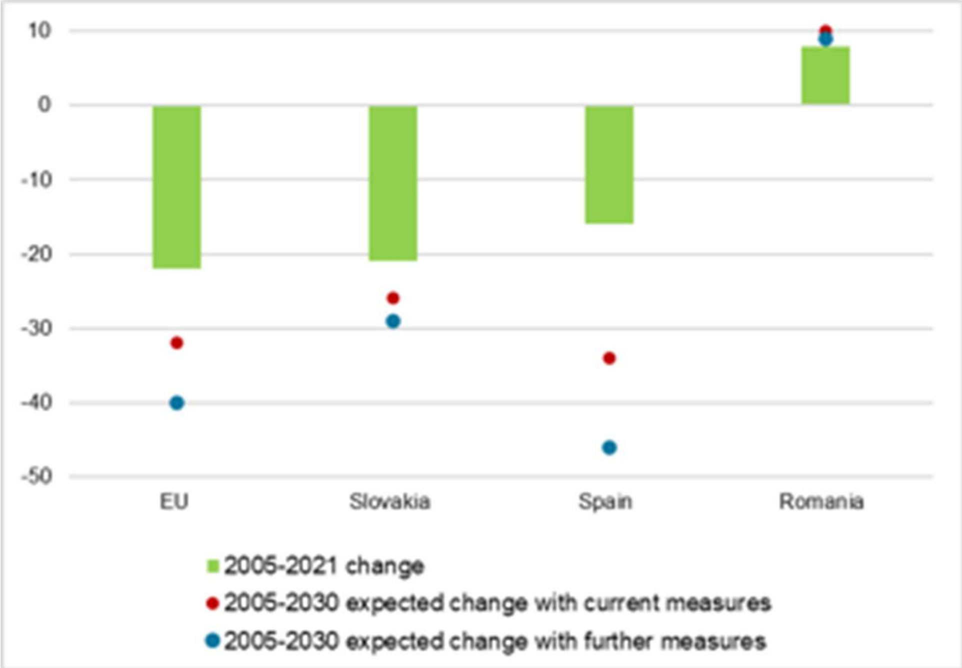

Figure 3. 16. Expected change in GHG emissions from energy use in buildings in EU, Slovakia, Spain, and Romania, in 2005-2030, according to [24]

To align with the EU's objective of a net 55% reduction in GHG emissions by 2030, relative to 1990, the building sector would need to cut emissions by 60% from the level recorded in 2015, in conformity with the EU's renovation wave [24]. Therefore, it's crucial to concurrently pursue the electrification of end-users in homes, the transition to greener electricity production, and the enhancement of building energy efficiency.

The European Commission's Renovation Wave Strategy, a key component of the European Green Deal, focuses on decreasing emissions, enhancing living standards, and mitigating energy poverty. It plans to intensify the refurbishment of buildings throughout the EU to boost their energy efficiency. The strategy's goal is to increase the rate of energy renovations, for both residential and non-residential structures, twofold over the coming decade, resulting in heightened energy and resource efficiency. To achieve climate neutrality across the EU by 2050, this enhanced level of renovation must continue.

Based on the following fundamental principles, the EU should implement a comprehensive and unified approach that includes a wide variety of sectors and stakeholders [25, 26]:

- Making EU buildings more energy-efficient and sustainable, with a reduced carbon footprint throughout their entire life cycle;

- Adopting a life cycle perspective and implementing circular economy concepts to diminish pollution and the GHG emissions associated with materials used in buildings; fostering green infrastructure and employing organic construction materials capable of carbon sequestration;
- Accelerating the adoption of renewable sources of energy, particularly from local sources, and encourage the wider utilization of waste heat; consolidation the energy systems regarding the decarbonization of heating, cooling, and transport;
- Upholding health and environmental regulations to guarantee superior air quality, effective water management, and safeguarding against disasters and climate-related risks;
- Combining green and smart technology to achieve utmost efficiency and decarbonizing the buildings.

The EU Policy Whole Life Carbon Roadmap for buildings provides a strategic plan to boost the total decarbonization of buildings and construction within EU by 2050, emphasizing recommendations to manage whole life carbon emissions in buildings [18, 27]:

- Standardize and upgrade energy performance certificates of EU and creation of publicly accessible databases by EU Member States, which would include measured and modelled data on energy efficiency and GHG emissions for their buildings; implement regulated WLC measures would reform the planning and execution processes in building industry;
- Implement and align regulations that enforce the transition to a circular economy (since the construction sector is responsible for roughly one-third of EU's overall waste), standardize the calculation process, and create certifications aligned with the Level(s) framework guidelines;
- EU procurement practices must evolve towards sustainability and circularity, assign the reporting of WLC emissions, and adopt harsher emissions benchmarks;
- Implement and promote financial incentives that promote sustainability, harmonize the EU taxonomy with regulations, integrate the taxonomy standards for climate mitigation, adaptation, and circular economy in buildings.

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Chapter 04

Life Cycle Methodology

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Life cycle analysis (LCA) is defined as an objective methodology for analysing and quantifying the environmental impacts of products and services throughout their entire life cycle, from the extraction of raw materials through the production phase, the use phase and the end of their life.

4.1 Introduction to LCA

The life cycle phases of a product are illustrated in Fig. 4.1.

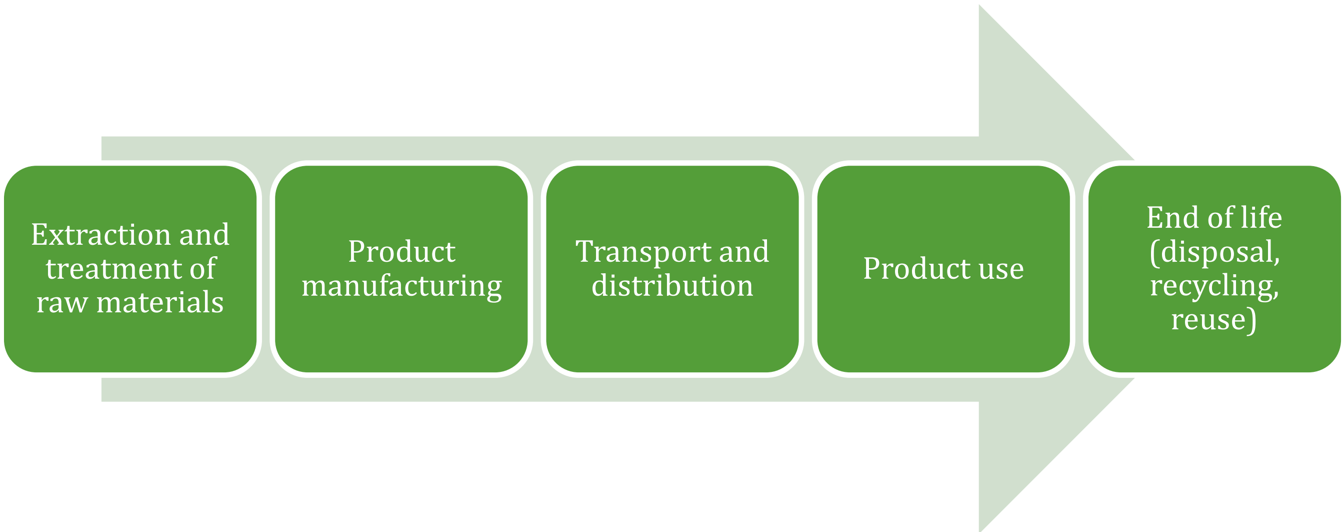

Fig. 4.1 Life cycle stages of a product

The LCA method is used to evaluate the potential environmental impacts of products, technologies or services on the environment, which are expressed using impact categories [1].

These impact categories are based on the energy and material flows of a product system composed of unit processes and characterized by a functional unit. Unit processes combine energy and material flows. The product system is a set of all inputs and outputs of the product [2]. The idea of comprehensive LCA assessment was conceived in the late 1960s and early 1970s at the American Midwest Research Institute (MRI), while almost identical ideas were developed in Europe around the same time [3]. The concept of LCA has been developed and used by companies as a resource management tool, with these studies focusing on waste management and packaging [4]. In the United States, researchers used the Resource and Environmental Profile Analysis (REPA) method to compare the environmental impacts of products in terms of energy and raw material consumption [5]. The origin and development of this method was associated with the oil and energy crisis, which significantly increased interest in energy and raw material resources. The final evaluation was based on cost benefit analysis. However, the impact of the product on human health, ecosystems or the environment has not been assessed [6-7]. At the end of the 80s, the LCA method was referred to by different names according to the country in which it was used. The initiative in the development of this method, especially in the unification of non-uniform procedures, was conditioned by the founding of the Society for Toxicology and Environmental Chemistry (SETAC) in 1979. The aim of this society was to organize thematic workshops where industrial, consulting, research and scientific institutes met, which dealt with the issue of life cycle assessment. The definition of valid terms that we use today was the result of these workshops, on the basis of which a book entitled A Technical Framework for Life Cycle Assessment [8] was published. The Society for the Promotion of Lifecycle Development (SPOLD) was founded due to the great interest of experts in LCA, whose main contribution was to develop a method of data transfer and sharing [9]. In the late 1980s and early 1990s, attention began to be paid not only to the impact of the product on human health, but also to the negative impact on the environment. On the basis of this expanding evaluation, the last stage of the product's life cycle - disposal - was included in the calculations of energy and raw material consumption, and the term "cradle to grave" was introduced. Since then, the term product life cycle assessment, as well as product life cycle analysis, has been used. A sharp increase in the interest of experts in LCA was recorded in the years 1990-1993 [8,9]. The use of LCA has expanded enormously since its introduction, so that it is now a well-known and widely used assessment tool in industry, research and politics. Recently, it has been motivated in terms of environmental policies [10].

To facilitate a harmonized approach, ISO has introduced the LCA group of Life Cycle Assessment (LCA) standards, which include:

- ISO 14040:2006 - Environmental management — Life cycle assessment — Principles and framework
- ISO 14044:2006 Environmental management — Life cycle assessment — Requirements and guidelines
- ISO 14046:2014 Environmental management — Water footprint — Principles, requirements and guidelines
- ISO/TS 14048:2002 Environmental management — Life cycle assessment — Data documentation format
- ISO 14067:2018 Greenhouse gases — Carbon footprint of products — Requirements and guidelines for quantification
- ISO/TS 14072:2014 Environmental management — Life cycle assessment — Requirements and guidelines for organizational life cycle assessment
- ISO/TS 14071:2014 Environmental management — Life cycle assessment — Critical review processes and reviewer competencies: Additional requirements and guidelines to ISO 14044:2006

4.2 LCA procedure

ISO distinguishes four steps in the LCA assessment process that are linked to the life cycle of a certain product, technology or service: 1. definition of the objective and scope, 2. inventory analysis, 3. assessment of impacts and 4. interpretation, as shown in the Fig. 2 [11].

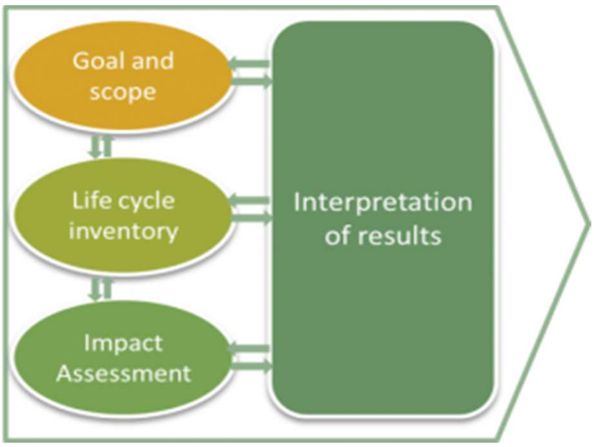

Fig. 4.2 Connection between the life cycle steps

Step 1 - Goal and scope definition

Defining the goal and scope is the first step in an ISO-standardized LCA. In the goal and scope definition phase, the purpose of the assessment and context in which the assessment is to be made are established and a decision is made on the details of the product system and data quality for the assessment (Fig. 4.3) [12].

The purpose and scope are defined at the outset, before any data is collected. This phase of the LCA methodology is very important because it is here that the exact approach to be followed is determined. During the analysis, knowledge from one phase can affect the outputs of the previous phase [13].

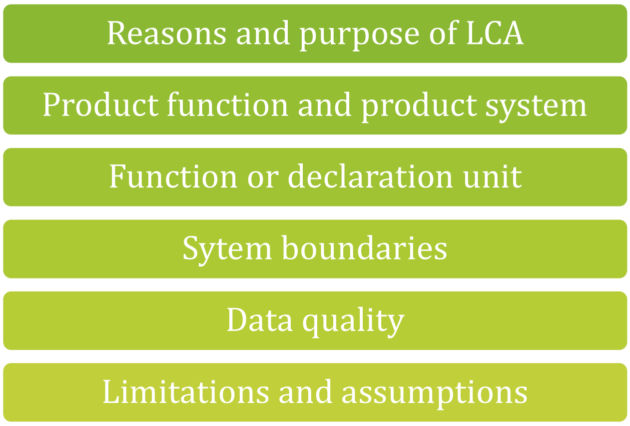

Fig. 4.3 The main parts of the Step 1 in LCA

Properties such as functionality, appearance, stability, durability, etc. are determined by market requirements. Product utility is identified through its functional unit, which can be expressed in different units [14]. Functional unit definition is a critical step in LCA because it determines the reference flows and alternative upstream and downstream processes to be included in the study. Functional unit is a measure that allows quantification of the function defined. It should represent performance of the functional outputs of the product system. It provides a reference to which inputs and outputs are related. Currently, there is an effort to establish a clear guideline for determining the functional unit of the system. ISO standards only require a functional unit that depends on the objective and scope of the study and that it is clearly defined and measurable. If LCA is used to compare alternative products, the basis of comparison must be equivalent use. This means that each system should be defined in such a way that the same amount of product or equivalent service can be delivered [15]. A functional unit is usually not just a quantity of material [16].

For construction products, the functional unit is described in the standard EN 15804. The functional unit used as a common denominator is the basis for summing up the material flows and environmental impacts of the life cycle phases and their modules for construction products and services. The functional unit of the construction product is based on the calculated important functional or performance characteristics of the construction product incorporated in the building, taking into account the functional equivalent of the building as well as the reference operating life of the product or the operating life of the building under specified conditions of use. For the LCA assessment of construction products, the functional unit can be used as illustrated in Fig. 4.4.

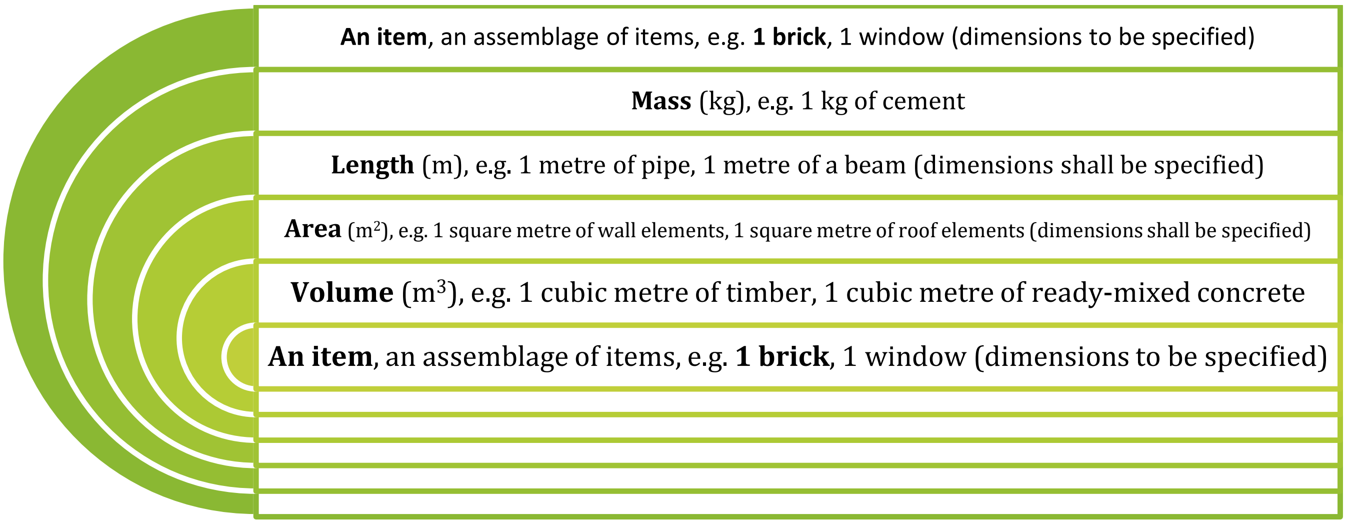

Fig. 4.4 Types of functional unit of building material

The boundaries of the life cycle assessment system determine which processes and activities comprise the overall LCA. This kind of analysis must take into account the material and energy flows of the primary processes together with the extraction of raw materials and, whenever possible, the production of intermediate raw materials or the production of equipment that could be included in the analysis. End of life is also another factor to consider: how to recover or dispose of products, by-products, waste and process materials [17-19]. The inclusion or exclusion of any step can significantly affect the overall outcome of the analysis. System boundaries are a way to define the study system for life cycle analysis: the system should include everything within the boundary, including processes, materials and intermediate products.

Generally speaking, there are several approaches within the LCA to define the system boundaries:

Cradle to gate

The cradle to the gate variant is based on the evaluation of the partial life cycle of the product from extracting the raw materials to the "gates" of the plant (i.e. before it is transported to the user). This variant is also called as "manufacturing of product" or "product phase" in building concept. In this variant, the phase of use and disposal is not taken into account and it is omitted.

The gate to gate is a reduced variant of cradle to gate variant and it includes an LCA analysis from factory entry gate to exit gate only. The product use/disposal phase is not included in the system boundary [18].

Cradle to grave

This variant is based on the assessment of the whole life cycle of the product, which includes the processes involved in the acquisition of raw materials and the production of the necessary materials and raw materials, the production of the product itself, the use of the product and its disposal.

Cradle to cradle

The variant from cradle to cradle, or "open loop production", is a specific type of evaluation, while the disposal step is a recycling process. This method is used to minimize negative impacts on the environment by applying the so-called sustainable production, operation and disposal practices [20].

Fig. 5 presents a system boundary for the building materials evaluation aimed at environmental product declaration (EPD) development according to the EN 15804 [21].

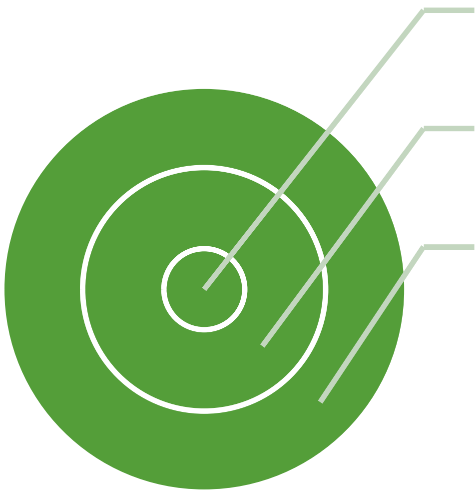

Fig. 4.5 System boundaries of building materials according to the EN 15804*

* The standard EN 15804 defines the particular processes within the life cycle stages of the product as follows: A1-A3 (product stage), A4-A5 (construction process stage), B1-B7 (use stage), C1-C4 (end of life stage) and D (benefits and loads beyond the system boundary).

The data used in the life cycle inventory are environmental data on the investigated processes, system data on the flow of raw materials, energy and products through the investigated processes. Thus, data should be understood as any information that is used in a life cycle inventory. Data quality is a specific characteristic of data expressed through data information (meta data) [21,22]. The quality of the data used in the life cycle inventory is naturally reflected in the quality of the final LCA assessment and is only as good as the information on which it is based. Data quality can be described and assessed in various ways, and it is very important that this data quality is described and assessed in a systematic way that allows others to understand and control the actual data quality. At the beginning of the analysis, it is necessary to establish the initial data quality requirements, which are defined by the following requirements:

- Time-related coverage: required time period (e.g. within the last 5 years) and minimum time interval (e.g. a year).

- Geographic coverage: the geographic area from which unit process data should be collected to meet the study objective (e.g. local, regional, national, continental or global).
- Technology coverage: the nature of the technology mix (e.g. weighted average of the current process mix, best available technology or worst operating unit) [23,24].

When evaluating the data quality, the precision, completeness, representativeness, consistency and reproducibility should be under consideration [25].

4.3 Step 2 – Life Cycle Inventory (LCI)

Life Cycle Inventory Analysis (LCI) is the second step in LCA assessment and is defined as a process that includes the compilation and quantification of all inputs and outputs for a given product system within its entire life cycle or part of it during which the assessment is carried out [26] (Fig. 4.6). It serves to calculate all input and output data with respect to the system under consideration. The main goal is the collection of environmentally important data about the processes that are included in the product system [27]. The result of the inventory should be an overview of all substances and their quantities entering and leaving the product system. This is a long list of requirements for material and energy, products and intermediate products, and last but not least, waste and harmful substances released into individual components of the environment (into the air, water and soil) [4, 28].

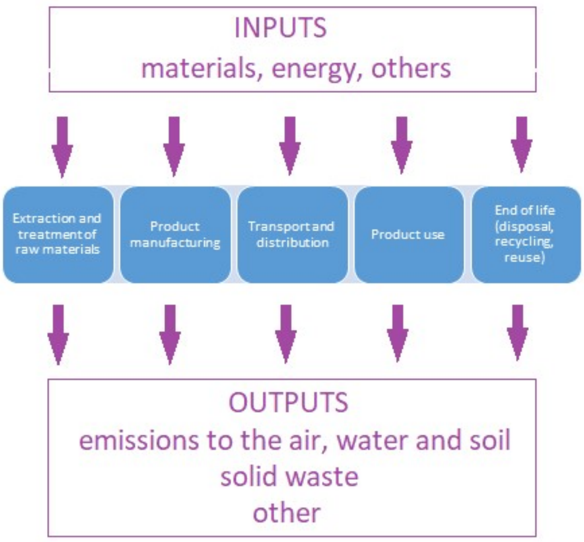

Fig. 4.6 Inputs and outputs in LCA inventory

The concept of LCI was adopted for cleaner production as early as the 1960s and has had wide industrial and academic use in recent decades [29]. Compared to other phases of LCA, LCI is considered a relatively simple procedure except for a few questions [8]. In most cases, base flows have an associated impact on the environment. The baseline flows are used to calculate the environmental impacts of the product using different impact assessment methods in the next step of the LCA assessment [30].

4.4 Step 3 – Life Cycle Impact Assessment (LCIA)

Life cycle impact assessment is the third step of the LCA process, which is aimed at understanding and quantifying the extent and significance of possible impacts of a product or service on the environment during its life cycle. Understanding these impacts is the first step in the field of prevention, reduction of negative impacts and corrective measures [31]. In this phase, the life cycle information that was collected during the inventory analysis (LCI) is translated into environmental impact results through impact categories and damage categories. In other words, impact assessment methods are used to systematic calculations to ensure that all data, or substances from LCI transformed into environmental impacts that they cause, in terms of environmental indicators. Unlike the other three phases of LCA, this phase is largely automated by various LCA software [32]. In the event that it is not possible to perform inventory analysis using primary data directly by collecting data from the production process or another phase of the life cycle, various data databases are used that are directly integrated into software tools (see the chapter 6).

The LCIA life cycle impact assessment aims to combine the results of the inventory analysis with the relevant environmental impacts as much as possible. Due to the complexity of this step, methodologies have been developed that aim to simplify and optimize the LCIA process. Life cycle impact assessment (LCIA) according to ISO 14044 (2006) takes place through two mandatory and two optional steps as presented in Fig. 4.7.

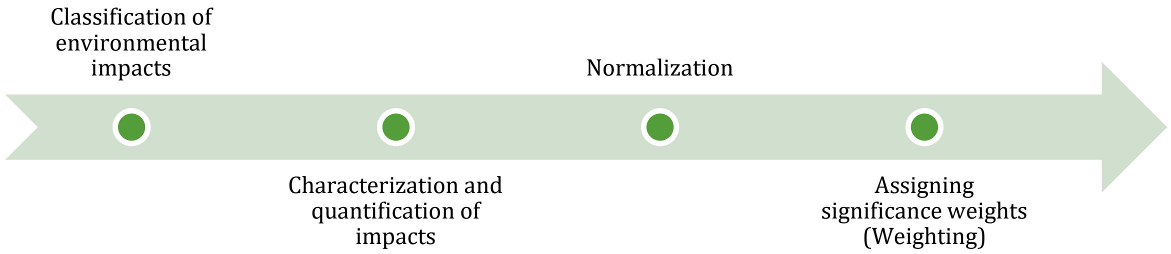

Fig. 4.7 LCIA processes

Classification of environmental impacts

The selection of impact categories in which the environmental impacts of the evaluated product will be expressed and the subsequent classification of all emissions, inputs and outputs from the inventory list is a mandatory step of all methods within the LCIA evaluation according to the ISO standard.

The basic strategy for classification is whether we will express environmental impacts through primary or total impacts.

1) The assessment of primary impacts in the area of the environment brings more measurable results (for example, emissions of sulphur oxides contribute to the acidification of water and soil, which can be directly expressed through the amounts of pollutants measured in the air). On the other hand, this approach has less environmental significance and is further away from problems directly observable in the environment, as the consequence of water acidification can be e.g. death of animal species.

2) The assessment of overall impacts in the environmental mechanism provides more relevant but more difficult to verify information (for example damage to ecosystems, affected human health).

This led to the creation of two different types of impact indicators that use indicators at two different levels of the environmental mechanism: mid-point impact indicators representing the first option and end-point impact indicators representing the second option.

The results in some calculation methods are based on measurable properties of elementary flows expressed using the so-called mid-point indicators in impact categories and others describe concretely observed damage to the environment using the so-called of end-point indicators in damage categories [32, 33]. In most methodologies, emissions and resource consumption are reflected in the form of impacts in three main areas of protection: ecosystem quality, human health and natural resources which serve as end-point indicators. In these main areas, several sub-indicators of impact are combined, which express the impact on the environment (mid-point indicators). Environmental impact categories that are relevant to the study are defined by their impact indicator, and basic flows from the inventory are assigned to impact categories according to the ability of substances to contribute to individual environmental problems. The impact categories are defined and selected to describe the impacts caused by the emissions and consumption of natural resources that are used during the production, use and disposal of the considered product or process. A schematic representation of the mechanism of environmental impact assessment, which explains the evaluation of substance emissions through mid-point and end-point indicators, is shown in Fig. 4.8.

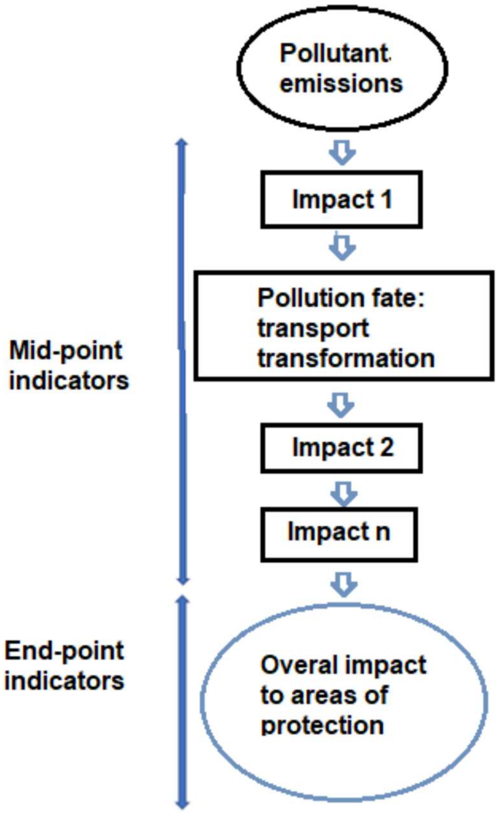

Fig. 4.8 Characteristic of mid-point and end-point indicators

The fate of the pollutant is defined by the environmental processes caused by the transport and transformation of the emitted substance in the environment. Depending on the physical and chemical properties of the substance and local conditions, the substance may be distributed among different components of the environment, transported over long distances by wind or water, and may undergo various chemical processes or degradation.

Whether the results of the impact assessment are evaluated through mid-point or end-point indicators is, among other factors, the main difference between LCIA methodologies [34, 35].

Mid-point indicators

If the impact assessment is based on mid-point impact indicators, the classification collects the results of the inventory into groups - categories of impacts, according to the ability of the substance to contribute to the same primary impact on the environment. For example, all elementary streams of substances that can have a carcinogenic effect on humans will be included in the same impact category called "carcinogenicity" and the characterization will be calculated by their contribution to this impact [36].

The characterization of elementary flows in the mid-level life cycle inventory leads to the collection of mid-point impact indicator values, which are collectively referred to as the mid-level systemic product impact profile. This profile is characterized as a result of a life cycle impact assessment and can also serve as a preparation for the characterization of impacts at the end-point level [37].

The basic division of impact categories is according to their geographical extent. Based on this, we divide them into global, regional and local. By global impacts we mean e.g. global warming and depletion of stratospheric ozone. In contrast to global impacts, regional impacts act on a smaller scale, these impacts include e.g. acidification, eutrophication, chronic toxicity or photooxidant formation. The spread of substances involved in the aforementioned impacts is diffuse and therefore their transfer over relatively long distances is possible. In the case of local impacts, pollution is caused by point sources of pollution, it manifests itself mostly in the same place as the source and reaches a maximum of several kilometres. Local impacts include e.g. resource depletion, acute toxicity, noise or waste production [38]. Typical impact categories are listed in the Table 4.1.

Table 4.1 Mostly used mid-point environmental indicators

Environmental indicator	Characteristics	Unit
Global warming (GWP)	An increase in the Earth's temperature due to an increase in the concentration of greenhouse gases in the atmosphere	kg CO_2 eqv
Ozone layer depletion (ODP)	Decreasing the concentration of stratospheric ozone due to the action of harmful substances, especially halogenated organic compounds	kg CFC11 eqv
Acidification (AP)	Increased acidification of water and soil due to hydrogen cations entering the environment through atmospheric deposition	kg SO_2 eqv
Eutrophication (EP)	Excessive content of nutrients (mainly nitrogen and phosphorus) in the waters	kg PO_4^3 eqv kg NO_3^- eqv
Photochemical ozone creation (POCP)	The formation of various dangerous substances during reactions of volatile hydrocarbons with oxygen radicals and nitrogen oxides in the troposphere, e.g. ozone	kg C_2H_4 eqv
Human toxicity (HTP)	Toxic effects of substances on the human body	kg 1,4DCB eqv
Ecotoxicity (ETP)	Toxic effect of substances on natural ecosystems	kg 1,4DCB eqv
Depletion of abiotic resources (ADP)	Use of renewable and non-renewable mineral resources	kg Sb eqv

These basic categories also include specifically used impact categories such as noise, odour, pathogens, land use, use of biotic resources, formation of solid particles, ionizing radiation and others. These specific categories have applications in specific LCA studies. For example, for the EPD development by LCA, the particular core and additional indicators and impact categories are required to be declared (Tables 2 and 3).

End-point indicators

End-point indicators are created by combining several mid-point indicators into one of three endpoints (Fig. 9). These endpoints, called areas of protection or damage categories, represent environmental impacts in the specified areas of environmental protection: human health, natural environment and natural resources. The category "human health" represents the negative impacts of the evaluated system in terms of damage to human health; the category "ecosystem quality" expresses damage to the ecosystem as a function of supporting the natural environment of the planet; and the category "natural resources" is related to the depletion of natural resources - raw materials and energy [39]. Fig. 9 shows the connection of the above-mentioned indicators (at the mid- and end-point level) to the areas of protection. Some methods use the term “damage categories” in connection to the areas of protection and the end-point indicators can be as “damage in human health”, “damage to natural environment” and “depletion of resources”. The units of the LCA end-point indicators are listed in Table 4 [40].

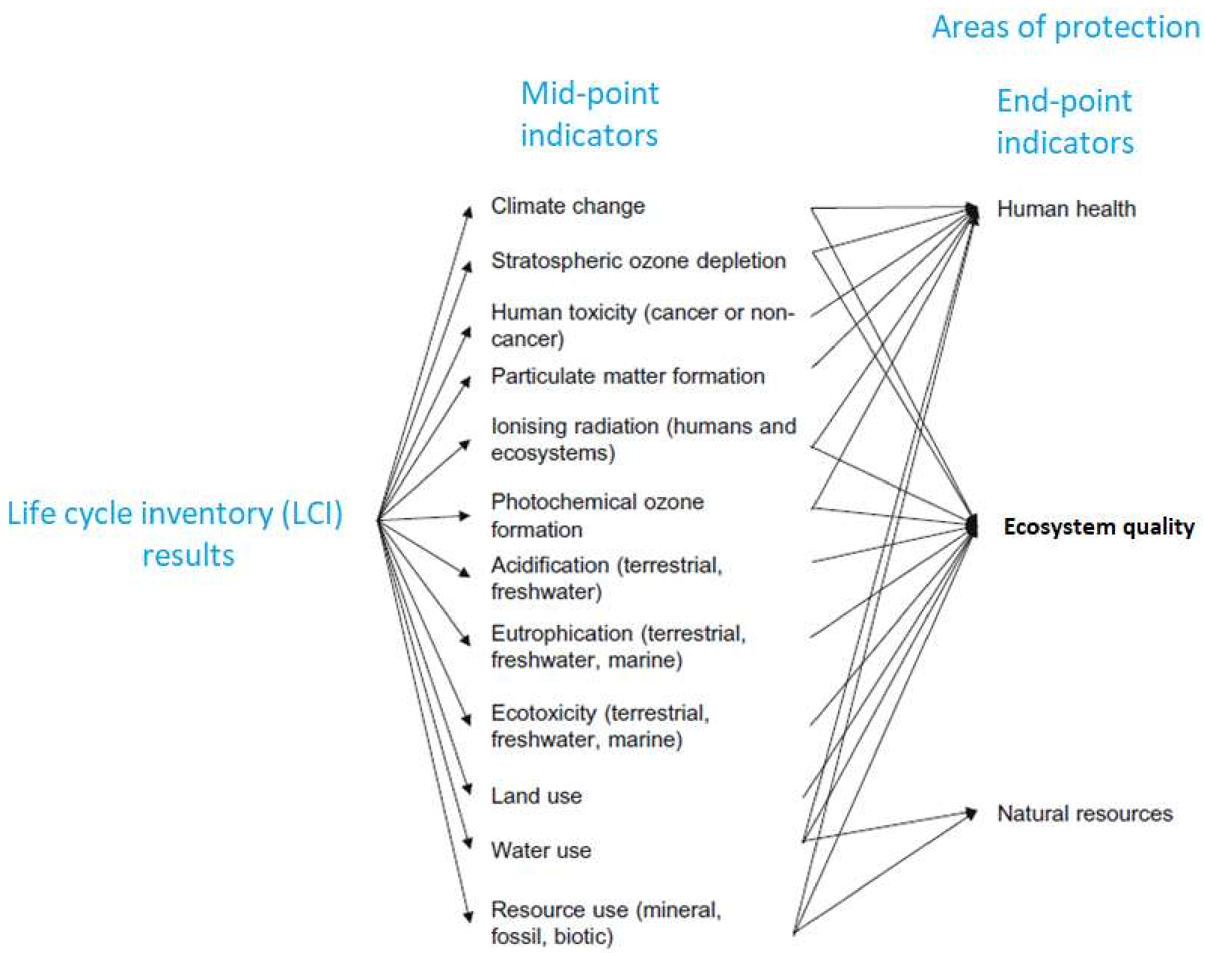

Fig. 4.9 Difference between mid-point and end-point indicators

Table 4.4 End-point indicators and units

Environmental indicator	Unit
Human health	DALY (disability-adjusted life years) – the number of years of reduced quality of life due to illness, disability or premature death
Ecosystem quality	PDF (m^2/y, m^3/y) – potentially extinct or extinct species in an ecosystem in a certain area or volume during a certain time period
Natural resources	MJ, or USD, Jen, Euro – there are different approaches and there is not yet a unified way of modelling damage in the form of resource depletion. Some proposals focus on estimating future energy demands and the cost of extracting the resource due to current depletion

Characterisation of environmental impacts

Characterization is the second mandatory step in the LCIA impact assessment process, where the impact of each emission is quantitatively modelled according to the underlying environmental mechanism. Impact is expressed as a score through a common unit for all submissions within a category, using characterization factors (CF). CF is a substance-specific factor calculated using a characterization model to express the impact of a particular elemental flux in terms of a common category indicator unit. The impact is calculated by multiplying the results from the inventory (amount of emissions, waste, or resources consumed) by the appropriate characterization factor for each substance within each impact category, as shown in equation (1).

$$Environmental\ impact = \sum_{s} CF(s) \times quantity\ of\ emission(s) \quad (1)$$

where the index s indicates individual chemical substances.

CF factors express the contribution of unit mass (1 kg) of emission to individual environmental problems. For example, the relative contributions of different greenhouse gases to climate change are commonly linked and compared using carbon dioxide equivalents in the global warming potential (GWP) category. For example, a calculated score of 500 in the GWP100 category means that 1 kg of a substance has the same impact on climate change as 500 kg of carbon dioxide over a period of 100 years [41].

However, CFs may vary depending on the LCIA methodology chosen. These different CF values are attributed to national differences in production processes or energy sources. Other differences between different LCIA methodologies include the use of different normalization and weighting factors [42].

Normalisation of environmental impacts

Normalization is an optional step in the LCIA process, where the calculated impact values are converted to a common reference unit, e.g. impacts caused by one person during one year to simplify the comparison process between individual impact categories. However, normalization brings the advantages of placing the characteristic impact indicator in a wider context. It is expressed in a way that enables the comparison of impact indicators so that the sum of the results of each category indicator is divided by the reference value according to the following equation (2):

$$N_k = S_k / R_k \quad (2)$$

where k denotes the impact category, N is the normalized indicator, S is the category indicator from the characterization phase, and R is the reference value or normalization factor. Normalization factors are chosen to represent the actual or potential magnitude of the corresponding impact category for a given geographic area over a certain time span. The reference value can be e.g. a country's annual national contribution to climate change in terms of GWP [43].

Weighting of environmental impacts

Allocation of significance weights is also an optional step in the LCIA, in which an assessment and/or weighting of the different categories and their environmental impacts is carried out, reflecting the relative importance of the impacts considered in the study. It is a process in which the results of normalized factors (indicators) of various impact categories are converted into values using weighting factors based on subjective assessments, that is, these weighting factors depend on social, political and ethical perspectives. This process consists of multiplying weighting factors by the results of normalization for each impact category according to equation (3).

$$EI = \sum V_k \times N_k \quad or \quad EI = \sum V_k \times S_k \tag{3}$$

where EI is the overall environmental impact indicator, Vk is the weighting factor for impact category k, N is the normalized indicator and S is the category indicator from the characterization phase. The weighting factors represent the relative importance of each environmental impact category. These factors are based on subjective perception and vary e.g. according to the geographical area based on socio-economic criteria.

The difference between the normalization and weighting steps is that normalization provides a basis for comparing different types of environmental impact categories (all impacts have the same unit), whereas weighting assigns individual weights or relative values to different impact categories based on their perceived importance or relevance [59]. Weighing is considered a qualitative as well as a quantitative step, which is not necessarily based on natural science, but often on political or ethical values [44-45]. In some cases of LCA, weighting is necessary [46].

4.5 Step 4 – LCA Interpretation

Interpretation step combines the observations of the inventory analysis and the impact assessment, in a manner consistent with the defined goal and scope to reach conclusions, clarify limitations that could be an obstacle to the initial goals, identify the main life cycle phases that contribute to the environmental impacts, and provide final recommendations. To establish and increase confidence in study's conclusions, in this step, there is performed a check of intended application of the study in accordance with goals and scope presented in the first step, check of completeness, consistency and sensitivity.

4.6 LCA methods

Since the publication of the first evaluation procedure in 1984, several LCIA methods have been gradually published and their development or harmonization is still ongoing (Fig. 4.10).

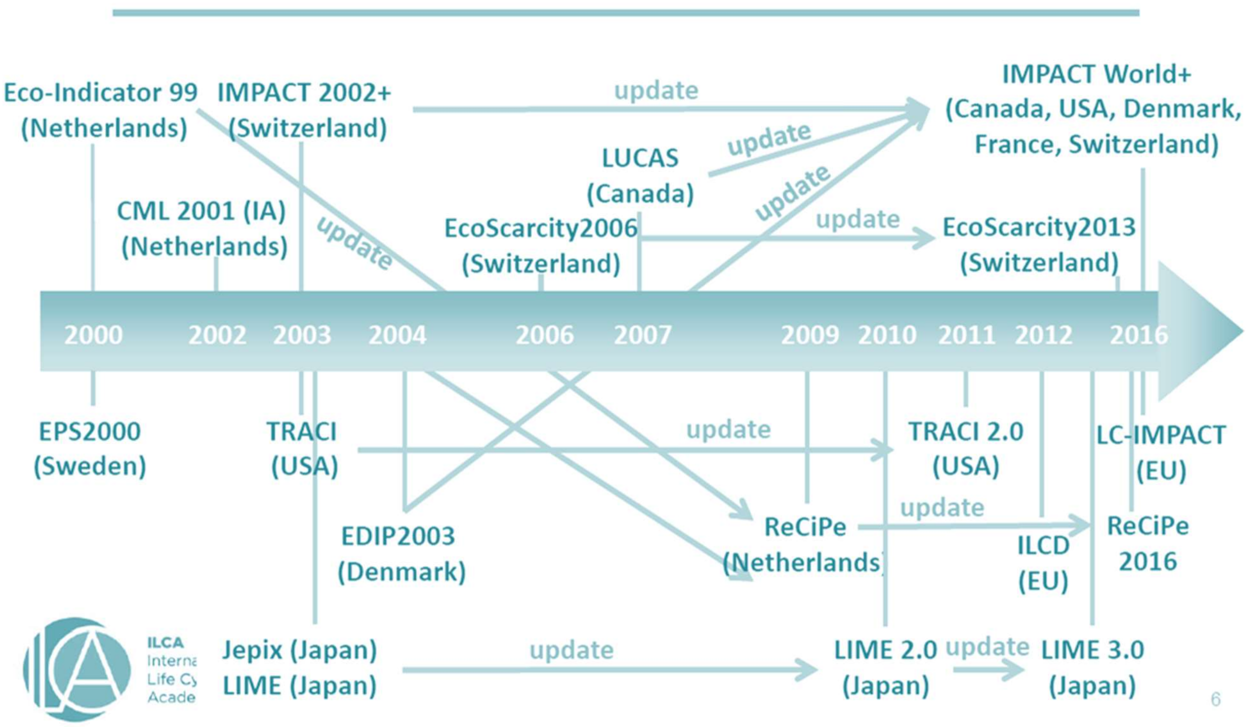

Fig. 4.10 LCIA methods history [47]

Individual evaluation methods differed mainly in environmental indicators and categories, i.e. in the way of modelling and presentation of results. Within this framework, LCIA methods are classified into two basic groups:

1) Classic methods of impact assessment, such as CML [51], TRACI and EDIP [52] that define quantitative modelling to limit uncertainties and LCI results are evaluated based on mid-point indicators in individual impact categories.

2) Methods such as e.g. Eco-indicator 99 [49] or EPS [50] which present the results using the end-point indicators.

In addition to these methods, there are also methods that combine characterization models for both approaches, thus modelling impacts at the level of mid- and end-points, and it is possible to choose the presentation of impact assessment results using impact categories or damage categories during the calculation. For such methods, we recommend e.g. ReCiPe and IMPACT.

However, there are other types of LCIA methodologies that are not quite categorized by modelling approach. These methodologies are considered specific LCIA methodologies, which relate to the assessment of some specific environmental areas or impact categories, such as total energy demand or ecological footprint [53]. An overview of such methodologies can be found in the following table (Table 5).

Table 4.5 Specifically oriented LCIA methods [52]

Method	Impact categories
Cumulative Energy Demand (CED)	Non-renewable sources: fossil fuel, nuclear energy Renewable sources: biomass, wind, water a geothermal energy
Cumulative Exergy Demand (CExD)	Non-renewable sources: fossil fuel, nuclear energy, primary energy, metals, minerals Renewable sources: kinetic and solar energy, biomass, wind, water
Ecological footprint	Carbon dioxide, nuclear energy, land occupation
EDP (Ecosystem Damage Potencial)	Land occupation and land transformation
Greenhouse Gas Protocol	Fossil fuels carbon dioxide, biogenic carbon dioxide, carbon dioxide from land occupation and land transformation, carbon dioxide capturing
IPCC (20,100,500)	Climatic change in a horizon of 20, 100 a 500 years
USEtox	Human toxicity (carcinogen, non-carcinogen), Eco toxicity.

In principle, ISO 14040/14044 does not make any recommendations as to which LCIA methods should be used, but some organizations recommend the use of a specific LCIA method or parts of it. The European Commission established specific recommendations for impact categories at the level of mid-point and end-point categories by systematically comparing and evaluating all relevant existing approaches in each category, leading to the recommendation of the best available approach (EC-JRC 2011) [43]. In addition, there are series of standards regarding the LCA of buildings and construction works and building materials, which define the mandatory and optional life cycle phases and particular processes to be involved in LCA, especially when developing the environmental product declarations (EPD) for construction products [21].

With the increasing number of available LCIA methods and indicators, the task of selection requires a specific effort by the solver to understand the main characteristics of these methods and to keep up-to-date with developments in the field of LCIA. When choosing an LCIA method, it is necessary to take into account requirements, recommendations, external and internal factors.

The correct choice of method is based on the subjective decision of the researcher or is based on the recommendations of colleagues. Therefore, it is very important that the trainee knows the individual methods (what they include). The International Life Cycle Reference System (ILCD) is being developed to help promote the availability, exchange and use of coherent and high-quality life cycle data, methods and studies to reliably support decision-making in public policy and business. In this environment, a project was launched to develop recommendations for a coherent and consistent methodology for life cycle impact assessment (framework, characterization models and characterization factors) based on an analysis of existing characterization models to identify best practices and identify research needs for the shortcomings of existing methods [52]. Among the currently most used combined assessment methods are ReCiPe and IMPACT.

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Chapter 05

Databases and Software for LCA

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Goal of LCA software is to analyse environmental and economic indicator during the life cycle. They allow to evaluate and compare the environmental and economic impacts of a product from specific databases. There are many software products and tools that can help with LCI, LCA and designing greener products.

5.1 Purpose of LCA software

In general, a life cycle analysis tool allows to make the right decisions regarding the manufacture and recycling of a product by taking into account its entire life cycle. It means that the software allows the entire product to be broken down into flows. The software allows to break down the entire life cycle of a product, from its components to the energy required to manufacture the product [1]

Most of the life cycle assessment software is based on the exploitation of databases specific to eco-design and the circular economy. There are general and specialized databases.

An LCA software allows to become aware of the global material and energy flows for the manufacturing of a product. From there, it can be improved the product in terms of material selection, suppliers and manufacturing processes. The goal is to create a product with a decreased environmental impact that best respects the fundamentals of the circular economy.

This "do better with less" manufacturing approach most of the time results in a decrease in the production cost of the product which can be a lever to increase the company's margins while getting ahead of the competition.

Eco-designing a product also makes it easier for innovations to emerge thanks to the specific specifications of eco-design, which invite smarter design.

Regulations are updating faster and it becomes strategic for companies to adapt now to continue their business by adapting to new market needs. Consumer demand for more environmentally friendly products and services is increasing at the same time. It becomes important for each company to communicate on the subject of the circular economy and to choose a positioning ahead of the competition to stand out and adapt to the new regulations so as not to suffer them in the near future.

There are several LCA software programs that offer free access. These programs share similar characteristics. However, the databases used and the ease of use may vary.

5.2 Databases

Ecoinvent – Swiss Centre for Life Cycle Inventories

The international ecoinvent database is the world leading life cycle inventory data source with more than 2500 users in more than 40 countries. The ecoinvent data are used in:

- Life Cycle Assessment (LCA),
- Environmental Product Declaration (EPD),
- Carbon footprinting (CF),
- Integrated Product Policy (IPP),
- Life Cycle Management (LCM),
- Design for Environment (DfE),
- ecolabelling and other applications.

The ecoinvent data contain life cycle inventory data of energy (electricity, oil, coal, natural gas, biomass, biofuels, bioenergy, hydro power, nuclear power, photovoltaics, wind power, biogas), materials (chemicals, metals, minerals, plastics, paper, biomass, biomaterials), waste management (incineration, landfill, waste water treatment), transports (road, rail, air, ship), agricultural products and processes, electronics, metals processing, and building ventilation.

The data are available in several formats as XML or Excel. The best option for working with ecoinvent data is to use them in the specialized LCA software SimaPro. This allows for using all features of the data format and documentation.

European Environment Agency – Data and Maps

The European Environment Agency (EEA) is an agency of the European Union, whose task is to provide sound, independent information on the environment. The EEA aims to support sustainable development by helping to achieve significant and measurable improvement in Europe's environment, through the provision of timely, targeted, relevant and reliable information to policymaking agents and the public.

European Life Cycle Database

The ELCD core database comprises Life Cycle Inventory (LCI) data from front-running EU-level business associations and other sources for key materials, energy carriers, transport, and waste management.

Canadian Raw Materials Database

The Canadian Raw Materials Database is a voluntary project involving a cross-section of Canadian materials industries to develop a database profiling the environmental inputs and outputs associated with the production of Canadian commodity materials. The database uses the techniques of life-cycle inventory (LCI), consistent with the method of life-cycle assessment (LCA).

Participants and commodities

Industry associations are participating on a voluntary basis with Environment Canada as chair. Materials industries participating are: aluminum, glass, plastics, steel and wood.

Compass® (Comparative Packaging Assessment)

COMPASS (Comparative Packaging Assessment) is a cloud-based streamlined life cycle assessment (LCA) solution tailored for packaging design evaluations. COMPASS puts the power of LCA in the hands of design professionals so that key environmental performance criteria can be easily incorporated into the concept development and material selection steps.

COMPASS provides consistently modelled, industry average data sets for materials and converting processes for packaging to allow reliable apples to apples comparisons. Currently supports nine regions around the world with additional regions in the pipeline.

Life Cycle Metrics

CONSUMPTION METRICS

Fossil Fuel Use

Water Use

Mineral Use

Greenhouse Gas

Human Impacts

Freshwater EcoToxicity

Eutrophication

EMISSION METRICS

Greenhouse Gas

Human Impacts

Aquatic Toxicity

Eutrophication

LIFE CYCLE PHASES

Material Manufacture

Conversion

Distribution

End of Life

CPM Life Cycle Inventory Data

The CPM LCA Database is developed within the Swedish Life Cycle Center and is a result of the continuous work to establish transparent and quality reviewed LCA data. The data in the CPM LCA Database is open and accessible for free to researchers and practitioners. User restrictions and guidelines are regulated within the licence agreement.

GaBi

GaBi is the next generation product sustainability solution with a powerful Life Cycle Assessment engine to support the following business applications:

- Life Cycle Assessment

- Design for Environment: developing products that meet environmental regulations
- Eco-efficiency: reducing material, energy and resource use
- Eco-design: developing products with smaller environmental footprints such as fewer GHG emissions, reduced water consumption and waste
- Efficient value chains: enhancing efficiency of value chains e.g. R&D, design, production, suppliers, distribution

- Life Cycle Costing

Cost reduction: designing and optimizing products and processes for cost reduction

- Life Cycle Reporting

- Sustainable Product Marketing: product sustainability labels & claims, Environmental Product Declarations (EPDs)
- Sustainability Reporting: environmental communication & product sustainability reporting
- LCA knowledge sharing: reporting and analysis for internal departments, management and supply chain
- Life Cycle Working Environment

Responsible manufacturing: developing manufacturing process that address social responsibilities

5.3 Software tools

openLCA is a free, professional Life Cycle Assessment (LCA) and Footprint software with a broad range of functions and available databases, created by GreenDelta. It is an open source software, i.e. its source code is freely available and can be modified by anyone. And it is also an open source and free software for Sustainability and Life Cycle Assessment, with the following features [2]:

1. Fast and reliable calculation of your Sustainability Assessment and/or Life Cycle Assessment

2. Very detailed insights into calculation and analysis results; identify main drivers throughout the life cycle, by process, flow or impact category, visualize results and locate them on a map

3. Best in class import and export capabilities; easy to share your models

4. Life Cycle Costing and social assessment smoothly integrated in the life cycle model

5. User-friendly; user interface in a variety of languages; advanced and efficient repository and collaboration feature (currently developed)

6. Continuous improvement and implementation of new features

SimaPro is a powerful solution for those looking to drive sustainable change. Built on robust science and life cycle thinking, the sustainability software is ideal for product designers, decision-makers and sustainability experts. Its fact-based LCA approach provides the insights you need to make better decisions, empower better choices and reduce the environmental footprints of products and services. SimaPro helps you effectively apply sustainability expertise to empower informed decision-making, change product life cycles for the better, and increase company's positive impact. The software empowers you to gain insights into the environmental performance of products and services and become an informed change-maker that truly drives sustainable change [3].

Sustainable Minds is a cloud software and services company, whose mission is to operationalize environmental performance into mainstream product development and manufacturing in an accessible, empowering, and credible way. SM LCA requires no previous LCA training or expertise. SM LCA is a standardized and consistent process that provides a cost-effective alternative to full-scale LCAs, which are complex, costly, time-consuming and difficult to conduct on loosely defined or rapidly evolving product concepts. SM LCA results are not intended to replace full-scale LCA results.

Experts at Sphera fully integrate the unit and cradle-to-gate processes from the ecoinvent database in the GaBi database format by mapping the flow nomenclature and all relevant impact information.

Umberto is one of the leading LCA software solutions worldwide. It has been used for more than 25 years by LCA experts from industry, consulting and research & education. The latest version Umberto LCA+ is delivered together with the ecoinvent database, and users can benefit from the standard integration of the database directly in the software.

Ecodesign Studio is an online tool for LCA and ecodesign.

Through its intuitive and user-friendly interface, users can easily model the life cycle of their product, analyze the results and deploy their eco-design strategy. Ecodesign Studio is thus a tool adapted to deploy life cycle thinking in companies, from SMEs to large corporations.

3DEXPERIENCE® platform

Ecoinvent is the official provider of LCA environmental data for the Dassault 3DEXPERIENCE® platform to be used for sustainability assessments in the design phase of industrial products. The 3DEXPERIENCE platform is provided by Dassault Systèmes, the 3DEXPERIENCE® Company, which provides businesses and people with virtual universes to imagine sustainable innovations for today and tomorrow.

As an SAP collaboration partner, ecoinvent offers more than 9’000 vendor-agnostic emission factors to be used in the background of the SAP Product Footprint Management, a cloud application, enabling calculation of product footprints periodically and at scale across the entire product lifecycle. The ecoinvent emission factors can be easily imported into the SAP Product Footprint Management by uploading an Excel file containing the datasets and corresponding factors. Discover the advantages of an ecoinvent licence and a free of charge trial in the SAP Store.

One Click LCA is the #1 easy and automated LCA & EPD software for the construction industry. The software is used in 130+ countries by leading businesses, including WSP, AECOM, Sweco, Saint-Gobain, ArcelorMittal. It integrates all leading standards, databases, and design software tools globally, including Autodesk Revit, Trimble Tekla, Grasshopper, Rhino, IES-VE, and DesignBuilder. The software can be used for buildings, infrastructure, renovations, construction products and materials, and portfolios.

EcoImpact is a complete cloud hosted, secure, enterprise level suite of product and packaging sustainability software to manage your corporate sustainability goals.

The COMPASS module leverages quick Life Cycle Analysis (LCA) that can be ISO compliant. COMPASS was originally conceived at the SPC (Sustainable Packaging Coalition) as a pioneering tool designed for packaging engineers.

Air.e LCA

Air.e LCA includes all the features needed in a professional LCA tool, with a competitive price and a great learning curve. Users can create complex Life Cycles, like Environmental Footprints, in an easy and transparent way. Air.e LCA is designed thinking in the best user experience and includes powerful tools for the LCA expert.

Makersite is the largest, integrated product management platform on the web. That includes all-in-one data, apps and community for eco-design and product stewardship. Made for entrepreneurs, engineers and product teams.

The ECOSPEED Scout software creates certified carbon footprints and holistic environmental assessments of products, processes and sites. The software is industry-ready, free of subjectivity and the first software to be certified for the eco-scout standard.

eBalance is a full-featured LCA software, developed by IKE Environmental Technology and shipped with Chinese and global high-quality databases. The eBalance package is a professional tool for LCA studies of all kinds of products. It is the best choice for LCAs of products manufactured in China and has been chosen by more than 1000 users from China and the world.

Carbonstop

Ccloud is an all-in-one carbon management SaaS solution for enterprises at corporate, product, project and activity level, developed by Carbonstop.

With perfect function and rich data, Ccloud enables users to measure, analyze, manage and report GHG emissions, following international standards.

Ccloud will facilitate more Chinese enterprises to achieve the carbon neutrality goal.

jimuLCA

E-C Digital provides cloud-based LCA solutions and sustainability consulting services. E-C Digital is the largest LCA Tool providers for manufacturing industry in China, covering steel industry, construction industry, battery industry, etc.

carbmee is an Enterprise Software Company headquartered in Berlin. They offer an Environmental Intelligence System that enables companies to reduce their carbon footprint by analyzing supply chains on the road to achieving net-zero. Their Environmental Intelligence covers LCA-grade carbon management for enterprises in different use cases like logistics, procurement or supply chain management.

The **TEAM™ 5.2** LCA software is a powerful and flexible tool allowing to build and use large databases representing the operations associated with products and processes and perform their related LCA.

eToolLCD is an intuitive, web-based, whole building life cycle assessment (LCA) and design software developed by engineers with a passion for sustainable buildings.

Granta Design solutions include GRANTA MI:Product Intelligence – tools to apply a comprehensive database of materials engineering, process, and eco data in order to assess environmental impact and risks in products and product designs. Design focused and performance based, genuinely sustainable outcomes are made easy.

EcodEX is an eco-design software that allows food companies to improve the sustainability of their new products or existing portfolio, in a cost-effective and simple way.

EcodEX allows product developers to easily make a sustainability assessment of a product, based on the evaluation of carbon footprint, water use, energy use, land use and other criteria.

EarthSmart is a flexible, web-based tool for Life Cycle Assessment (LCA) – evaluating the environmental impacts of a product or service across its entire life cycle, from raw materials to disposal and recycling. EarthSmart LCA software has the power, depth, and rigor demanded by sustainability practitioners, and user-friendliness that makes it accessible to people from almost any discipline.

eQopack is an ecodesign SaaS tool developed by Quantis in partnership with Kleis Technology.

It was designed to equip packaging engineers with a user-friendly platform to embed environmental sustainability within the packaging innovation process and to allow them to make more sustainable design choices and accelerate innovation toward sustainability.

Air.e HdC is a professional software tool designed for Carbon Footprint experts to help them in calculating and assessing GHG emissions of organizations, products, services, events, and projects using a life cycle approach. Air.e HdC has been developed to follow international standards such as ISO 14040, PAS 2050, GHG Protocol, ISO 14064, ISO 14064 and ISO 14069.

Instant LCA Packaging™ is an innovative eco-design and eco-labeling tool, enabling non-experts to easily and instantly evaluate the environmental impacts of their packaging. The first tool to use pre-integrated LCA models based on ISO standards and recognised LCA databases, it guarantees reliable results.

PackageSmart LCA helps packaging designers to evaluate the environmental impacts of their design decisions and clearly depict where and what changes could be made. For some this may bring focus to durability and re-use and for others lightweighting or biodegradeability. EarthShift Global has developed a simplified LCA software, PackageSmart.

PLACES is an open-sourced prototype greenhouse gas calculator that tracks the environmental impact of plastic waste management and recycling solutions in India and Indonesia. PLACES allows users to calculate carbon savings based on various plastic polymers, tonnes of plastic waste and different end-of-life (EOL) fates. For more information, visit The Circulate Initiative website.

Pleiades ACV is an LCA tool based on the description of a district / building, the behaviour of its occupants and the dynamic thermal simulations by Pleiades STD COMFIE.

LCA4Waste is a decision support tool to analyse and compare the environmental impact of waste management in energy intensive industries and in dedicated waste treatment processes. It is a Microsoft Excel-based computer program available free of charge (with a reduced set of LCIA indicators; based on ecoinvent v2.2), developed by the Chair of Ecological Systems Design, ETH Zurich.

References

[1.] https://altermaker.com/how-choose-lca-software/

[2.] https://www.openlca.org/

[3.] https://simapro.com/