EnTRAINER

Energy Transition Audits towards Decarbonization

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Document History

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List of Acronyms

Acronym	Meaning
AIoT	Artificial Intelligence of Things
BECCS	Bioenergy with carbon capture and storage
CAPEX	Capital Expenditure
CCGT	Combined Cycle Gas Turbine
CCUS	Carbon Capture, Utilization, and Storage
CDP	Carbon Disclosure Project
CFLs	Compact Fluorescent Lamps
CH4	Methane
CHP	Combined Heat and Power
CO2	Carbon dioxide
COT	Carbon Tracing Platform
DAP	Decarbonization Action Plan
DERs	Distributed Energy Resources
DESFA	National Natural Gas System Operator in Greece
DHW	Domestic Hot Water
DRM	Decarbonization Roadmap
EC	European Commission
EGR	Enhanced Gas Recovery
EGS	Engineered Geothermal Systems
EOR	Enhanced Oil Recovery
ESCO	Energy Service Company
ESG	Environmental, Social, and Governance factors
ETA	Energy Transition Audit
ETS	Emissions Trading System
EU	European Union
EV	Electric Vehicle
GHG	Greenhouse Gas
GoO	Guarantee of Origin
GWPs	Global Warming Potentials
HDVs	Heavy-Duty Vehicles
HEREMA	Energy Resources Management Company. Greece
HVAC	Heating, Ventilation, and Air Conditioning
KPI	Key Performance Indicators
LCFFES	low-carbon fuels, feedstocks, and energy sources
LED	Light-emitting diode
LEED	Leadership in Energy and Environmental Design
LMD	Laser Metal Deposition
MMBI	Mining and Metals Blockchain Initiative’s

N2O	Nitrous oxide
NECP	National Energy and Climate Plan
NZE	Near Zero-Emission
OEMs	Original Equipment Manufacturers
OPEX	Operating Expenditure
P2X	Power-to-X
PI	Process Intensification
PNIEC	Energy and Climate National Integrated Plan
PNRR	National Recovery and Resilience Plan in Romania
PV	Photovoltaic
RES	Renewable Energy Sources
ROP	Regional Operational Program
SBTi	Science Based Targets Initiative
SME	Small and Medium – sized Enterprise
WP	Work Package

Executive summary

This Report has been developed through the implementation of the 'EnTRAINER' project, funded by the Programme for Environment and Climate Action (LIFE) under the Grant Agreement No 101076424. The EnTRAINER project aims to introduce a paradigm shift from conventional energy audits through a new, holistic and complete methodology of 'Energy Transition Audits' (ETA). With this new approach, the focus is not only to provide energy efficiency action plans, but to provide also decarbonization action plans with a complete multi-benefit scheme evaluation of the audited sites.

The document aims to define detailed guidelines for the implementation of decarbonization actions which are proposed as a result of the **E**nergy **T**ransition **A**udits (**ETA**). These actions will be incorporated into a **D**ecarbonization **A**ction **P**lan (**DAP**) and will be shaped into a complete **D**ecarbonization **R**oadmap (**DRM**), tailored to the specific needs of the audited companies.

This report serves as a deliverable for WP2 *Paradigm shift towards a holistic energy transition audit methodology*, which focuses on the development methodology for ETA actions. Led by the TECHNICAL UNIVERSITY OF CLUJ-NAPOCA (UTC), this collaborative effort involves contributions from all project partners: ARISTOTELIO PANEPISTIMIO THESSALONIKIS (AUTH), UNIVERSITAT POLITECNICA DE VALENCIA (UPV), SERVELECT SRL (SERVELECT), AGENZIA PER L'ENERGIA ALTO ADIGE – CASACLIMA (CASACLIMA), PANEPISTIMIO DYTIKIS MAKEDONIAS (UOWM), BEON GESTIONA SOCIEDAD LIMITADA (BEON) and USE EFFICIENCY ASSOCIATION (USEEFF).

Deliverable D2.2 *Decarbonization roadmap* describes how the actions proposed by the auditor and the working group defined for ETA should be embedded in a well-defined internal strategy, which aims to lead towards the achievement of company's short, medium and long-term decarbonization targets.

In the framework of EnTRAINER project, this document:

- outlines the directions that will be addressed in the development of training materials for the education and training activities to be implemented under WP5.
- will be improved significantly considering the conclusions drawn by the auditors after the ETA implementation phase foreseen in WP3. The improved version of the deliverable will also contain details of ETA deployment and lessons learned through real case studies, obtained in WP3 following ETA deployment in different industries from partner countries.
- is completed by an additional resource, i.e., Deliverable D2.1 *Holistic Energy Transition Audit Methodology.* To ensure comprehensive understanding and optimal utilization, it is highly recommended to utilize both documents in conjunction. This report acts as a complementary companion to D2.2, making frequent references to its subchapters throughout various sections.

Deliverables D2.1 *Holistic Energy Transition Audit Methodology* and D2.2 *Decarbonization roadmap* will be applied, tested and improved through the implementation of the ETA actions within EnTRAINER WP3, and the training activities in WP5. By the conclusion of the EnTRAINER project implementation, an improved version of these deliverables will be provided, reflecting the

experience gathered from ETA implementation and the design of roadmaps for the audited companies.

More information about the EnTRAINER project can be found at https://entrainer-project.eu

1. Introduction

1.1. Importance of decarbonization

The importance of decarbonization lies in its critical role in addressing the mandatory global challenge of climate change. Decarbonization refers to the process of reducing or eliminating greenhouse gas (GHG) emissions, particularly in the scope of this project the carbon dioxide (CO2), from various sectors such as energy, transportation, industry, agriculture etc. There are several key reasons why DECARBONIZATION is highly important, as highlighted in Figure 1.

Figure 1: Key reasons for decarbonization.

Overall, decarbonization is crucial for safeguarding the environment, addressing climate change, promoting sustainable development, improving public health, driving innovation, and ensuring a resilient and secure energy future. It requires collective action, policy support, technological advancements, and international cooperation to achieve a sustainable, low-carbon society.

The plan of European Union (EU) to transform its industry for the net-zero era is built upon the European Green Deal, which is the EU's comprehensive strategy for sustainable growth. This plan requires the active involvement of the industrial sector to achieve climate neutrality and circularity in the EU economy. The European Climate Law, established in 2021, legally obligates the EU to achieve climate neutrality by 2050 and sets a target of reducing domestic GHG emissions by at least 55% by 2030 compared to 1990 levels [1-3].

To meet these goals, the 'Fit for 55 package' was introduced in 2021, consisting of various legislative proposals aimed at reforming EU policies and aligning them with the objectives of the climate law. Notable initiatives within this package include the updated emissions trading system (ETS) and the newly implemented carbon border adjustment mechanism, both of which became law on May 10, 2023. These measures play a significant role in regulating emissions and ensuring a level playing field for industries.

There has been a growing recognition of the urgency to expedite both the green and digital transitions while reducing strategic dependencies on critical products. This has led, in recent years, to widespread calls for increased government intervention in the economy and a resurgence of industrial policies. Presently, almost all countries are implementing some form of industrial policy, with the EU specifically embracing a more proactive industrial policy agenda.

In 2020, the European Commission (EC) adopted a new industrial strategy for Europe with the aim of making EU industry more environmentally sustainable, digitally advanced, and globally competitive, while also strengthening Europe's industrial and strategic independence. This strategy introduced an ‘ecosystem approach’ which involves closely monitoring strategic dependencies in 14 key industrial ecosystems representing 70% of the EU economy. These ecosystems include energy-intensive industries and renewable energies [1-3].

In the 2021 update of the industrial strategy, the focus shifted towards addressing the impacts of the pandemic, adapting to the evolving global competitive landscape, and accelerating the twin transitions of green and digital. Additionally, the updated strategy proposed a range of supplementary actions to tackle strategic dependencies.

In 2022, the REPowerEU plan was devised to reduce the EU's reliance on Russian fossil fuels. The plan focuses on deploying renewable energy sources (RESs) such as photovoltaic and wind capacities, as well as heat pumps, and aims to decarbonize the industrial sector. Recent amendments to EU energy legislation, proposed under this plan, have been agreed upon by the Council and Parliament. These amendments aim to accelerate the adoption of renewable energy sources, promote energy efficiency, and encourage energy savings.

Member States have been given the opportunity to include REPowerEU chapters in their recovery and resilience plans, with the Commission actively encouraging them to incorporate measures that foster the production of net-zero technologies. This demonstrates the EU's commitment to driving sustainable manufacturing practices and facilitating the transition to a carbon-neutral industry.

Overall, there has been a growing recognition of the need for government involvement in the economy to facilitate the green and digital transitions and reduce strategic vulnerabilities. The EU, through its industrial strategy, is actively working towards these objectives by adopting an ecosystem approach and implementing measures to enhance Europe's industrial and strategic autonomy.

The Net-Zero Industry Act proposed legislation to promote decarbonization and the transition to an industry with net zero GHG emissions. The Act aims to impose clear obligations and firm commitments on the industrial sector to reduce emissions and contribute to the achievement of set climate targets.

The legislative proposals include regulations on the standardization and implementation of cleaner production technologies and practices, supporting innovation and investment in low-emission technologies, and fostering collaboration between the public and private sectors to facilitate the transition to more sustainable and environmentally sustainable industries. The objective of enacting this legislation is to ensure that the industrial sector assumes accountability and actively participates in reducing GHG emissions, aligning with the global climate objectives [1-3].

The Green Deal Industrial Plan is a strategic initiative of the European Union that is part of the European Green Deal. This plan aims to transform the European industrial sector into a driver of sustainability and the transition to a low-carbon economy. The Green Deal Industrial Plan focuses on promoting innovation, productivity and competitiveness in industrial sectors, while reducing environmental impact and supporting sustainability.

The initiative aims to create green jobs, invest in clean and energy-efficient technologies, implement more sustainable production processes, promote the circular economy and reduce GHG emissions generated by industry. Through the Green Deal Industrial Plan, the EU aims to strengthen Europe's leadership in sustainability and ensure a sustainable transition to a green and globally competitive industry.

As a result, EU Member States are obligated to formulate national long-term strategies outlining their intended actions to achieve the necessary reductions in GHG emissions. These strategies should align with the commitments made by Member States and incorporate some of the recommendations put forth in European directives. In the future, certain recommendations from these directives are expected to become mandatory for EU Member States to ensure consistent progress towards meeting their climate targets and fulfilling their obligations under the Paris Agreement and EU objectives [3].

In this context, addressing the issue of climate change is increasingly becoming a top priority in business strategy, as there is growing political and social pressure for a swiftly transition towards a sustainable, low-carbon economy [4, 5].

Decarbonization is defined as the process of reducing CO2 emissions resulting from human activities. There are many paths to decarbonization, and it is very important not to mix decarbonization up with de-industrialization.

There are six pillars of climate mitigation, all needed to reach zero net emissions of GHGs by 2050 and negative emissions thereafter. The first five pillars aim to eliminate CO2 emissions from the energy system, hence 'decarbonization'. The sixth aims to eliminate GHGs emissions from agriculture: CO2, methane (CH4), and nitrous oxide (N2O).

Industry is responsible for a large share of global GHG emissions, because industrial processes employ high temperatures and depend on high energy densities to enable the technical processes involved. The industry sector in 2022 was directly responsible for emitting 9.0 Gt of CO2, accounting for a quarter of global energy system CO2 emissions. Annual emissions slightly declined in both 2020 and 2022, but not enough to align with the Net Zero Emissions (NZE) by 2050 Scenario, in which industrial emissions fall to about 7 Gt CO2 by 2030 [6].

Although there have been some modest advancements in energy efficiency, renewable energy adoption, international collaboration, and innovation, progress in these areas has been slow and insufficient. To achieve significant milestones in line with the NZE Scenario by 2030, there is a pressing need for greater improvements in materials and energy efficiency, quicker adoption of low-carbon fuels, and faster development and implementation of near zero-emission production processes such as carbon capture, utilization, and storage (CCUS) as well as hydrogen technologies. Government policies play a major role in expediting progress by mitigating risks associated with emerging technologies and implementing mandatory CO2 emission reduction measures. [6]

1.2. Purpose of the report and project context

When a company starts on its sustainability transformation and decarbonization actions, the road can take many unexpected turns. To achieve timely and cost-effective results, it is crucial for companies to have a phased plan that clearly delineates actionable measures for integrating suitable technologies, accessing financing options, and overcoming organizational barriers.

The primary goal of this report is to offer guidance on creating a decarbonization roadmap that outlines the necessary actions for a company to decarbonize its operations and establish net zero strategies.

This deliverable in its current form is intended to be a digital document utilized by energy auditors during the Energy Transition Audit (ETA) process, along with the audited Clients – energy managers, top decision makers and other stakeholders. It can be tailored to suit the specific needs of audited industries and appended to energy transition audit reports.

Additionally, this report aims to contribute to raising awareness about the importance of creating a decarbonization roadmap, as follows:

- A roadmap provides a **clear and structured pathway** for achieving decarbonization goals. It outlines the specific steps, targets, and milestones necessary to transition to a low-carbon future. It helps in aligning efforts, setting priorities, and providing a sense of direction to policymakers, businesses, and stakeholders.

- Decarbonization is a complex and long-term process that requires **planning and coordination** across various sectors and stakeholders. A roadmap allows for strategic planning, enabling the identification of technological, policy, and financial requirements and ensures that actions are coordinated and integrated to maximize the effectiveness and efficiency.
- A roadmap provides policymakers with valuable **guidance for developing effective policies and regulations**. It helps in identifying policy gaps, assessing the impact of existing policies, designing new ones to support decarbonization efforts and facilitates policy coherence and consistency across different levels of governance.
- Decarbonization requires substantial investments in clean technologies, infrastructure, and innovation. A roadmap provides investors, financiers, and businesses with a clear vision of the decarbonization trajectory, fostering confidence and facilitating investment decisions, and also helps in attracting **funding and mobilizing resources** towards low-carbon projects and initiatives.
- Developing a roadmap involves **engaging and collaborating** with various stakeholders, including government agencies, businesses, civil society organizations, and the public. It creates a platform for dialogue, consensus-building, and collective action ensuring that diverse perspectives are considered, fostering ownership and buy-in from stakeholders, thereby increasing the chances of successful implementations.
- A roadmap serves as a **monitoring and evaluation** tool, enabling the tracking of progress towards decarbonization goals. It allows for periodic assessments, identifying potential blockages, and making necessary adjustments to ensure the effectiveness of decarbonization strategies. It facilitates accountability and transparency in the implementation process.
- Designing a decarbonization roadmap can foster **international cooperation and collaboration**. It provides a framework for sharing best practices, knowledge, and experiences across countries, enhances coordination in addressing global climate change challenges and facilitates the exchange of technology, expertise, and financial support.

The outputs of this report will be used as input to other project activities:

- It will be a document that completes the ETA methodology proposed within the EnTRAINER project.
- Within WP3, auditors will use it as a primary tool during the implementation of ETAs in high-intensive industrial companies. Following these actions, it will undergo validation and enhancement to ensure its adaptability in its final version. Ultimately, it will be designed to accommodate ETAs conducted in various industries and company's types, making it a versatile and comprehensive tool.
- This report will serve as a fundamental element for the development of training materials in WP5, specifically for the training and educational programs targeting energy managers, aspiring energy professionals, and company's employees. The content of this document will be used to create comprehensive training resources for these individuals.

1.3. Delineation

The purpose of the decarbonization roadmap is to present an evidence-based and experience-based perspective of how the outcomes of the energy transition audit should be transposed in short, medium or long term decarbonization actions. This ensures that both the Beneficiary company and the ETA auditor, acting as an energy transition expert and consultant, as well as external stakeholders, have a lucid and transparent trajectory to understand expectations and potential benefits for them.

The roadmap is not meant to be and will not be a substantial handbook or officially approved by any law methodology.

As a working definition, EnTRAINER project focuses on those companies operating within industrial sectors that significantly contribute to the overall quantity of CO2 emissions through their activities.

In the current version of this report, a considerable share of the information is dedicated to the decarbonization technologies from the partner countries in the project. This is intended to assist those drafting the decarbonization roadmap in selecting strategies that best fit the needs of the companies being audited. The final version of this report, due at the conclusion of the EnTRAINER project, will be completed and balanced with examples of roadmaps for companies from various industries, made following the implementation of ETAs.

1.4. Guidance in reading the deliverable

The project aims to shift the paradigm from the traditional energy audit process by introducing a holistic and comprehensive methodology known as 'Energy Transition Audits'. This innovative approach shifts the emphasis towards a multi-faceted approach, offering a range of benefits and delivering a comprehensive action plan for achieving complete decarbonization of the audited sites. For this purpose, an audit methodology was designed, described in detail in a report that constitutes as a project deliverable, with the title D2.1 *Holistic Energy Transition Audit Methodology*.

The present report entitled as D2.2 *Decarbonization roadmap* serves as a supplementary resource to D2.1 report, providing guidance to energy auditors and beneficiary companies. Its purpose is to assist in the development of a decarbonization roadmap, outlining the essential steps for companies to decarbonize their operations and establish strategies aligned with achieving net zero emissions.

For thorough comprehension and optimal utilization, it is recommended to use both documents in tandem. This document, acting as a complementary report to D2.1, makes frequent references to subchapters from D2.1 across various sections. Consequently, employing these two reports together will enable a more comprehensive and cohesive approach to the subject matter, promoting better integration of the information provided.

Deliverables D2.1 and D2.2 will be applied, tested and improved through the implementation of the ETA actions within EnTRAINER WP3, and the training activities in WP5. In the final form, they will be brought to a form that can be easily used by the energy auditors and will be completed with examples of roadmaps for specific industries from the project partners countries.

D2.2 *Decarbonization roadmap* report is structured in three main chapters, completed with a section of conclusions.

In the first chapter, a review is made. The context in which large, energy-consuming industries had to initiate decarbonization actions is presented. This highlights the actuality and necessity of this document, which is ultimately intended to be a working document for energy professionals, but not only for them.

The second chapter supports a better understanding of the decarbonization actions that large, energy-consuming companies have at hand to reach their proposed CO2 reduction targets.

The review of the technologies that allow the reduction of CO2 emissions available for energy intensive industries is useful for energy auditors in defining the plan of decarbonization measures as a result of the ETA. Auditors can review the available technologies and suggest the use of the ones that are the most appropriate, considering the available resources of the company, the targeted economic sector and the national/international regulations in place.

Chapter 3 serves as a comprehensive guide for both auditors and beneficiary companies of an ETA, assisting them in designing and implementing a decarbonization roadmap. This chapter is closely interconnected with the ETA methodology described in detail into D2.1.

This chapter emphasizes and outlines the key stages that companies should undertake to achieve their net zero objectives. The highlighted steps are interconnected with subchapters from D2.1 and additional tools developed specifically for energy auditors are emphasized, as illustrated in Figure 2.

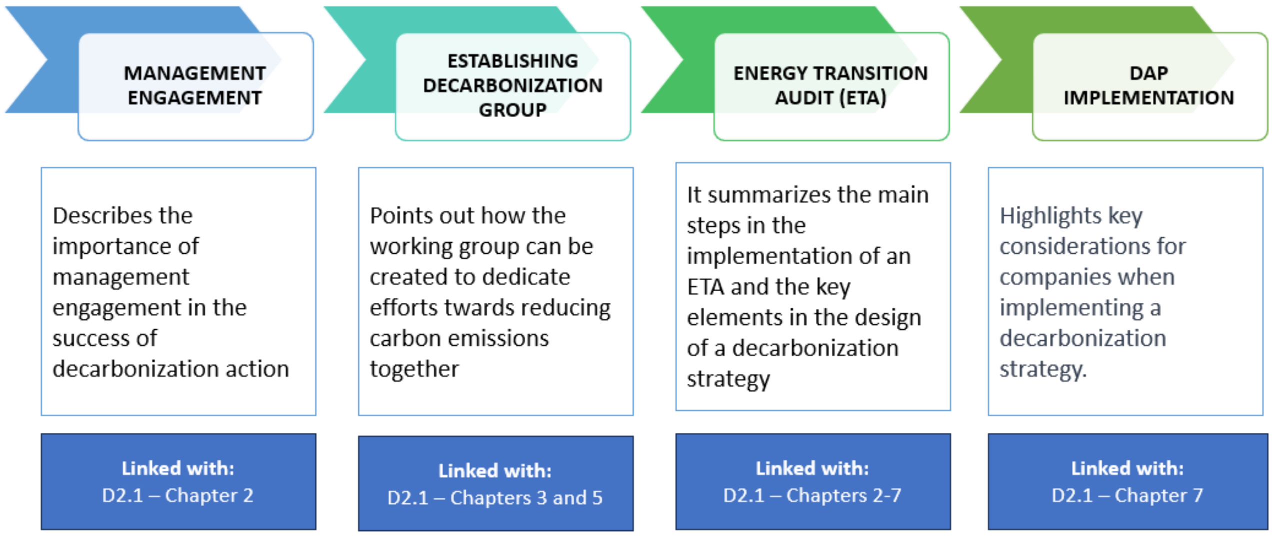

Figure 2: Main steps of decarbonization roadmap implementation.

2. Understanding decarbonization - Definition and strategies

Decarbonization is the process to reduce human-caused CO2 to limit the unprecedented, life-threatening impacts of global warming and climate change. Decarbonization requires a coordinated global shift to alternative energy sources other than fossil fuels (oil, gas, and coal).

At present, energy use is the main source of CO2 emissions–contributing 83% of CO2 emissions globally. Over 34 billion metric tons of CO2 emissions are emitted every year into the atmosphere. The endeavour to mitigate climate change and shift to a low-carbon economy by reducing or eliminating CO2 emissions from diverse sectors, involves decreasing the reliance on fossil fuels, which are major contributors to GHG emissions, and moving towards cleaner, renewable energy sources, along with adopting energy-efficient technologies and practices [7, 9].

Achieving complete decarbonization in complex and interconnected industrial environments needs a comprehensive and multifaceted approach and should focus on the key action areas emphasized in Figure 3.

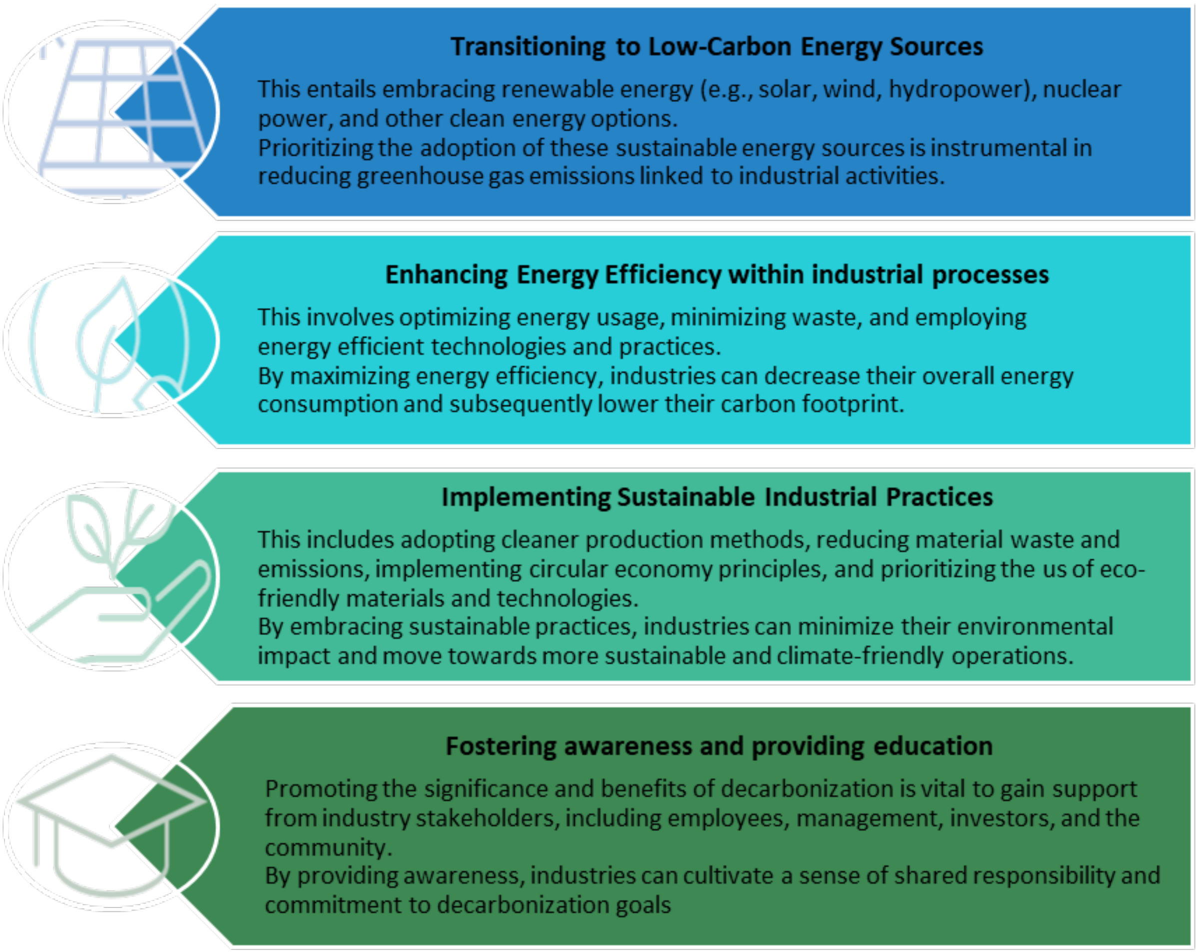

Figure 3: Key areas for decarbonization.

By focusing on these action areas—(a) transitioning to low-carbon energy sources, (b) enhancing energy efficiency, and (c) implementing sustainable industrial practices—the industry sector can make significant strides towards achieving full decarbonization. This multidimensional approach addresses the interconnected challenges of reducing emissions and fostering a sustainable future for industrial operations and represents also the EnTRAINER project main concept.

Cross-disciplinary research emphasizes that decarbonizing the industrial sector is widely regarded as the costliest endeavour. This is primarily because many of the available options for reducing emissions in this sector are either prohibitively expensive or not yet available at a large scale.

Because supply side constraints would limit the transportation and buildings sectors contributions to the 2030 reduction target, industrial companies would have to implement more expensive decarbonization technologies, such as electric boilers and CCS, to get the EU to the 55% reduction target [6, 10].

After 2040, when power, transportation, and buildings reach almost their full abatement potential, industry would need to abate another 40% of its last, most expensive emissions. Part of the very hard-to-abate industrial emissions are offset by bioenergy with carbon capture and storage (BECCS) on processes like ammonia or cement production. As a result, industry emissions could be reduced by more than 95% in 2050. The residual emissions would be offset outside the sector, for example by natural carbon sinks such as reforestation [10].

A net zero strategy comprises of two components, i.e., a pathway for reductions and a pathway for removals. While these pathways can be pursued simultaneously, the primary focus should be on reductions initially. The reductions pathway establishes the pace of decarbonization in accordance with scientifically grounded trajectories. On the other hand, the removals pathway offers additional measures to offset unavoidable residual emissions when reductions alone are inadequate to achieve climate goals aligned with the Paris Agreement.

Thus, a credible net zero target: (1) covers all relevant emissions, (2) prioritizes a reduction in emissions in line with climate science, and (3) neutralizes the residual balance of emissions through carbon removals. Companies should take a phased approach to build their net zero pathways [11]:

1. **Establish a baseline**: Calculate a full value chain emissions baseline.
2. **The reduction pathway**: Develop a Science-Based Targets initiative (SBTi) - approved target to deliver absolute reductions in scopes emissions.
3. **The removal pathway**: Develop a credible emission removal strategy to offset residual emissions.

Therefore, a well-designed decarbonization strategy is essential for providing a clear pathway, guiding policy decisions, attracting investments, fostering collaboration, and ensuring effective monitoring and evaluation. It serves as a vital tool in achieving the necessary transformation to a low-carbon and sustainable future.

2.1. Essential Insights into evaluating CO2 emissions

Net-zero emissions, as defined, refers to the significant reduction of GHG emissions to the lowest feasible level. Any remaining emissions are counterbalanced by absorption methods such as those provided by oceans and forests. A business achieves net-zero when it has successfully eliminated all possible carbon emissions and then offsets any remaining emissions through additional mitigation measures beyond its value chain.

The net-zero process starts with calculating emissions across Scope 1, 2, and 3, setting science-based targets, developing decarbonization pathways until 2030, and gradually moving towards long-term carbon capture, storage, and sequestration for those emissions which cannot be reduced.

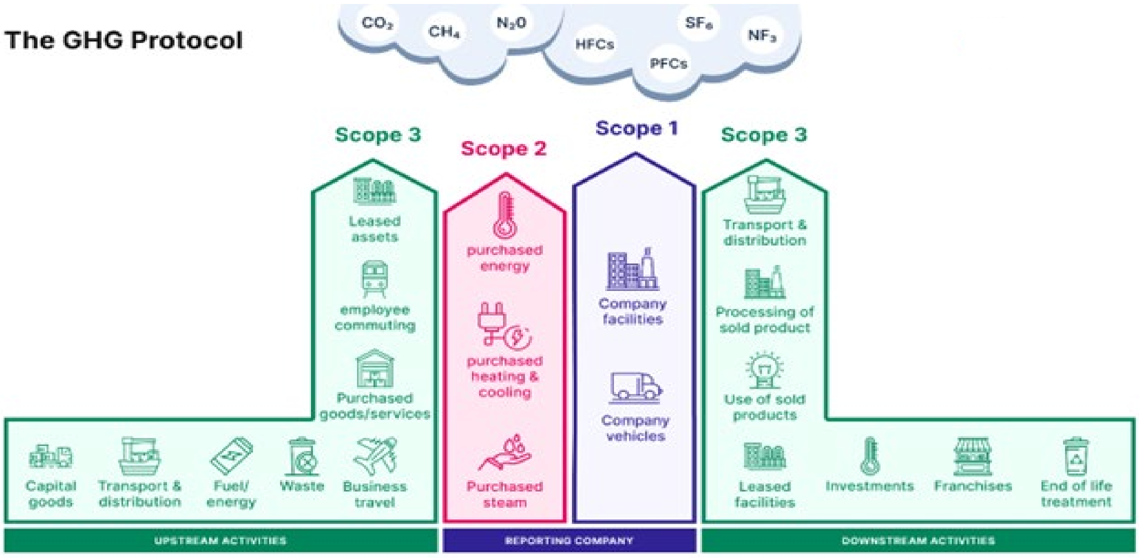

Figure 4: Mapping of Scopes 1, 2 and 3 [12].

These Scopes identify the location within the value chain to calculate a carbon footprint that the emission generating activity occurs:

- **Scope 1** – direct emissions occurring from sources owned or controlled by a company. Examples are fuels (stationary and mobile) use and refrigerant losses.
- **Scope 2** – indirect emissions associated with the purchase of electricity, steam, heat, or cooling, generated by the producer(s) and provider(s).
- **Scope 3** – indirect emissions associated with activities occurring across a company's value chain – outside of its direct influence. This covers a variety of tertiary activities.

While all three scopes are important, the EU recommends prioritizing emissions reduction efforts in the following order:

- Scope 1: Focus on reducing direct emissions from owned or controlled sources, as they have the most immediate impact and are within the company's direct control.

- Scope 2: Address indirect emissions from purchased electricity, heat, or steam, which can be reduced through sourcing renewable or low-carbon energy options.

- Scope 3: Identify and address significant indirect emissions from the value chain, including supply chain emissions, business travel, and customer use of products or services. These emissions require collaboration with external stakeholders and may involve more complex measurement and reduction strategies.

To evaluate CO2 emissions, companies should follow several steps. Firstly, they need to conduct a thorough assessment of CO2 emissions by considering all pertinent scopes and sources within the company. This involves collecting data on energy consumption, fuel usage, transportation activities, and other relevant metrics from various departments and sources.

To obtain accurate estimates, companies should employ standard emission factors or calculate site-specific emission factors. Monitoring and measurement tools like energy meters, emission tracking software, or data management systems should be utilized to track and report emissions continuously. Lastly, it is crucial to regularly review and update emission data to maintain data accuracy and reliability.

The EU provides guidelines for reporting CO2 emissions, including the European Union Emissions Trading System (EU ETS), which covers Scope 1 emissions from certain industries. Companies subject to EU ETS are required to monitor, report, and verify their emissions annually.

Once emissions are identified and assessed, companies can set reduction targets aligned with EU regulations or international frameworks like the Paris Agreement. Targets should be ambitious, time-bound, and consider the prioritization of scopes based on the company's context.

Visibility into CO2 emissions from direct and indirect sources enables enterprises to commit to a sustainable business framework, and devise policies to reduce the carbon footprint.

2.2. Pillars of decarbonization

A decarbonization roadmap should assess four key 'pillars' of industrial decarbonization: energy efficiency; industrial electrification; low-carbon fuels, feedstocks, and energy sources; and carbon capture, utilization, and storage. Each represents a high-level element of an industrial decarbonization action plan, and a cohesive strategy will require all four pillars to be pursued in parallel. Application of these pillars can enable the industrial sector to reach near-zero CO2 emissions, with the balance of reductions required for an overall net-zero outcome achieved through the application of alternative strategies reaching beyond the four pillars (such as negative emissions technologies) [13].

1. **Energy efficiency** is a foundational, crosscutting decarbonization strategy. Reducing the energy consumption of the industrial sector directly reduces CO2 emissions associated with fossil fuel combustion.
2. **Industrial electrification** enables industries to shift from combustion fuels to electric power, capitalizing on advancements in low-carbon electricity from both grid and onsite generation sources. For grid-purchased electricity, this strategy is predicated on the assumption of 'greening of the grid' – i.e., parallel advancements made in the electric power sector to

increase use of nuclear, renewable, and low-carbon fuel sources and reduce combustion emissions.

3. **Substitution with low-carbon fuels, feedstocks, and energy sources (LCFFES)** such as hydrogen, biofuels, or solar thermal power, can further reduce combustion-associated GHG emissions for industrial processes.
4. **Carbon Capture, Utilization, and Storage (CCUS):** is a comprehensive approach to reduce challenging emissions sources by capturing and utilizing CO2 and storing it securely to prevent its release into the atmosphere. [3]

2.3. Available technologies for energy-intensive industries

2.3.1. Energy efficiency

Energy efficiency actions should be the priority and stay like this, as even from the conventional energy audits, the main outcome is the energy efficiency action plan. Moreover, the continuous dynamic of the technology results in significant improvements, both in productivity and lower specific energy use. Therefore, all the industries will continue to be interested in strengthening their economic competitiveness by implementing energy efficiency measures.

A variety of energy efficiency measures and technologies can be employed to reduce energy use. The best technology choice is determined by a combination of energy savings, availability, supporting policies, and other important factors. A sample list of common options appears below [14].

Motors and Pumps (industrial, agricultural, and commercial) represent a substantial opportunity for energy efficiency improvements. It is estimated that electric motors account for 69% of electricity use in the industrial sector, 38% in the commercial sector, 22% in the residential sector, and 39% in the transportation and agriculture sectors combined [15].

Variable-Speed Drives (VSD) and High-Efficiency Motors are used to control motor speed and torque by varying motor input frequency and voltage. Installing a VSD makes it feasible to closely correlate demand on the motor with the energy consumption by the motor and results in significant energy savings.

Lighting is often the first stop for energy improvements, due to its short investment payback period. Light-emitting diode (LED) bulbs are considered top-tier in terms of energy efficiency, and their prices have recently become more competitive with other efficient lighting technologies such as compact fluorescent lamps (CFLs). Other types of efficient lamps are: **High Performance T8s, HID Lamps** and **T5Hos.** Automated control technology enables building managers and owners to reduce the need for lighting, heating, or cooling during low-occupancy hours of operation. **Occupancy Sensors and Timers** are used to turn the lights on or off automatically. **Dimming controls** are devices used to lower the brightness of a light.

Heating, Ventilation, and Air Conditioning (HVAC): Programmable Thermostats are designed to adjust the temperature according to a series of programmed settings that take effect at different times of the day. **HVAC: Building Automation Systems** can reduce energy consumption and operating costs by centralizing automated control of the heating, ventilation, air conditioning, lighting, and other systems.

Process Equipment: Automatic Scheduling determines how long equipment is required to operate, turning it on and off as needed.

Smart Meters are electronic devices that record the consumption of electric energy in intervals of an hour or less and communicate that information to the utility for monitoring and billing. Since smart meters allow consumers to monitor their electricity consumption rates in real time, they can be paired with other behavioural incentives (i.e., price signals during peak-consumption hours) to positively reinforce energy conservation.

Table 1: Specific actions related to energy efficiency in each project partner's country.

GREECE
In Greece, various technologies for increasing energy efficiency are mainly used through existing financial support schemes. The National Energy and Climate Plan (NECP) sets out a set of energy efficiency improvement measures, the most ambitious ones related to buildings and transport. According to the available final energy consumption figures, cumulative energy savings of at least 7.3 Mtoe should be achieved over the period 2021-2030. In addition, an objective is set for the annual energy renovation of a total floor area of the thermal zone of central public administration buildings equal to 5,400 square meters, representing 3% of the total floor area. Also, a central quantitative objective is going to be established for the renovation and replacement of residential buildings with new nearly zero-energy buildings, which could be translated in aggregate amount to 12-15% of all residential buildings by 2030. The annual objective is to have an average of 60,000 buildings or building units upgraded in terms of energy and/or replaced with new more energy-efficient ones. Moreover, in the past few years and in compliance with the EU targets for decarbonization, Greece has announced several actions that are related to decarbonization activities and technologies, including provisions for the crucial part of decarbonizing the industry sector. To start with, the 'Green transition of SMEs' program has been published on the 6th of March 2023 by the Special Management Agency for Operational Program 'Competitiveness, Entrepreneurship & Innovation'. It includes a set of eligible actions for providing support to SMEs by subsidizing certain expenses. It comprises of 2 actions, i.e., 'Action 1: Green Transformation of SMEs' with budget from EUR 200,001 to EUR 1 million, and 'Action 2: Green Productive Investment of SMEs' with budget between EUR 30,000 and EUR 200,000. Among others, eligible are costs for equipment (GREEN) for energy efficiency/energy savings improvement, with up to 50% funding. In this category, eligible are costs related to commissioning, transport, installation of equipment including the corresponding necessary ICT (hardware & software), which aim to improve energy efficiency and save energy. Moreover, within the 'National Plan for Recovery and Resilience – Greece 2.0', several actions for the 'Green Transition' have been announced, including 'Energy and entrepreneurship' in component '1.2 Renovate' , which describes investments for energy efficiency improvement of buildings, energy efficiency upgrade of the production process, including waste heat recovery, installation of new or replacement of existing heating or cooling system as well as hot water supply

with RES system, high efficiency cogeneration for self-consumption. Also, the installation of smart systems and IT equipment, electrical vehicles for the distribution of products and raw materials within and outside the production area and charging points, and the installation of energy efficient equipment. Finally support actions (energy Audit, energy and technical consulting, Energy Performance Certificate, monitoring and management of the implementation of the investment plan) can be also financed. Finally, the 'Green Businesses' and 'Support to Improve Energy Efficiency in Industrial Processes' programmes aim at the deployment of environmentally friendly products and the energy consumption and cost reduction within the industrial processes.
ITALY
Regarding energy efficiency in the sectors subject to the Energy Audit obligation (energy-intensive companies and large enterprises), Italy is quite far ahead, as these companies are forced to install monitoring systems for energy consumption, to send an annual report on energy consumption to ENEA and to improve at least one of the energy efficiency measures identified by the auditor within four years after the first energy audit. The very high cost of almost all energy vectors and the incentive system of so-called white certificates have also pushed large companies and energy-intensive businesses to make their plants more efficient to be more competitive by lowering production energy costs.
ROMANIA
Romania established coherent and effective investment schemes to prioritize energy efficiency measures, enabling a successful transition to a decarbonized economy aligned with their Paris Agreement commitments and energy union objectives, as national long-term strategies in April 2023 [16-17]. Sustainable Development Operational Program 2021-2027 - a program dedicated to sustainable development that targets energy efficiency in the industrial sector and supports large enterprises and SMEs in improving their energy efficiency. The financial allocations for this type of investment amount to approximately EUR 470 million. Regional Operational Programs (ROP) 2021-2027 - Energy efficiency works targeting residential and public buildings as well as the district heating systems will be eligible for finance in the new ROP as part of priority axe 3 – A region with environment friendly cities. The approximate budget available for these interventions amounts to EUR 870 million, divided between 8 regions of Romania [17]. Long-term national renovation strategy proposes measures to improve energy efficiency, to reduce GHG emissions and to increase the renewable energy share in the total energy consumption through renovation of the national stock of buildings. The measures developed under the strategy are designed to reduce energy poverty (currently estimated at 1.7 million households), to improve thermal comfort and the level of safety in buildings, and to support the development of skills and innovation in the energy efficiency sector. The budgetary implications for the implementation of the Strategy are estimated at EUR 5 billion by 2030, which will be covered by the state budget and European funds available through the new operational programs for 2021-2027 and the Recovery and Resilience Facility – approximately EUR 870 million will come from the ROP 2021-2027, and EUR 2.2 billion are available through the allocations of the national recovery and resilience plan.
SPAIN
Spain is conducting a national plan towards decarbonization and energy efficiency (Energy and Climate National Integrated Plan, PNIEC 2021-2030), which includes different measures and

policies promoting CO2 emissions-free technologies that are being currently implemented. Public administration is handing economic advantages for new renewable plants, considering the competitive aspect of traditional generation plants in the transition towards a more sustainable electrical system.
Other incentive and funding programs, such as the IDAE grants, support energy efficiency projects and the implementation of management systems.
In 2022, Spain registered 254.5 M tons of CO2 emissions from energy through consumption of oil, gas and coal for combustion related activities and process emissions, which shows a 2.2% decrease from 2011.
The sector with the highest level of GHG emissions was transportation (27%), followed by industrial activities (20.8%), agriculture (14%) and electricity generation (11.8%). Out of the total emissions, 77% were attributed to CO2. Also, various policies promoting CO2 emissions-free technologies are applied.

2.3.2. Technologies dealing with electrification

Battery Technologies optimize the energy-power trade-off and maximize energy density through advanced materials and designs. Engineering analytics are applied to cut development costs. Further, sustainability requires the elimination of heavy metals like cobalt and cadmium. Recycling or disposal of batteries is also a key to ensure a minimal impact on the environment.

Electric Vehicle (EV) Charging Infrastructure improvements in charging time, affordability, and convenience greatly affect the adoption of electric vehicles.

Grid-scale Storage plays an important role in electrification as it improves the operating capabilities of the grid and lowers costs. Innovations in grid storage technologies, such as pumped hydro, compressed air energy, thermal energy, fuel cells, flywheel storage and batteries, offer more flexibility with variable power sources and higher energy demands, allowing higher penetration of renewables, thus accelerating the integration of renewable energy sources.

Energy Intelligence offers predictive analytics solutions for EVs. Big data analytics also drives better decision-making in planning for new EV infrastructure development and integrations.

Thermal Management Systems are crucial for electric devices to ensure their optimal performance and efficiency. This electrification trend includes all innovative heat management solutions that maintain batteries, power electronics, and electric motors at optimal temperatures.

Internet of Things is a key enabler of asset digitization, data collection, and computational capabilities in electrification efforts to better manage interconnected assets. It enables the real-time transfer of information and allows EV manufacturers to stay competitive.

Off-grid Energy Generation offers a more cost-effective alternative to extending existing grids in remote locations. These solutions allow end users to easily move away from grids that utilize fossil generation and adopt renewable energy sources. This aids sustainable electrification.

Microgrids and Energy Communities technology supports the development of a flexible and efficient electric grid by integrating distributed energy resources (DERs), such as solar and geothermal energy, together with batteries and intelligent demand response techniques.

Lightweight Technology solutions applied to electric vehicles improve efficiency and increase the range. Advances in lightweighting include developing new composite materials and innovative structural designs. Moreover, lightweight technologies translate to compact and power-saving solutions, leading to reduced cost of EV ownership and improved performance.

Sector Coupling: Energy storage technologies, power-to-X (P2X) applications, and demand-response solutions interlink the power-producing sector with power-demanding sectors.

New energy sources: floating offshore wind, solar trackers and floating solar, mini nuclear facilities [18].

Table 2: Specific actions related to technologies dealing with electrification in each project partner's country.

GREECE
The electrification concept is massively targeted, with the increase of the renewable energy sources integration into the existing electrical networks. Aim is to increase the exploitation of the generated clean energy, by PVs and wind power, combined with energy storage. In 2020 energy and climate targets, the country's energy policy focuses on boosting the use of renewable energy, especially for electricity generation, in tandem with increasing the share of energy demand covered by electricity, especially for transport and heating and cooling. Greece recently made several significant changes to its support scheme for renewable electricity generation to increase the rate of deployment. Greece is also taking steps to reduce the time needed for licensing and permitting projects for renewable energy, electricity infrastructure and energy storage. In August 2022, Greece approved its first Offshore Wind Law, which aims at 2 GW of offshore wind capacity by 2030. Greece is a global leader in the use of solar thermal to cover domestic hot water demand. There are also major investments planned to boost transmission and distribution capacity to support much higher levels of generation from wind, solar PV and hydro. The government also aims to connect the most populated islands to the mainland electricity grid by 2030. As for specific actions, the 'Green transition of SMEs' program has been published on the 6th of March 2023 by the Special Management Agency for Operational Program 'Competitiveness, Entrepreneurship & Innovation'. It includes a set of eligible actions for providing support to SMEs by subsidizing certain expenses. It comprises of 2 actions, i.e., 'Action 1: Green Transformation of SMEs' with budget from EUR 200,001 to EUR 1 million, and 'Action 2: Green Productive Investment of SMEs' with budget between EUR 30,000 and EUR 200,000. Among the eligible costs relative to the GREEN transition are costs for the installation of PV plants and storage systems to improve the self-consumption, including, commission and installation of PV plant with up to 10kW installed capacity, commission and installation of electric storage systems with minimum useful capacity

equal to the energy produced by the corresponding PV station for a hour, installation of EV charging units, smart energy meters and telemetry (smart metering).
Regarding the transport sector, as the stock of vehicles on Greek roads is also among the oldest in the EU, subsidies and fiscal measures aim to increase the adoption of EVs. Within the 'Green transition of SMEs' action, eligible are costs for the electrification of transport means (GREEN) with up to EUR 50,000 maximum amount of granted budget.
Moreover, within the 'National Plan for Recovery and Resilience – Greece 2.0', several actions for the 'Green Transition' have been announced, including the 'Framework for installation and operation of EV charging infrastructure' in component '1.3 Recharge and refuel', which is compliant with the Law 4710/2020 'Promotion of e-mobility in Greece'. This law promotes the installation of publicly accessible e-vehicle charging infrastructure by 2022.

ITALY

The main technology for electrification of thermal needs is the heat pump. For example, in the industrial sector, if there is production of waste heat at low temperatures, heat pump systems can be used to generate hot water for other processes and consequently to reduce the consumption of natural gas. Through these systems it is also possible to obtain incentives such as White Certificates. Moreover, waste heat recovery systems from compressors (of compressed air systems) that recover heat to produce hot water for DHW use or for washing tanks and machinery in the food industry are quite common. However, large-scale implementation of these heat recovery processes is still uncommon, despite several studies that have demonstrated their potential.

ROMANIA

Companies and municipalities in Romania are researching and implementing the latest technologies dealing with electrification:
- The number of charging stations for electric cars is now up to 950 in Romania but growing constantly (as the number of electric cars is also growing and the need for high-capacity EV chargers is increasing as well).
- Companies are interested in creating new generations of higher capacity batteries, but also recycling the lead from used batteries.
- Microgrids that ensure onsite power generation and onsite battery energy storage are also being more and more used in Romania. The scalable microgrid control platform with island-mode capability, comprehensive energy conservation and load reduction measures also contribute to the energy security of the electro-energetic system.

SPAIN

Spain is actively promoting electrification in industrial sectors as part of its decarbonization efforts. The government provides incentives, grants, and tax benefits for industries to invest in electrification projects, integrated within the framework of the PNIEC program. These incentives aim to encourage industries to replace fossil fuel-based systems with electric alternatives with the use of electric machinery, equipment, and processes in manufacturing, production, and other industrial activities.
In terms of renewable energy sources, 58% of the installed capacity of the Spanish generation system is renewable, a percentage that continues increasing every year. During 2022, 5,663 MW were connected to the grid (1,382 MW wind power and 4,281 MW photovoltaic), to which 2,649 MW were added in self-consumption projects. Renewable energies represent a very significant

percentage of the energy mix, accounting for 42.1% of the country's electricity production. Last year, wind energy covered 22.1% of demand, while photovoltaic and hydroelectric energy covered 10.1% and 8% respectively. Technologies using biomass have a significant potential in Spain, with over 857 MW of installed power. Biomass power plants, both exclusively dedicated and co-firing with coal, contribute nationally to renewable energy generation and there is a Biomass Technology Platform and research institutions who support the development of this kind of energy source. On the other hand, technologies for deep geothermal energy are null due to the lack of high temperature deposits. Some plants use medium temperature; however, their prevalence is restricted due to geological and economic factors, as well as insufficient institutional support. Finally, solar thermal energy has slowly increased its capacity in recent years, although to a much lesser extent than photovoltaic energy. Currently, the installed capacity in the country is around 2,304 MW. However, several subsidies to increase these technologies are foreseen in the national plan, especially for the residential sector, so a considerable increase is foreseen in the coming years. Measures to promote renewable energies aim to reach 74% of the total energy production with these technologies, with the consequent contribution to the decarbonization plan.

2.3.3. Technologies for deep geothermal energy

Geothermal energy is a natural form of renewable energy generated from the heat of the earth core. Developments in drilling technology and geophysical techniques mean that systems can be engineered at depths more than 5km. Boreholes are drilled to access natural reservoirs of hot water and transferred to heat exchangers for use as direct heat. In the case of ‘hot rocks’ or ‘Engineered Geothermal Systems (EGS)’ schemes, water is pumped from the surface into rock formations where it is heated and returned to the surface. Old mine workings are another source of heat and are a good resource if located close to a heat load. The heat is then used to generate electricity via a turbine/engine and, if a heat load is present, the residual heat can be used via a combined heat and power (CHP) process. After the heat has been exploited, the water is recycled back down into the ground via a second borehole. Deep geothermal energy can be used for electricity production, or to provide heat for commercial, industrial and residential buildings. It can also be used in industrial processes, such as cooling, or in aquaculture and horticulture.

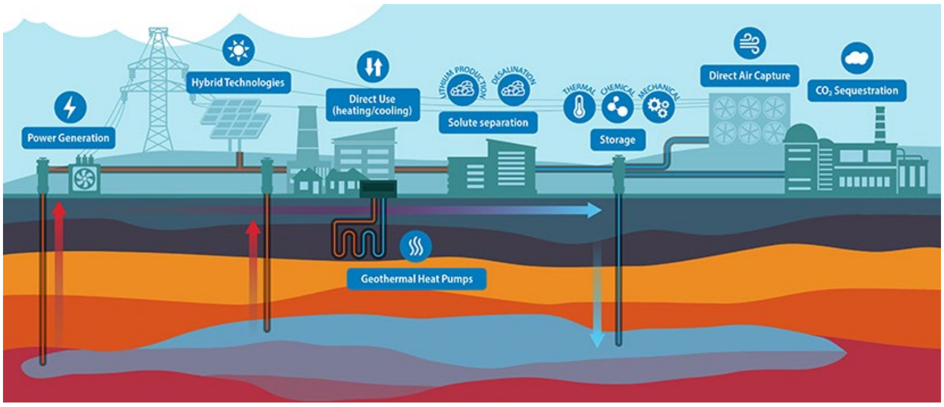

Figure 5: Geothermal Energy’s full potential [21].

Table 3: Specific actions related to technologies for deep geothermal energy in each project partner's country.

GREECE
The contribution of geothermal energy to cover the thermal needs in Greece is low, identified mainly in the tertiary and the agricultural sector. However, the participation of geothermal energy in the final thermal energy consumption is expected to be increased together with the share of other RES. Within the next period, biomass and geothermal energy district heating networks of 30-40 MWth are envisaged to be developed. With regards to domestic electricity production, geothermal plants are expected to contribute by 1.1% in the future. All the above are to be supported by various institutional actions, such as laws, ministerial decisions and financing programmes, targeting to increase the geothermal energy share into the Greek energy mix. Currently, aiming at improving energy efficiency, the programme 'Promotion of RES systems for heating and cooling and for cogeneration of heat and power for own consumption' promotes thermal energy, among other RES, for heating/cooling and power production for self-consumption by financing relevant projects. In addition, there are various regional operational programmes implemented or planned concerning projects for heating/cooling using energy generated from RES. An indicative example is the district heating project in the Municipality of Alexandroupolis with a maximum heat transfer capacity of 10 MWth, taking advantage of the geothermal field of Traianoupolis. Furthermore, the obligation that all the new private buildings as of 2021 and all the new public buildings as of 2019 should be nearly zero energy buildings is expected to increase the share of RES, including geothermal energy, for heating/cooling by 2030. Regarding the regulatory framework concerning geothermal applications, Law 3175/2003 on the utilization of geothermal energy and various Ministerial Decisions facilitate the rational use of geothermal energy, determine the conditions and procedures for their designation, exploration and management, as well as the authorizations for the construction of heating/cooling projects for own use and the exploitation of low-temperature fields for agricultural holdings. Finally, the Ministry of the Environment and Energy created a working group in charge of recommending a draft law on addressing all the issues preventing the promotion of geothermal applications.
ITALY
Italy has an historical record: it has been the first country in the world to produce electricity from geothermal energy, more than a century ago. Today, it is still among the top producers in the world and in first place in Europe. In 2021 in Italy, electricity production from geothermal energy was 0.51 Mtoe and thermal production was 0.14 Mtoe. Production data are as follows: 34 active plants and 817 MW of installed power. All the plants are installed in the provinces of Pisa, Siena and Grosseto. Condensing (85% of MW installed) and single flash (14% MW installed), plants are mainly used for electricity production. Only 1 MW is produced by binary cycle plants. The contribution to the national energy capacity is 1%, while the contribution to the national energy demand is 1.7%. Regarding direct heat use, 226 plants are installed, producing 5,885 TJ, subdivided as follows: 1,602 TJ for room air-conditioning, 2,451 TJ for thermal use, 620 TJ for agricultural use, 1,157 TJ for aquaculture and 57 TJ for industrial processes. The main district heating plants are installed in the Tuscan geothermal areas. In fact, 72.1% of heat consumption from geothermal energy is

concentrated in Tuscany and Veneto. The geological characteristics of the Italian territory are favourable to the development of geothermal energy and could allow the exploitation of this resource through almost all available technologies, being able to exploit low-, medium- and high-enthalpy resources at different depths and in numerous areas of the country. An official estimate of the geothermal potential referring to the entire territory is lacking, but the MiSE has published the geothermal zoning of the Italian territory on a municipal scale, which can be a valuable aid in identifying the most favourable areas.
ROMANIA
Romania is third or fourth in Europe in geothermal energy potential. Exploration is currently being conducted at 24 sites. The sites are in the counties of Arad, Bihor, Harghita, Ilfov, Satu Mare, Timiș and Vâlcea. Selected operators are entitled to 49-year concession contracts for exploitation. Exploration for hydrocarbons has already uncovered over 200 wells with temperatures of up to 120 degrees Celsius. The optimal level for heating homes is 90 degrees, while at 45 degrees, the water can be used for thermal baths. Public funds have been invested in projects for heating public buildings. There is a long way before establishing accurate data, but the country is scattered with underground sources of geothermal waters and the Geological Institute of Romania estimated that, in geothermal energy potential, Romania is third or fourth in Europe. Italy, Greece and Iceland being at the top of the list [22].
SPAIN
Geothermal energy has not been prioritized in Spain as the focus has so far been on wind and solar energy. According to the Spanish geological and mining institute, the potential of high temperature geothermal resources for electricity generation is very limited and concentrated in some places (such as the volcanic archipelago of the Canary Islands). On the other hand, the medium and low temperature (50-90°C) geothermal energy is available in almost half of the territory and very low temperature resources (0-30°) is everywhere, which can be used to air-condition and DHW for dwellings. However, lack of knowledge, high initial cost and lack of regulation have slowed down the take-off of geothermal energy in Spain over the past years. From an industrial point of view, medium-temperature resources may be the most interesting, although currently these resources are only partially exploited and only to a small extent in some heating and DHW of buildings (including hotels and residential areas), swimming pools, spas or some few greenhouses. Nevertheless, recently this year, grants have been approved for feasibility studies for innovative projects to exploit deep geothermal energy, within the framework of the EU-funded NextGenerationEU Recovery, Transformation and Resilience Plan. It is hoped that this will begin to further exploit the country's geothermal potential and that industry will also begin to harness this resource where it is available.

2.3.4. Technologies using biomass

Biomass can be converted into several useful forms of energy using different conversion technologies. Bioenergy is the term used to describe energy derived from biomass feedstocks. To convert raw biomass into useful energy, three main process technologies are available: bio-chemical, thermo-chemical, and physio-chemical. Bio-chemical conversion encompasses two primary process options: anaerobic digestion (to biogas) and fermentation (to ethanol). For the thermo-chemical conversion routes, the four main process options are pyrolysis, gasification, combustion, and hydrothermal processing. Physio-chemical conversion consists principally of extraction (with esterification) where oilseeds are crushed to extract oil.

Bioenergy consists of solid, liquid, or gaseous fuels which can be obtained from the available technologies. Liquid fuels are commonly used in transportation vehicles but can also be used in stationary engines. Solid fuels are directly combusted to obtain heat, power, or CHP. Gaseous fuels can be applied to the full range of end-uses.

Several factors affect the choice of conversion process including the type, quantity, and characteristics of biomass feedstock, end-use requirements, environmental regulations, economics, location, and project-specific factors. It is the form in which the energy is required, and feedstock availability determines the process route. How biomass conversion technologies are implemented and operated will affect the GHG emissions that may arise from their use.

Table 4: Specific actions related to technologies using biomass in each project partner's country.

GREECE
The use of biomass for energy generation and/or fuel production in Greece is limited in relation to the availability of residual biomass. According to the estimations by the Greek Ministry of Development, the energy equivalent of the agricultural and forest residues available annually is ranging from 1,000,000 to 7,500,000 tons. The corresponding contribution of bioenergy amounts to 8% of the total, with the goal through the NECP to be 12% on the way to 2050, which is a milestone year for achieving climate neutrality in the EU. More specifically, in the industrial heating sector, about 190,000 tons of olive stons, 73,000 tons of residues from agricultural industries (cotton ginning plants, kernels from fruit processing industries, almond shells, rice husks, industrial pellets, and 106,000 tons of wood residues (wood industries, industries non-metallic minerals) were consumed. In total, approximately 2,300,000 tons of biomass were consumed, corresponding to energy production of 9.4TWh. On the other hand, in the power generation sector, there are 25 power stations with total installed capacity of 15.5 MWe, ranging from 100 kWe to 5 MWe each. The use of bioenergy (primary solid biomass) will continue to make a significant contribution to heating and cooling, but without a significant increase until 2030, mainly due to the reduction of its use in the urban centres on environmental grounds. The doubling of the installed capacity of bioenergy plants, which is expected to reach and exceed 0.3 GW of installed capacity by the end of 2030 with the simulations of both energy models, is of particular interest. Respectively, the forecast for the use of bioenergy increases marginally both in absolute terms and in percentages and is estimated from 18% in 2020 to 21% of final energy consumption of the residential sector in 2030. The participation of biomass in thermal demand coverage is estimated to be up to 1,087 ktoe by 2025, 1,086 ktoe by2027 and 1,142 by 2030. Finally, as part of the national strategy to promote biofuels, any investment in the field is subsidized from Law 3299/2004 on promotion of investment. Subsidies vary from 40-55% according to region, and the type of the enterprise (in case of SMEs and specific regions they can reach up to 55%).
ITALY
Legambiente's Renewable Municipalities 2022 census indicates that solid biomass and biogas plants are present in 4,105 municipalities, with a total installed capacity of respectively 1,540 MWe

and 3,409 MWe. To these should be added more than 2 million modern, high-efficiency domestic biomass installations fuelled by wood, wood chips or pellets (estimating the number of installations is extremely difficult).

In Italy, the potential for unused woody residues is very large. ENEA estimates that the agricultural sector produces 4 million tons of (unused) residues annually. These are generated by the management of orchards, olive groves and vineyards (pruning and explants). The forestry sector, whose use for energy purposes is more established, may still contribute about 2.5 million tons annually. These values, when related to potentially available energy, yield approximately 19 TW of available thermal energy capacity per year.

The best use of biomass in our country involves small-to medium-sized plants, well located to minimize the fuel supply pool (biomass transport). District heating systems (heat only) provide maximum energy efficiency. Combined heat and power systems, even if connected to a network of utilities for heat utilization, inevitably have low overall efficiency. In fact, the power plants are in operation even in seasons when there is no demand for heat, which must be dissipated without use.

Different is the case of cogeneration plants linked to industries, which absorb heat all year round. Well-designed and sized plants, if fuelled by locally produced biomass, bring positive spin-offs to the area by improving the economy of agricultural and forestry activities. Such plants are very present in the alpine regions, even if they are not always fed by local biomass, which would otherwise be available.

In Italy in 2021, biogas production, in terms of electricity (obtained mainly in cogeneration) was 8,142 GWh, while thermal energy production was 13,663 TJ. 83.3% of total national biogas power generation is provided by northern Italian regions. The main one is Lombardy, which concentrates 34.4% of the national production, followed by Veneto (15.3%), Emilia Romagna (14.8%) and Piedmont (12.7%). Most of the energy produced by biogas plants in Italy comes from plants fuelled by agricultural and forestry activities (69.5%) and animal manure (16%).

ROMANIA

In Romania, the consumption of firewood will register a reduction of about 20% compared to the level of 2018 until 2030. As firewood has the highest share in the biomass, the decrease, because of the reduction in the consumption of firewood, the total consumption of energy resources coming from biomass will decrease until 2030 to the value of 39 TWh.

The consumption of biofuels will increase until 2030 to the value of 4.1 TWh/year, enough to reach the national target for 2020 of 10% SRE share in the transport sector. Biogas will register rapid growth, up to a production of 3,500 GWh in 2030, due to the development of the agricultural sector and, to a lesser extent, the modernization of wastewater treatment plants.

By 2030, small power plants fuelled exclusively with biomass, bioliquids, biogas, waste and waste and sludge fermentation gases will be developed, until such plants will have a total installed power of 139 MW. The boilers of some of the current thermoelectric plants will be adapted to allow the burning of additional biomass. Overall, a total of 0.9 TWh of electricity will be produced in 2030 by burning biomass. Complete regulations regarding the use of biomass to produce electricity will be developed, to prevent the irrational use of this resource.

SPAIN

In Spain, biomass is one of the main renewable energy sources, along with wind and solar energy, and there are more than 30 biomass power stations in rural regions and a few others that are under

construction. According to the 2021 report of Red Eléctrica Española (REE), from 2014 to 2019, the total installed biomass capacity has grown by 9%. Specifically, there is an installed capacity of 857 MW of biomass. On the other hand, according to data from the Biomass Observatory, biomass production in Spain in 2020 was approximately 11.6 million tons and the number of pellet and biomass fuel plants is also increasing every year. However, biomass utilization in Spain is well below its potential and the European average, as it has abundant agricultural and forestry residues.
There are several government incentives for the production and use of biomass, such as subsidies and grants for the installation of biomass systems in homes and buildings. Biomass is mainly used to produce heat in rural regions. In industry, biomass is used for example in paper production and furniture manufacturing. Biomass furnaces also exist in some Spanish industries. However, not many companies are using biomass and there is still a large remaining potential to be unlocked in the country.

2.3.5. Technologies using hydrogen

Hydrogen technologies are those related to the production and use of hydrogen, as a part hydrogen economy. Hydrogen technologies are applicable for many uses. Some hydrogen technologies are carbon neutral and could have a role in preventing climate change and a possible future hydrogen economy. Hydrogen is a chemical widely used in various applications including ammonia production, oil refining and energy. The most common methods for producing hydrogen on an industrial scale are steam reforming, oil reforming, coal gasification and water electrolysis.

Hydrogen is not a primary energy source, because it is not naturally occurring as a fuel. It is, however, widely regarded as an ideal energy storage medium, due to the ease with which electricity can convert water into hydrogen and oxygen through electrolysis and can be converted back to electrical power using a fuel cell. There is a wide number of different types of fuel and electrolysis cells. As an energy buffer, hydrogen produced via water electrolysis and in combination with underground hydrogen storage or other large-scale storage technologies, could play an important role for the introduction of fluctuating renewable energy sources like wind or solar power.

The potential environmental impact depends primarily on the methods used to generate hydrogen as a fuel.

Among increased investment, government support, engineering development and a skilled workforce, digital technology is one of the critical levers for accelerating the transition to green hydrogen – especially artificial intelligence of things (AIoT) – a combination of artificial intelligence and internet of things technology that enables the optimization and automation of systems through enhanced data management and analytics.

Here are four areas in which digital technology could help expedite the green hydrogen transition:

1. *Digital twins*. Before committing capital, investors want to know which system configuration will optimize their return. From PV to electrolyzer capacity, to buffers (such as energy and hydrogen storage), multiple variables will be considered. Digital twins can model multiple designs and scenarios, including variables such as weather, off-takers demand volatility and local infrastructure

(current and future), optimizing each design to maximize return on investment and minimize risk. Estimates indicate that digital twin analysis can optimize capital expenditure (CAPEX) by 10-15% whilst reducing risk by 30-50%, along with a marginal change in operating expenditure (OPEX) [23].

2. *Monitoring and control*. Energy consumption, plant performance, production rates, purity and storage are among the key performance indicators (KPI) for hydrogen production which require visibility to ensure efficient production. AIoT can offer rapid anomaly detection using intelligent alarms, sensors on assets to monitor KPIs, and asset health and cloud-based remote monitoring beyond control rooms. Providing real-time monitoring of plant operations and asset health, coupled with remote control of assets, can reduce costs by 10-20% through lower energy consumption and a streamlined workforce. Leveraging monitoring models, consistent with design digital twins, allows investors to see where they stand regarding the business plan and to take actions to reduce eventual losses.

3. *Advanced analytics*. Analytics can transform data into business intelligence with actionable insights. For green hydrogen, churning and learning through data from plants, tanks, pipes, energy off-takers and even the weather, and the application of plant level or fleet level analytics can provide corrective action recommendations to maximize yields. Energy losses can be prevented by forecasting failures and optimizing electrolyzer uptime, thus increasing revenues and decreasing OPEX. Leveraging analytics models consistent with their digital twins allows investors and bankers to 'close the design loop' and take strategic and tactical decisions to optimize their returns.

4. *Certificates of origin*. Guarantee of origin (GoO) is a prerequisite for monetizing green hydrogen by certifying the renewable nature of all consumed electricity. AIoT-monitored installations can leverage near real-time data to automate input to GoO issuers – this avoids manual processing, offers more confidence and reliability, and increases futureproofing as more and more certifications evolves towards real-time and automation. AIoT can also ensure end-to-end traceability along the entire life cycle of the green hydrogen, from cradle to grave.

Table 5: Specific actions related to technologies using hydrogen in each project partner's country.

GREECE
Hydrogen is under development and incentivized in Greece, but not only for industry applications. The first step in Greece towards the regulation of hydrogen use as an alternative fuel in the transport sector was introduced by Law 4439/2016 on the adoption of Directive 2014/94/EU of the European Parliament and of the Council of 22 October 2014 on the development of alternative fuel infrastructures and simplification of licensing procedure. Currently, there are already available hydrogen stations. In the framework of the NECP, it is mentioned that through pilot activities the generation of green hydrogen via RES will be promoted for the better exploitation of the RES potential. Moreover, in the NECP the coupling of electricity and gas sectors is proposed (power-to-gas) through storage applications that include the use of electricity generated by RES to produce gases, such as hydrogen. In 2020, the Committee for the National Strategy for hydrogen has been established, launched by the Greek Ministry of Environment & Energy, towards the development of the 'National Strategy

for the Promotion of Technologies – Applications of Hydrogen and Renewable Gases'. The establishment of the Committee coincided with the adoption of the first Regulation for the European Hydrogen Strategy by the European Council. Aim of the Committee is to assess the risk and estimate the costs of various technological applications for the production and use of hydrogen with particular emphasis on the role of hydrogen transport/storage networks and infrastructures in relation to the existing natural gas network and the views of the energy industry. The Committee has calculated the effects of the development program on an annual basis in 2030 as follows:
- Reduction of CO2 emissions: 750 ktoeCO2, or 1.5% of the total GHG emissions for 2030;
- Reduction of gas and oil imports equal to 500 ktoe, which corresponds to a reduction of 10% and a reduction of import costs by EUR 230 million;
- Total investments in the hydrogen supply chain of about EUR 3-4 billion;
- Jobs in the hydrogen supply chain 3,000-4,000;
- Domestic added value: 90-110 million euros.

It is expected that the total turnover of the hydrogen supply chain in Greece will be in the order of EUR 10 billion per year in 2050. By then, approximately 60 GW of renewable energy sources will be required to power electrolysis units (30 GW by 2040). The National Strategy envisages fast-tracking renewable energy project licensing procedures for hydrogen production, licensing and grid connection and government subsidies until 2030 due to the immaturity of the technology, a factor that makes investment costs very high.

The National Natural Gas System Operator (DESFA) S.A. has already started the construction of the first pipeline in Greece to transport 100% hydrogen. In addition, all new DESFA pipelines are designed and constructed to be able to transport 100% hydrogen. Moreover, DESFA is participating in the European natural gas managers to create a pan-European hydrogen network.

In April 2021, the General Secretariat for Industry, which falls under the Hellenic Ministry of Economy and Development, issued a call for the submission of proposals related to investments in the hydrogen value chain, i.e., the safe and sustainable productions of low-carbon hydrogen, industrial equipment, solutions for storage, transport and distribution, and industrial applications of hydrogen.

Finally, currently, in Greece there are many projects related to hydrogen. The most mature ones have already received approval from the EU under the Important Projects of Common European Interest (IPCES) in the hydrogen sector. In fact, Greece is one of the 23 European countries which signed the 'Manifesto for the development of a European Hydrogen Technologies and Systems value chain'.

ITALY

In 2021 ENEA and Confindustria (the most representative industry association) published a position paper regarding the 'Action Plan for Hydrogen in the Industrial Sector'. It shows that there already exist on the market some equipment that can run on hydrogen or with a hydrogen-methane mix, such as:

- Steel sector → the existing plants could operate without modification with 10% hydrogen mixtures
- Paper industry → there are already components on the market, such as burners and combustors, suitable to be fuelled either with hydrogen mixtures around 20 %
- Chemical industry → in processes using thermal energy, there are already burners and combustors on the market, suitable to be fuelled either with hydrogen mixtures around 20 %

● Ceramics sector → there are already products and solutions that allow the use of hydrogen mixed with natural gas in high percentages (over 50 %). Vice versa, for some sectors hydrogen may not be a good solution. For example: ● Cement sector → there are many doubts about the actual availability of hydrogen in the quantities required by the production process, plus the large amounts of water vapor produced by hydrogen combustion could adversely affect the product. In addition, the production process relies on calcination, which releases CO2; so, the most appropriate way to decarbonize is to adopt CO2 capture, separation and storage or utilization (CCUS). ● Refineries sector → Refineries already use hydrogen in their production processes; however, it is produced by steam reforming and the remaining part by catalytic reforming processes of Virgin Naphtha (so-called grey hydrogen). Unfortunately, it seems very difficult to switch to the use of green hydrogen. For other sectors (i.e., glass, food industry), further study is needed. Right now, the Italian government has allocated 2 billion EUR of PNRR funds to fostering the transition to green and zero-emission hydrogen for those industries that are today most polluting and difficult to convert (hard-to-abate), EUR 230,000,000 to promote the creation of fuel stations for hydrogen experimentation in road transport and EUR 300,000,000 to test the conversion to hydrogen of non-electrified railway lines with high passenger traffic and heavy use of diesel trains, as in Lombardy, Puglia, Sicily, Abruzzo, Calabria, Umbria, and Basilicata.
ROMANIA
The Romanian Ministry of Energy announces the initiation of the development process of the 'National Hydrogen Strategy and Action Plan', part of the National Recovery and Resilience Plan (PNRR). The strategy will aim to achieve the targets of the energy transition process and decarbonization of the economic sectors, as well as the realization of the legal framework for facilitating investments in hydrogen along the entire value chain. The Ministry of Energy will subsequently ensure the adoption and entry into force of the changes to the legislative and regulatory framework that led to the implementation of Reform 4 of Component 6 (milestone #126) of the Recovery and Resilience Plan of Romania and the successful implementation of some key measures within the national hydrogen strategy and action plan. The changes will need to remove any legislative and administrative obstacles to the development of renewable and low-carbon hydrogen technology, so that the entire hydrogen value chain can be developed, including the mandatory use of hydrogen-ready appliances and equipment by end-users. In Romania, the most promising hydrogen uses are in industry (steel, ammonia, fertilizers, refineries, and high value chemicals), transport (long-haul aviation, maritime shipping, HDVs and some railway segments), existing district heating systems and, potentially, long-term or seasonal energy storage beyond 2030. Other uses, such as gas blending or green hydrogen use in CCGTs are rather a waste of economic value, given the comparatively high costs of producing hydrogen.
SPAIN
In Spain, the economic potential of green hydrogen to reduce carbon footprint has been embraced with some enthusiasm by the national government, regional administrations, the private sector and, to some extent, civil society. A National Hydrogen Roadmap has been created to promote the deployment of these technologies across the industrial sector, setting a target of achieving at least 25% renewable hydrogen out of the total hydrogen used in industrial applications by 2030, either as a feedstock or for energy-calorific purposes.

Spain could have one of the most competitive renewable hydrogen prices in the EU thanks to the possibility of developing projects that hybridize solar and wind power generation, the availability of land and experience in the development of renewable projects [24]. Various pilot projects and initiatives are underway, but there is still much to develop.

2.3.6. Technologies for carbon capture, utilization and storage (CCUS)

CO2 is one of many gases in the exhaust streams of power stations and industrial processes. To be used or stored, it first needs to be separated. This can be done in a number of ways, such as passing the exhaust fumes through solvents or across catalysts and other substances that selectively bind to CO2.

One way to strip the carbon out is through chemical absorption. This is when waste gases are passed through solvents like ammonia, which absorb the CO2 in a chemical reaction. This absorption is then reversed by blasting the ammonia with high temperature steam, releasing the purified CO2. This type of capture can be retrofitted onto existing buildings. This makes it the most popular CCUS technology trailed to date.

Another way to strip out CO2 is by oxyfuel combustion. This is when the fossil fuels are burned (e.g., during power generation) in a purer mixture of air. This mix contains just oxygen and CO2, with the nitrogen removed. Burning the fuel in purer air means that the exhaust gases are more concentrated with CO2, making it easier to capture and store the waste gases after burning. Oxyfuel combustion is slightly simpler than chemical absorption as no solvent is required. The unit that carries out this process is also relatively small. This means there is a possibility of retrofit to an existing plant with some alterations.

CCUS will be useful in decarbonizing industries that are likely to have residual emissions by 2050. Obvious examples are heavy industries like steel making and power generation that use natural gas or biomass. CCUS capture rates are not 100% efficient, so there will still be some residual emissions. Today, around 5kg of CO2 can be captured per person per year across the world, to a total of around 39.5 million tons. Yet, global CO2 emissions are around 33 billion tons. So, a significant gap remains. Although, planned pipeline will double the amount that can be captured per person, a much greater scale up is needed – around a thousand times the current level per person – to sequester the global average person's carbon emissions of five tons (5,000 kgs) per year [25].

Transporting and using CO2: Before it can be used or stored, captured CO2 has been transported, usually via pipelines. For this, it is compressed into a liquid state and can then be moved through the pipelines, by ships or in road tankers. Sharing infrastructure such as pipelines between multiple emissions sources, creating 'industrial clusters', is becoming increasingly attractive. Clustering can combine emissions from power stations and industry into a single pipeline, cutting costs and providing the scale needed to make CCUS projects viable. Captured CO2 can be used to make a multitude of materials. It can be converted to building materials such as concrete (mineralization), used to make plastics via polymerization as a feedstock for microalgae that is converted to biofuels, among others. These processes can be very energy intensive. The additional cost of using CO2, as well as the waste produced in making new materials, can impact the viability of CCU projects.

CO2 can also be used directly in commercial processes such as food and drink, horticulture and in enhanced oil recovery. In food and drink, CO2 can be used to carbonate drinks, freeze and chill food and in packaging. In horticulture, it can be added to greenhouses to enhance the production of crops that use CO2 in photosynthesis.

The main use for CO2 today is enhanced oil recovery, a process to increase the maximum amount of oil and gas that can be extracted from a site. By injecting CO2 into the reservoir, more hydrocarbons are forced out than would be otherwise. The additional revenue of these fuels imparts a value on the CO2 used to extract them.

Storing captured CO2 – geologically, minerally or in oceans – prevents it from entering the atmosphere and contributing to climate change. Geological storage, in sedimentary rocks in old oil and gas fields or saline formations (porous rocks), can include re-using existing oil and gas infrastructure. Europe has several areas that have significant storage capacity potential, such as Spain (up to 14 GtCO2) and Norway (134 GtCO2). One often-cited concern around geological storage is that CO2 will leak out over time. However, studies have found this is unlikely, stating that even if there is a 50% probability of 0.0008% leakage per year, if 'well-regulated' over 98% of the stored CO2 would remain in the subsurface for over 10,000 years. For this reason, geological storage is the most credible option for CO2 examined to date [26].

Ocean storage is another option. While technically possible, injecting CO2 into the ocean and either letting it diffuse or trapping it in a specific location, would lead to the formation of carbonic acid, a direct cause of ocean acidification. For this reason, it is not seen as a credible means of storing CO2.

Mineral storage is also used. This is where CO2 is chemically bound to calcium and magnesium-rich rocks, holding it in place at specific sites. As calcium and magnesium are stable and abundant, the CO2 will not be released into the atmosphere. However, this reaction can be slow under normal temperatures and so would need to be heated (using more energy) to increase the speed.

Table 6: Specific actions related to technologies for CCUS in each project partner's country.

GREECE
Carbon Capture is under development and incentivized. Within the 'National Plan for Recovery and Resilience – Greece 2.0', several actions for the 'Green Transition' have been announced, including 'Produc-E Green' in component '1.3 Recharge and refuel'. The investment aims at establishing sustainable urban mobility and promoting storage of CO2 emissions, operating without using oil extraction/ recovery activities. Extensive study work had been undertaken to identify locations in Greece that can be developed to store CO2 captured from current emitters and the work had concluded that currently the only site that can be developed in the immediate term is located at the Kavala fields. Towards the effort for CCS in Greece, the Hellenic Hydrocarbons and Energy Resources Management Company (HEREMA), fully owned by the Greek state, plays an important role in realizing Greece's potential as a leading energy and carbon abatement resource. In April 2022,

HEREMA was appointed as the licensing authority for the geological storage of CO_2, including the issuance of exploration and storage permits. This also includes the overall management of the rights of the Hellenic state for the storage of CO_2 and other gases and liquids, such as natural gas and hydrogen (Law 4920/2022, Government Gazette A '74/ 15.04.2022). Important steps have been taken as there is already an institutional framework and the first approved application for CO_2 storage in Prinos (Kavala). The Prinos CCS project concerns in the first phase the storage of 0.5-1 million tons of CO_2 per year and has been included in the Recovery Fund. CO_2 captured from local emitters (up to 150 km distant) will arrive at the facility by pipeline whilst CO_2 captured at remote sites would arrive by ship and enter a buffer storage facility. HEREMA plans to study other potential sites for CO_2 storage in Greece, such as in Grevena, Magnesia and in western part of Thessaloniki. CCS is at the centre of interest for industries with significant emissions (e.g., cement industry, metallurgy, power generations, refineries), especially in view of the further increase in the cost of purchasing CO_2 emission rights expected in the following years. It should be noted that annual CO_2 emissions by large industries in Greece, such as refineries, cement producers, electricity and metal groups are estimated at 30 million tons. Moreover, the Centre for Renewable Energy and Sources (CRES) had been participating in a project called DigiMon (Digital monitoring of CO_2 storage projects), which aimed at accelerating the implementation of CO_2 capture and geological storage by developing and demonstrating an affordable, intelligent, flexible and socially acceptable integrated early warning measurement system to monitor any CO_2 geological storage project.
ITALY
To date, there are no large-scale CO_2 capture and storage plants in Italy. Eni plans to build a plant with a storage capacity of 500 Mt of CO_2 in Ravenna starting in 2024.
ROMANIA
Now, large-scale implementation of CCUS in Romania faces the challenge of defining a viable business case which can be achieved through utilization of captured CO_2 for EOR (Enhanced Oil Recovery) and EGR (Enhanced Gas Recovery), as well as the establishment of a transport infrastructure. CO_2-EOR operations have traditionally focused on optimizing oil production, not the storage of CO_2. However, CO_2-EOR can nonetheless result in very effective storage. In general, nearly 100% of the initially acquired/purchased CO_2 for CO_2-EOR operations (not that which is recycled) will be stored at the end of active injection. Multimodal transport of CO_2 consists in a smart usage of pipelines and ships. At the scale of Danube - Black Sea area and, why not, for a large part of Europe, promoting the multimodal transport of CO_2 could surpass the difficulties of building pipelines everywhere as well as, for example, those of public acceptance and transboundary cooperation, apart others. Instead of a unique network of pipelines, multimodal transport of CO_2 means a large usage of specialized ships on the inland waterways, and short pipelines between the emission sources as well as suitable storage locations with the closest harbours. Related to the Southern part of Romania, from previous and present CCUS studies, the industrial CO_2 emissions (verified on 2017), the appropriate geological structures for CO_2 storage as well as oil and gas deposits for EOR and EGR, are well documented.

More information about CCUS in Romania were gathered by the H2020 project under the grant agreement 837754, Strategic planning of regions and territories in Europe for low carbon energy and industry through CCUS. The results are available online at [27].
SPAIN
Over the past decade, Spain has been standing out both for its facilities and its participation in projects of great relevance at European level for carbon capture, its utilization and storage. The progress is carried out through the CO2 Capture, Transport, Storage and Use Management Plan by PTECO (CO2 Technologic Spanish platform). It is focused on improving technologies aiming at decarbonization that are applied in industries where the cost of the capture is low and have access to transportation and storage lines. The facilities of the CO2 Capture Technology Development Centre in Spain allow research with all types of coals and incorporate different oxy-combustion technologies. CCUS are also implemented along with biomass, accomplishing CO2 capture efficiencies around 70-80%. In addition, in Spain, the carbon footprint of most industries will start to be registered on a mandatory basis, establishing limits with financial penalties and giving companies the opportunity to offset their emissions through their participation in national CO2 absorption projects that are responsible, among other things, for the recovery, protection and management of ecosystems. In addition, companies in the industry will be obliged to develop their emission reduction plan for the coming years.

2.3.7. Technologies dealing with process intensification (PI)

Process intensification (PI), a technique aimed at modifying conventional chemical processes into more cost effective, productive, greener and safer processes offers the opportunity to address some of the challenges encountered in CO2 capture and conversion. PI technologies are characterized by equipment size reduction through enhanced and targeted mixing, and mass/heat transfer, leading to improved selectivity, high energy efficiency, reduced capital cost and waste reduction. The smaller processing volumes handled in intensified systems offer the potential to reduce material costs and improve safety. Even greater intensification levels can be realized by astutely combining synergies of equipment, materials and methods, and by combining two or more technologies in each process. Such combinations can utilize the specific advantages of each component, whilst aiming to suppress any associated constraints of a particular aspect of the process. For instance, in the case of CO2 reduction, electrochemical reduction can be incorporated with photo catalysis, which provides the driving force to initiate the process. Similarly, replacing an intensive energy source with a more efficient and ideally renewable source can lead to intensification of CO2 reduction. For instance, compared to CO2 activation using high-cost thermal energy, high-energy non-thermal plasma has shown an improved performance. For such combinations or substitutions to be effective, it is important to understand the important properties in material and/or devices that will efficiently and affordably reduce CO2 to value-added products. Herein, the intensification of carbon capture and of key CO2 reduction methods including photocatalytic, electrochemical, biochemical and thermochemical processes is reviewed, focusing on the integration of the three PI approaches of equipment, materials and methodology.

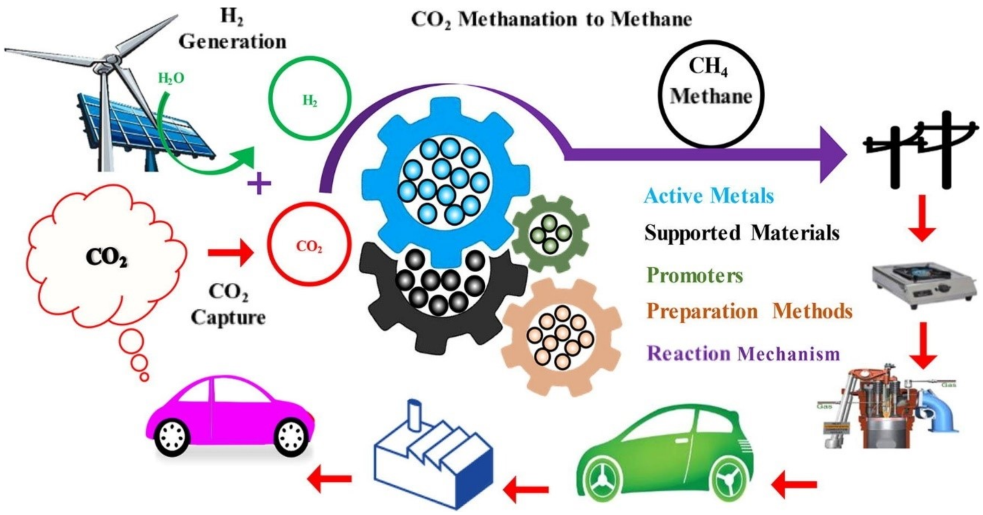

Figure 6: CO2 conversion cycle [28].

Process intensification can be achieved by four approaches [29]:

Low thermal budget transformative technologies (mid- to long-term): Technologies that may use alternative energy sources while offering disruptive changes in the current production methods (e.g., electrolysis and electrodialysis)

Alternative thermal processing (near- to mid-term): Technologies that use an alternative source of energy while maintaining the current production methods to gain more flexibility/control (e.g., induction and resistance furnaces)

Transformative supplemental technologies (near-term): Emerging energy efficiency and supplemental technologies that reduce thermal demand (e.g., smart Internet of Things devices for system optimization)

Waste heat management technologies (near-term): Emerging waste heat reduction, recycle, and recovery technologies (e.g., thermoelectric devices and heat pipes)

Table 7: Specific actions related to technologies dealing with PI in each project partner's country.

GREECE
Technologies dealing with process intensification are also incentivized for adaptation, as part of the energy efficiency improvement measures. Within the context of the strategy plan 'Industry 4.0', efforts are made to motivate industries towards digital transition, to achieve better efficiency of the processes and adopt cutting-edge technologies and digital skills that are compliant with the term of the Fourth Industrial Revolution.
ITALY
In Italy, PI are mainly applied in energy-intensive industries, where process heat can be recovered and reused. Besides this, another key sector for Italy where intensification plays a key role in decarbonization is agriculture. Agricultural emissions gradually decreased between 1990 and 2010 from about 34.5 MtCO2e to 30.1 MtCO2e. Therefore, intensification of the agricultural sector can result in a significant reduction of GHG emissions [30].

ROMANIA
Technologies dealing with process intensification are also incentivized for adaptation, as part of the national energy efficiency plan.
SPAIN
Technologies dealing with process intensification are also incentivized for adaptation, as part of the energy efficiency improvement measures.

2.3.8. Technologies concerning the circular economy

The concept of the circular economy is fundamentally based on the creation of a single extraction, production and consumption system; materials and products are kept within the cycle as long as possible, with losses minimized or ideally eliminated. This can overcome the limitations of classic decarbonization processes, which, being linear and therefore partial, do not allow for complete carbon neutrality, as can be observed in Figure 7.

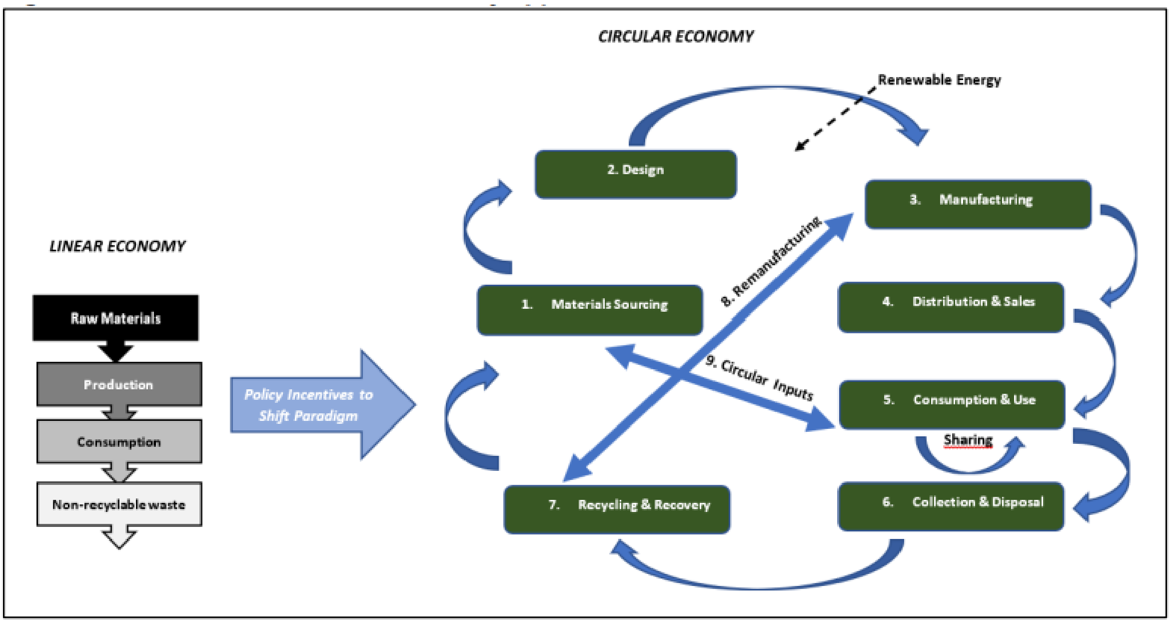

Figure 7: The concept of the circular economy [31].

Circular Economy trends in 2023 [32]:

1. Waste-to-Resource: The world generates tons of waste annually, most of which end up in landfills. The circular economy retains the value of products or resources by putting them back into the product cycle after use. Besides mechanical recycling, one of the biggest circular economy trends is to upcycle this waste to energy by incineration, gasification, anaerobic digestion, and pyrolysis. This allows waste management companies to get rid of the waste effectively as well as provide an additional stream of clean energy for power utilities. While every industry produces waste, some industries, like energy, food, agriculture, and fashion, are larger contributors than others. Startups are working on waste upcycling solutions that focus on waste from such polluting industries.

2. Reusing products extends their lifecycle while reducing waste and the use of new raw materials, thus, making it one of the top circular economy trends. However, there is often a lack of information about the products available for reuse. To tackle this issue, various types of sharing platforms are on the rise. For instance, asset sharing platforms allow businesses to earn revenue by lending materials or machines that otherwise mostly remain unused. Similarly, food sharing applications reduce food waste while preventing losses from unsold food. Apart from reusing materials, there is a shift away from single-use packaging to reusable packaging. The latter is made with durable materials to survive multiple lifecycles.

3. Internet of Waste: In traditional waste management systems, municipalities and waste management companies often end up spending a lot of money and effort to collect waste. The collection system usually works on fixed schedules, without considering the trash capacities of dumpsters. As a result, garbage trucks often visit dumpsters that are not yet full or those which overflow with garbage. Therefore, IoT-based smart waste management solutions reduce the inefficiencies in trash collection. Smart bins transmit real-time fill level information to waste collectors and eliminate inefficient visits to near-empty trash bins, saving time, fuel, and labour.

4. Artificial Intelligence: Separating or sorting garbage is as important as an effective waste collection to ensure that the right materials are sent for recycling. Unfortunately, this process is still a bottleneck for many waste management facilities as most of them follow a single-sort system in which all the recyclables end up in the same box. But the recyclables like plastic and cardboard need to be separated. AI-powered sensors differentiate among items made from different materials as well as nuances among the ones of the same materials. It also detects chemical contamination in the items. This is why the use of AI in waste management is one of the emerging circular economy trends. Moreover, AI-driven machines sort recyclables much faster than humans using computer vision and deep learning algorithms. AI enables waste management companies to reduce the need for manual labour, thus, cutting costs and maximizing efficiency.

5. Bio-Based Materials: Products made from non-renewable resources largely contribute to environmental pollution and reach the end of their lifecycle very quickly. Therefore, companies are producing new bio-based materials obtained from renewable resources, making it an important circular economy trend. Bio-based materials are generally compostable and easier to recycle, allowing companies and consumers to reduce their carbon footprints. They find applications in packaging, construction, healthcare, and automotive sectors.

6. Remanufacture: Both recycling and remanufacturing reduce solid and hazardous waste, but the former uses more energy to dismantle a product. Moreover, recycling implies breaking down a product to convert it into raw materials that are used for making new products. But remanufacturing involves rebuilding a product to its original condition with reused, repaired, and some new parts, making it as good as new. Advanced technologies like Laser Metal Deposition (LMD), an additive manufacturing process, not only restore a component but also add extra features for improved performance. This allows Original Equipment Manufacturers (OEMs) to cut down their capital expenditures while also reducing the carbon footprint.

7. Blockchain secures its position as a top emerging trend by enabling two important functions in the circular economy — providing transparency and traceability and incentivizing circular behaviour. Startups use blockchain's immutability to verify the origin of products, assuring that they meet their sustainability claims. For example, The World Economic Forum's Mining and Metals Blockchain Initiative's (MMBI) Carbon Tracing Platform (COT) — a unique proof of concept, traces carbon emissions across the supply chain. This enables mining companies to meet Environmental, Social, and Corporate Governance (ESG) demands.

8. Repair: Reusing products extends their lifecycle, but products often become unfit for reuse. Repair solutions address this, extending the life of products. Moreover, it reduces waste and the use of new raw materials. Take for example the tons of electronic waste globally. Repair solutions hold the potential to bring much of it back to the cycle. This is why repair solutions are an important circular economy trend and companies are adopting them to reduce their carbon footprint and save costs on raw materials.

Table 8: Specific actions related to technologies concerning the circular economy in each project partner's country.

GREECE
The concept of circular economy is widely elaborated in Greece through technologies and processes. Within the 'Green transition of SMEs' programme, which has been published on the 6th of March 2023 by the Special Management Agency for Operational Program 'Competitiveness, Entrepreneurship & Innovation', eligible are costs that aim to minimize and save resources utilizing practices of reuse and recycling of raw materials, while minimizing the use of natural resources in the framework of the circular economy. Some examples of eligible equipment are listed below: - Units for the management of liquids & solids of waste, - Systems that limit the soil, subsoil, water and air pollution, - Equipment to reduce water consumption and losses, - For recycling, such as mechanical waste bins, metal waste compactor, etc., - Equipment for waste, such as waste loading and sorting machines, waste shredders, drilling, sandblasting, primary sedimentation equipment, secondary treatment equipment-activated sludge and biological/chemical method removal, - Equipment to reduce defective products, such as production control x-ray machines, - Equipment to optimize water consumption resources/water reuse, such as water filtration systems (osmosis, desalination, etc.), and smart water saving systems.
ITALY
In 2020, the last available year of data, in the EU, the circular material utilisation rate was 12.8%. In Italy the value reached 21.6%, second only to that of France (22.2%) and almost ten percentage points higher than that of Germany (13.4%). It is interesting to note that for this specific indicator, Italy is in fourth position compared to all 27 EU countries. Furthermore, Italy has experienced a trend of growth in the rate of circular use of matter practically continuously over the years, starting from 11.6% in 2011 to 21.6% in 2020. In Italy, the recycling rate of all waste has almost reached 68%, which is the highest figure in the EU. The ranking overall of circularity in the top five economies of the EU is based on 7 indicators, i.e., the rate of overall recycling of municipal and special waste; the rate of utilisation of material from

recycling; the resource productivity; the ratio of waste generation and material consumption; the share of energy from renewable sources in the total gross energy consumption; repair; land consumption. Italy and France are the countries with the best circularity performance, each scoring 19 points.
ROMANIA
The EC supported Romania in developing a circular economy strategy, which was officially adopted by the Romanian government on September 21, 2022. The adopted strategy provides an overview of the circularity potential of 14 economic sectors in Romania (including automobile industry, chemical industry, metallurgic industry, construction materials, etc.), establishing a clear general direction aimed at accelerating the transition from a linear economic model to a circular one. The priorities for the development of policies aimed at promoting circularity in Romania focus on: reducing the consumption of virgin raw materials through sustainable extraction, recycling and recovery activities; reducing the consumption of consumer goods by extending the life of the products; reducing the impact of production activities on the environment; reducing the environmental impact of waste and wastewater management and disposal activities and improving policy coherence and governance, communication and collaboration between local, regional and national authorities.
SPAIN
In line with European policies, Spain has a circular economy strategy and different action plans that outline the path to achieve the objectives set for 2030 aimed at reducing national consumption of materials, waste generation, efficiency in water use or increasing the reuse of waste, among others. In addition, to achieve these objectives, the Strategic Project for Economic Recovery and Transformation (PERTE) for Circular Economy was approved last year, which will provide significant subsidies to industries with the aim of improving the competitiveness and innovation of the industrial fabric through the reduction of the consumption of virgin raw materials; eco-design; waste management and digitalization.

3. Design of the Decarbonization Roadmap

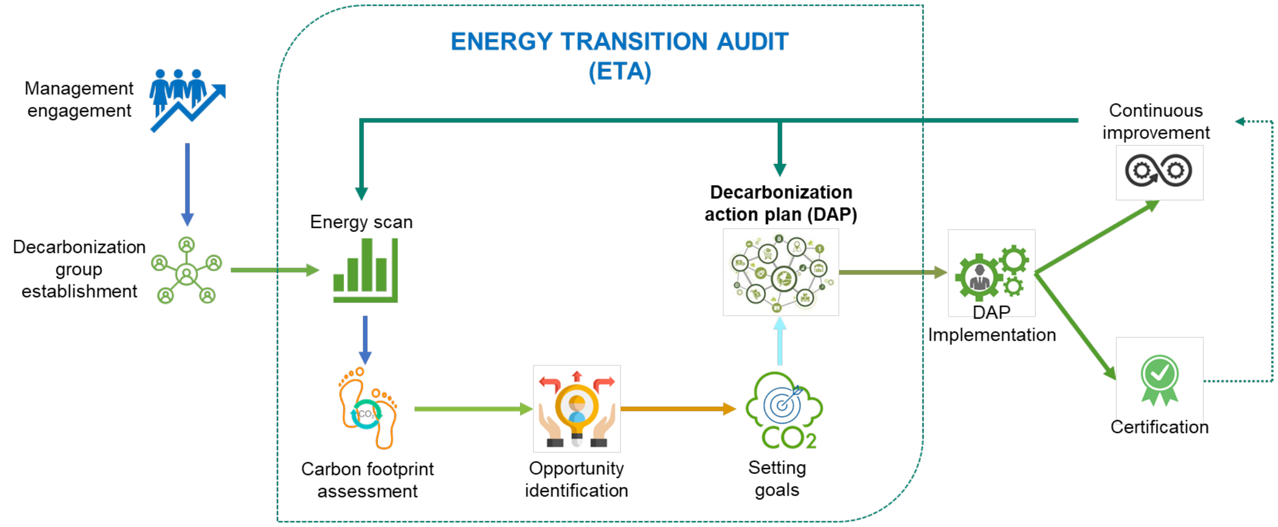

Figure 8: Decarbonization roadmap workflow.

3.1. Obtaining top management commitment/engagement

The **D**ecarbonization **R**oadmap (**DRM**) starts at the governance and strategy level of the company, launched by the top decision makers, but with the clear involvement and technical assistance of the energy professionals – energy managers. For real change and progress to be made, there is need for a clear mandate that sustainability and carbon reduction are prioritized and integrated within all business plans. All the aspect of the DRM continues throughout the entire process as the decisions made at this level significantly influence how each step is approached and the success of the entire process.

In this context, the top management engagement is crucial for the success of decarbonization actions, for at least the following reasons:

- ✓ Management's vision and guidance provide a framework for aligning business operations with long-term sustainability goals.
- ✓ Since management controls the allocation of resources, including financial, human, and technological resources, their engagement ensures that adequate resources are dedicated to decarbonization efforts. This includes funding for renewable energy projects, energy efficiency upgrades, research and development of clean technologies, and training programs for employees.
- ✓ When management demonstrates a strong commitment to decarbonization, it sets a positive example for employees and encourages their active participation and support. This fosters a culture of sustainability and creates a sense of shared responsibility towards achieving carbon reduction targets.

Top management engagement for decarbonization can be triggered by various sources that can differ depending on the industry, market conditions, regulatory landscape, and societal expectations:

- Awareness campaigns on climate change, sustainability, and the importance of decarbonization can prompt management to act for it.
- Changes in environmental regulations and legal frameworks related to carbon emissions.
- Pressure from investors and shareholders to address climate-related risks and sustainability issues.
- The emergence of cost-effective clean technologies and innovative solutions that could provide opportunities for companies to reduce carbon emissions while achieving operational efficiencies.
- Demands from customers, business partners, and supply chain stakeholders for sustainability commitments can impact management engagement.
- The presence of dedicated energy managers or sustainability professionals within a company due to their expertise in energy efficiency, renewable energy, and emissions reduction strategies.

In case of energy auditors or ESCO companies to persuade the top management of a company to design and implement a Decarbonization Roadmap, the following aspects can serve as arguments:

- **Engage in dialogue:** Initiate open and transparent discussions with top management to understand their perspectives, concerns, and priorities. Listen actively, address their questions and doubts, and emphasize the potential positive impact of decarbonization on the company's financial performance and reputation.
- **Building a compelling business case**: Development of a comprehensive presentation of the potential risks and opportunities associated with decarbonization. Presentation of a compelling business case that highlights the long-term benefits, such as cost savings, improved brand reputation and social responsibility, access to new markets, reduced of dependence on external energy sources and mitigated regulatory risks.
- **Align with organizational goals:** Demonstrating how decarbonization aligns with the company's overall mission, vision, and strategic objectives. Showing how it can enhance competitiveness, drive innovation, and create long-term value for the company.
- **Improved working environment:** The decision makers consider and aim to create good working environment, which could lead to improved productivity.
- **Multiple benefits identification and highlight:** The benefits which are not directly related to energy savings and the possible outcomes of implementing the ETA methodology could enhance the companies' management engagement.
- **Demonstrate quick wins:** Start with small-scale decarbonization projects that can deliver quick wins and showcase the benefits of taking actions. Celebrate these achievements and use them as examples to reinforce the importance of decarbonization efforts.
- **EU and national regulations**: Through providing insights into the existing regulations and specifically the ones related to energy audits and the environmental impact of the companies, the managerial staff could be approached.
- **Brand reputation**. Businesses who do not have a plan for how to thrive in a net zero economy will fall behind their competitors and face reputational risk. Maintaining a leading position by

setting a credible net zero strategy ensures that your stakeholders, employees, and clients recognize your company’s contribution to the global emissions reduction challenge. In addition, improving confidence with investors by demonstrating strong sustainability credentials could attract new sources of green investment.

- **Customer & employee expectations**. Increasingly, stakeholders at every level are putting pressure on businesses to take actions toward reducing their waste, emissions, and environmental impact. Present and future employees expect companies to show leadership and bold action on climate change mitigation, biodiversity protection, emissions reductions, and environmental stewardship.
- **Involve top management in decision-making:** Actively involve top management in the decision-making process related to decarbonization. Seek their input and involvement in the development and implementation of carbon reduction initiatives. This will help create a sense of ownership and commitment among top leaders.
- **Educate and raise awareness:** Providing educational resources and conduct awareness sessions to help top management understand the urgency and significance of addressing climate change. Share relevant data, reports, and case studies that highlight the economic, environmental, and social implications of carbon emissions.

3.2. Establishing a decarbonization working group

Establishing a decarbonization group involves bringing together a dedicated team of individuals with the expertise and willingness to drive the company's efforts towards reducing carbon emissions.

Figure 9: Main pillars of a decarbonization working group.

By considering the following aspects, the company could establish a dedicated decarbonization group that will play a crucial role in driving the efforts of company to reduce carbon emissions and transition towards a more sustainable future (Figure 9):

- The management should clearly articulate the **objectives and scope** of the decarbonization group, to determine whether the group will focus on a specific area or encompass the entire decarbonization efforts of company.
- The management will **identify the key stakeholders** who should be involved in the decarbonization group. This may include representatives from various departments such as operations, sustainability, finance, human resources, and technology with relevant expertise, knowledge, and a passion for sustainability and decarbonization.
- The working group should be a **cross-functional team** that represents different areas of the company. This diversity will ensure a holistic approach to decarbonization, with input from various departments and stakeholders. It is also important to select a capable and passionate **individual to lead** the decarbonization group. This person should have the necessary skills to drive the group's initiatives, coordinate efforts, and act as a liaison between the group and top management.
- To ensure a well-coordinated and efficient team, **clear roles and responsibilities** for each member of the decarbonization group should be defined by assigning specific tasks and areas of focus.
- The decarbonization group will be granted the **necessary resources**, including budget, tools, and support, to effectively carry out their initiatives.
- Regular **communication channels** within the decarbonization group to facilitate collaboration and information sharing will be set up. This may include regular meetings, email updates, shared project management tools, or dedicated communication platforms.
- To help ensuring accountability and maintaining visibility of the group's efforts a mechanism must be established to **monitor the progress** of decarbonization initiatives and regularly report outcomes to key stakeholders and top management.
- **Engaging with external stakeholders** can provide valuable insights, best practices, and support for the group's initiatives.
- The company should encourage a **culture of continuous learning** and improvement within the decarbonization group by staying updated on emerging technologies, regulations, and industry trends related to decarbonization, and adjust strategies and actions accordingly.

3.3. Performing preliminary energy scan

In summary, the Preliminary Energy Scan (or Walk-through Audit) involves a simple study of some major equipment and major energy sources, while the Detailed Audit involves a thorough study of practically all equipment/systems and all the energy sources.

For companies considering the implementation of an ETA and having already undergone a conventional energy audit can utilize their existing energy audit as a starting point and build upon that foundation.

For those companies that do not already have an existing energy audit, the Preliminary Energy Scan should focus on the major consumers, covering at least 70% of the total energy consumption. Only the directly available data are used for a simple analysis of the energy consumption profile and performance of the technical systems, therefore it can be completed with limited diagnostic instruments. It is essential to perform a preliminary data collection and analysis to establish a baseline for the decarbonization process.

The Energy Scan does not require measurements and detailed data collection. It is not time-consuming, and results are rather generic and include simple calculations. During the Energy Scan the auditors rely on their experience together with all the relevant written, oral visual information that can lead to a quick investigation of the industry's energy consumption profile, and the identification of opportunities to improve energy efficiency. Audits may deploy minimum resources to simply check for energy saving opportunities, that are readily identifiable and to implement them to achieve savings immediately. It is the simplest type of energy audit and is the most basic requirement of the energy audit. Economic analysis is typically limited to the calculation of a simple payback period through the accomplished energy savings.

Preliminary Energy Scan is a relatively quick practice to:
- Develop the energy consumption profile of the company.
- Identify the energy sources, the cost per source and the emissions per source.
- Examine the possibility of limiting/eliminating the usage of fossil fuels and the installation of RES systems.
- Set the energy baseline, as 'reference point'.
- Identify immediate actions for savings, especially those without or with low-cost.
- Prioritize the areas of attention.
- Detect areas suitable for more detailed study and measurements.

The performance of a Preliminary Energy Scan is essential to assess whether to proceed with a detailed energy audit in industry.

3.4. Energy Transition Audit

3.4.1. Carbon footprint assessment

Performing a carbon footprint assessment for a company involves measuring and analysing the company's CO2 emissions across its operations, including direct and indirect emissions and compute the total CO2 emissions. Considering that the EnTRAINER project focuses more on the first two Scopes, but to the extent that the collected data allows, it could be expanded to include the third Scope as well.

The process on how to conduct a carbon footprint assessment should consider the following aspects:
1. **Set of boundaries and objectives:** Define the boundaries of the assessment, considering all relevant operational activities, facilities, and value chain components. Determine the goal of the assessment, including whether it will cover only direct emissions (Scope 1) or also include

indirect emissions from purchased energy (Scope 2) and emissions from the entire value chain (Scope 3).

2. **Data collection**: Gather relevant data on energy consumption, fuel usage, transportation, waste management, water consumption, and any other activities with the potential to generate CO2 emissions. Ensure data accuracy and consistency by using utility bills, fuel consumption records, financial reports, and other reliable sources.
3. **Identification of emission sources**: Categorize the data into emission sources based on the GHG Protocol's scopes. Common emission sources include combustion of fossil fuels, electricity consumption, transportation, waste generation, and business travel. Identify both direct emissions from owned or controlled sources and indirect emissions from purchased energy.
4. **Calculation of the emissions:** Calculate CO2 emissions using recognized emission factors or emission calculation tools specific to each emission source. Emission factors provide conversion rates to estimate emissions based on the quantity of fuel consumed or energy used. Consider using widely accepted protocols such as the GHG Protocol, ISO 14064, or other relevant industry-specific standards.
5. **Emissions and hotspots analyses**: Analyse the emissions data to identify significant emission sources, emission hotspots, and areas where emissions reduction opportunities exist. This analysis will help prioritize efforts for emission reduction strategies and set meaningful reduction targets.
6. **Benchmarking and comparing**: Compare the emissions data of the company with industry benchmarks or similar organizations to gain insights into its performance and identify areas for improvement. Benchmarking can provide valuable context and help identify opportunities to achieve best practices within the sector.
7. **Report and disclose**: Prepare a summarizing report that summarizes the carbon footprint assessment findings, including emission inventories, emission sources, and hotspots.

3.4.2. Opportunity Identification

To identify the existing opportunity available in the external environment, the working group should identify the relevant stakeholder which can be involved in the company's decarbonization process.

The main steps for opportunity identification are:

1. Organizing a **workshop** involving important stakeholders to create a process or business flow.
2. Creating a schematic for a **process or business flow**.
3. Identifying opportunities for **enhancing efficiency and technology**, typically with lower capital requirements.
4. Exploring options for significant **process changes or transitioning to alternative fuels and/or energy carriers**, often involving higher capital investments.

3.4.3. Setting a Goal/Reduction Target

Identifying a carbon footprint and announcing a reduction target is an important first step in developing a Decarbonization Roadmap and involves establishing specific and measurable objectives to reduce carbon emissions within a defined timeframe.

Process on how to set a decarbonization target is:

1. **Assess the baseline:** Determine the current carbon emissions of the company obtained during the comprehensive carbon footprint assessment. This will serve as the baseline against which progress will be measured.
2. **Consider science-based targets**: Generally, science-based target setting methods have three components: a carbon budget, which defines the overall amount of CO2 that should be emitted, an emissions scenario, defining the magnitude and timing of emissions reductions and an allocation approach, defining how the carbon budget is allocated to individual companies.
3. **Determine the target scope:** Decide whether the target will focus on specific emission sources or cover the entire company's emissions. It could include direct emissions (Scope 1), indirect emissions from purchased energy (Scope 2), and (if decided that way) emissions from the value chain (Scope 3).
4. **Set an ambitious yet achievable target**: Consider the company's current emission levels, available resources, industry benchmarks, and the urgency to address climate change. Set a target that is both ambitious enough to drive significant change and feasible to achieve within the chosen timeframe.
5. **Define the target type**: Determine the type of target that will be set. It can be an absolute target, aiming for a fixed reduction in emissions, or an intensity-based target, which focuses on reducing emissions per unit of activity (e.g., emissions per unit of revenue or production).
6. **Establish the time frame**: Define the timeframe within which the target will be achieved. Consider long-term goals as well as intermediate milestones to track progress and maintain momentum.
7. **Consult internal stakeholders:** Engage relevant stakeholders, including internal departments, senior management, sustainability teams, and external experts, to gather input and ensure alignment with organizational priorities. Seek their perspectives on target feasibility and potential strategies to achieve it.
8. **Determine the reduction pathway:** Develop a roadmap or plan outlining the strategies and actions required to reach the target. Identify specific initiatives, such as energy efficiency measures, renewable energy adoption, supply chain optimization, or process improvements. Consider collaborating with suppliers and partners to address Scope 3 emissions.
9. **Define KPIs** and metrics to measure emissions reductions regularly.

Setting a decarbonization target requires careful consideration of the emissions of the company, industry context, available resources, and stakeholder input. By following these aspects, a company can establish a clear and meaningful target to guide its decarbonization efforts and contribute to a sustainable future.

3.4.4. Decarbonization action plan →Decarbonization roadmap

Transposing a decarbonization action plan into a decarbonization roadmap involves taking the specific actions identified and organizing them into a structured timeline and framework. As a result, the company will have a structured framework that outlines the timeline, responsibilities, and resources required for successful implementation. This roadmap will serve as a guide for driving progress and achieving the desired emissions reduction targets.

The steps to transpose the action plan provided by an Energy Transition Audit into a Decarbonization roadmap should be as follows:

Review of Decarbonization Action Plan (DAP)	• Assess the feasibility, effectiveness, and alignment of these actions with the company's goals and targets. • Assess whether these targets are specific, measurable, attainable, relevant, and time-bound (SMART). • Ensure that they are aligned with the company's overall decarbonization objectives and any external commitments or regulations.
Prioritizations of the actions	• Prioritize the identified actions based on their importance, potential impact, feasibility, and interdependencies. • Consider the sequence in which actions need to be implemented, considering any dependencies or prerequisites for certain initiatives. • Assess the cost-effectiveness of each action by considering the potential emissions reduction achieved relative to the resources required for implementation. Prioritize actions that provide substantial emissions reductions while optimizing resource allocation.
Establish Timelines	• Assign estimated timelines or deadlines to each action or milestone within the roadmap. This could include start dates, completion dates, or specific timeframes for different phases of implementation. • Ensure that the timelines are realistic and achievable. These may include specific milestones, timelines, responsible parties (groups), resource allocation, metrics for tracking progress, and any external factors or dependencies that need to be considered.
Allocate Resources	• Determine the necessary resources, including financial, technological, and human resources, for implementing each action. • Assess the budget and funding requirements for each initiative and allocate resources accordingly.
Consider Dependencies and Constraints	• Consider any dependencies or constraints that may impact the implementation of certain actions. These could include regulatory requirements, availability of technology or expertise, stakeholder engagement, or external factors such as market conditions or policy changes.

Develop Tracking Mechanisms	• Establish KPIs and metrics to track the progress of each action and the overall decarbonization efforts. • Determine how progress will be measured and reported and establish a system for regular monitoring and reporting. Regularly review and refine the decarbonization roadmap as new information becomes available or circumstances change. • Continuously assess progress, evaluate the effectiveness of actions, and adjust as necessary to ensure alignment with goals and objectives.

3.5. Implementation - Energy Transition Pathway

The company should consider its internal strategies and guidelines to determine the best way to proceed with the implementation of the decarbonization action plan. These strategies may involve budget allocation, resource allocation, project prioritization, and alignment with organizational goals.

Visual representations, such as Gantt charts, timelines, or other graphical formats, should be created to present the roadmap for decarbonization (Figure 10). These visuals clearly illustrate the sequencing and interdependencies of the planned actions, making it easier for involved persons to comprehend the plan and provide their support.

			-60% Scope 1 & 2		-40% Scope 3
	2025	**2028**	**2030**	**2035**	**2040**
Energy Supply	• Local compensation of reactive energy at the level of the transformer stations. S2	• PV panels for self consumption. S2	• Replacing one of the conventional gas boilers with a 1000 kWel CHP unit. S1 S2	• Changing electricity supply to high voltage level by constructing a new substation. S2	
Production Processes	• Thermal insulation and sealing of APC and APH furnace components. S1 • Insulation of steam trans-port and distribution valves. S1	• Residual heat recovery from hot exhaust gases at APC and APH. S1		• Replace Production Line 3 with new clear technology. S2	
Automation Systems	• Adjustments of process parameters at the ZM level, in correlation with the specific energy consumption recorded. S2 • RPM adjustment and on/off operation of oil cooling pumps when changing rollers for ZMs. S2	• Replacement of automation panels with converters and electric drive at ZM1 S2			
Buildings		• Install a Air-to-Water Heat Pump for Domestic Hot Water. S1 S2	• Changing building envelope to reach nZEB standards for adminis-trative buildings. S1 S2		
Other	• Stimulating operators to use proposal sheets for improving processes and increasing energy efficiency, through periodic campaigns. S1 S2	• Add to Work Plan actions at the departmental level and in management meetings and the Sustainable Energy topic. S1 S2			• Buy Carboon Offsets. S1 • Change to greener suppliers. S3

• S1 – Scope 1 • S2 – Scope 2 • S3 – Scope 3

Figure 10: Example of decarbonization strategy representation.

Effective communication of the decarbonization roadmap is crucial. The company should engage with relevant stakeholders, including employees, management, investors, and external partners, to ensure their understanding and buy-in. By effectively communicating the benefits of the plans and demonstrating its feasibility through visual representations, stakeholders can be more engaged and supportive to the decarbonization efforts.

3.6. Continuous Improvement

A key trait of the DRM is iteration, creating continuous improvement. It is a living and breathing document that will need to be amended to reflect changes in the company’s business, technology, or the operational environment.

Conducting a periodical strategic review can reveal that certain opportunities have generated higher savings than anticipated, while others may have fallen short. This assessment might lead to changes in the company's operational approach or target markets. Furthermore, as renewable technologies continue to witness substantial investments across various industries, the evolving landscape can redefine what constitutes best practices in a rapidly changing environment. It is important to consider and address these factors from the Decarbonization Action Plan to achieve optimal carbon-related outcomes and, equally importantly, favourable economic results within the DRM. It is also needed to regularly update and report the carbon footprint on an annual basis, taking full advantage of the enhanced data collection methods that have been implemented. This may involve modifying existing actions, adding new initiatives, or realigning priorities to ensure the plan remains relevant, effective, and aligned with organizational goals and external developments.

Hence, it is important to motivate the company to undertake such actions by considering the following key aspects, which embody the fundamental principles of sustainability:

Periodical review of DRM

- Decarbonization Roadmap should be periodically reviewed to assess its progress and effectiveness.
- This review process involves evaluating the implementation of actions, tracking the achieved outcomes, and identifying any gaps or areas for improvement.

Feedback mechanisms

- Establish feedback mechanisms that allow stakeholders to provide input, suggestions, and observations regarding the decarbonization initiatives.
- Encourage open communication and collaboration to gather insights from employees, suppliers, customers, and other relevant parties.

Performance evaluation

- Conduct thorough evaluations to measure the performance and impact of the implemented actions.
- Assess the progress made towards emissions reduction targets, analyze data and metrics, and identify areas where adjustments or enhancements are required.

Incorporate lessons learned

- Learn from successes and challenges encountered during the implementation of the action plan.
- Capture and document lessons learned to avoid repeating past mistakes and capitalize on effective strategies. Use these insights to refine future actions and approaches.

Technological advancements

- Keep abreast of emerging technologies, scientific advancements, and industry best practices in decarbonization.
- Regularly assess the suitability of new technologies and innovative solutions that can enhance the effectiveness and efficiency of emissions reduction efforts.

Evolving regulatory landscape

- Stay informed about evolving regulations, policies, and market mechanisms related to decarbonization.
- Monitor changes in carbon pricing, emissions trading schemes, or government incentives that can influence the strategic direction of the action plan. Ensure compliance with new requirements and seize opportunities that arise.

Benchmarking and collaboration

- Engage in benchmarking exercises to compare the organization's performance and progress against industry peers or leaders.
- Identify areas where the company can learn from others or collaborate on joint decarbonization initiatives to achieve mutual benefits and accelerate progress.

Set stretch goals

- Continuously challenge and set stretch goals within the decarbonization action plan.
- Encourage ambitious targets that push the boundaries of emissions reduction efforts. This drives innovation, fosters creativity, and promotes a mindset of continuous improvement throughout the company.

3.7. Certification

Decarbonization certification refers to the process by which companies or organizations are formally recognized and certified for their efforts and achievements in reducing carbon emissions and transitioning to a low-carbon or carbon-neutral state. These certifications provide credibility and assurance to stakeholders, demonstrating a commitment to environmental responsibility and sustainability.

In some cases, the end goal of this process is obtaining formal certification. Pursuing a Carbon Roadmap and obtaining certification are entirely independent processes, and there is no reason why they cannot be run in parallel. Many businesses are now choosing to do both.

Certification schemes related to decarbonization may exist at different levels, such as national, regional, or industry-specific initiatives, each with its own specific criteria and standards. Some commonly recognized certifications include:

1. **Carbon Neutral Certification**: This certification confirms that a company or organization has achieved net-zero carbon emissions by offsetting or balancing their carbon footprint through activities such as investing in renewable energy projects or supporting carbon sequestration initiatives.

2. **Carbon Disclosure Project (CDP)**: CDP is a global platform that assesses, and rates companies based on their disclosure and management of climate-related risks and opportunities. CDP certification signifies a company's transparency and proactive approach in addressing climate change.

3. **ISO 14001: 2015** is an internationally recognized environmental management standard. It certifies that a company has implemented an effective environmental management system, including measures to reduce GHG emissions and mitigate environmental impacts.

4. **LEED Certification**: LEED (Leadership in Energy and Environmental Design) certification is specific to the building and construction industry. It evaluates the environmental performance and sustainability aspects of buildings, including energy efficiency, water conservation, and emissions reduction.

5. **Science-Based Targets** (SBT): The Science-Based Targets initiative ensures that a company's emissions reduction targets align with the latest climate science and contribute to keeping global temperature rise well below 2 degrees Celsius. SBT certification confirms that a company's emissions targets are scientifically credible.

These certifications, among others, provide tangible evidence of a company's commitment to decarbonization and sustainability. They can enhance the company's reputation, attract environmentally conscious customers, investors, and partners, and demonstrate compliance with regulatory requirements or industry best practices.

4. Concluding remarks

EnTRAINER project introduces a paradigm shift from conventional energy audits to a new, holistic, and complete methodology of Energy Transition Audits. This innovative approach prioritizes a multi-benefit framework and delivers a comprehensive action plan aimed at achieving complete decarbonization of the audited sites.

This report serves as a deliverable for WP2 *Paradigm shift towards a holistic energy transition audit methodology*, which focuses on the development of methodology for ETA actions.

Deliverable D2.2 *Decarbonization roadmap*, tested and improved through the implementation of the ETA actions within EnTRAINER WP3, and the training activities in WP5.

An enhanced and more comprehensive version of this deliverables will be furnished by the conclusion of the EnTRAINER project implementation.

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