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Market monitoring and analysis

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EXECUTIVE SUMMARY

The Task 6.1 foresees the realization of a detailed analysis of the markets that will be associated with GICO products and services.

The Deliverable 6.4 is related to task T6.1: Market analysis. The main goal of deliverable D6.4 is to perform a comprehensive market analysis based on a SWOT analysis, a PESTLE analysis aimed at collecting data on market needs, identify the full range of potential customer segments, opportunities, and threats for the positioning of the innovative project on the market.

The market analysis will be performed to identify the optimal system sizes within the related CHP markets for a significant exploitation of the results in real environment. Sector needs, current practice, and trends for future developments in and outside Europe will be investigated, as well as market structure, agents, and world market information.

The analysis will be performed with this approach:

a) General market study that includes a PESTLE analysis which is applied to characterize the Political, Economic, Socio-Cultural, and Technological factors and changes to understand the general environment;
b) Market Porter's analysis for GICO innovative exploitable results and objective markets to determine the level of competition expected and support business model development;
c) Evaluation of the specific market environment: a SWOT analysis (strengths, weaknesses, opportunities, and threats) to identify the internal and external factors that are favorable and unfavorable for commercial exploitation.

This report is composed of the following parts:

- **Chapter 1 Introduction:** quotes a brief introduction on biomass, biofuels, gasification and syngas definitions and related characteristics;
- **Chapter 2 Market analysis and potential:** description of the package of technologies that is developed in the GICO project, the potential market and market size;
- **Chapter 3 PESTLE analysis**: Political, Economic, Socio-Cultural, and Technological factors and changes to understand the general environment;
- **Chapter 4 Market Porter's analysis:** analysis aimed at understanding the level of market competitiveness which is manifested by five forces in the company's microenvironment (i.e. threat of substitute products or services, threat of established rivals, threat of new entrants, the bargaining power of suppliers and the bargaining power of customers) that determine the profitability of a business;

- **Chapter 5 SWOT analysis:** analyses to evaluate company/innovation internal strengths and weaknesses against external opportunities and threats to recognize their competitive advantages;
- **Chapter 6 Conclusion:** quotes a comprehensive discussion and outlook;
- **Chapter 7 References:** quotes the references of all the report.

This deliverable is the starting point for Task 5.3 (LCA, LCC and S-LCA). Continuous market monitoring is applied to detect new trends and possibilities and allow the consortium to react and adapt the projects' outcomes to the market changes. Towards the end of the project (M44), the states of development achieved (proof of principle/concept, prototype etc.) of the studied GICO innovations is compared to the progress of any competing technology.

1. INTRODUCTION

This chapter introduces the market analysis through a brief technical and economic description of biomass and bio-residues, gasification, syngas, and bio-syngas produced by Renewable Energy Source (RES), biofuels and in particular methanol produced by RES or CO_2, gasification, and cogeneration.

The GICO activities aim at developing small to medium scale residual biomass Multigeneration plants (2-20 t/day and 500-5.000 kWe, compatible with the standard residual biomass availability of few thousand tons per year) able to overcome the main barriers that prevent renewable energy technologies from forming the backbone of the energy system. GICO develops new materials (CO_2 capture sorbents; high temperature inorganic removal sorbents; catalytic filter candles; membranes for oxygen separation and methanol production) and technologies (Hydrothermal Carbonization; Sorption Enhanced Gasification; Hot Gas Conditioning; Carbon Capture, Storage and Use; Power To Gas via Plasma conversion).

The GICO system will be able to:

- produce intermediate solid (5 €/MWh vs 15 €/MWh), gaseous high quality **BioSyngas** (10 €/MWh vs 30 €/MWh with zero particulate and ppb contaminants level) and bioenergy carriers from residual biomass;
- capture CO_2 (CCS) (40 €/t vs 90 €/t) receiving waste with high alkali content and producing (Carbon Capture Utilisation) bricks and convert CO_2 to CO and O_2 (90% vs 10% efficiency) storing renewable electricity excess **(Carbon Capture Storage Utilisation);**
- produce renewable biofuel: **bio-methanol** (35€/MWh vs 75 €/MWh);
- produce **renewable electricity** (100 €/MWhe vs 220 €/MWhe for electricity) and **renewable heat.**

1.1. Residual Biomass

The general definition of biomass (from dictionary, i.e., from first documents in 1930-1980) is "organic matter (available on a renewable basis) that can be converted into energy" (different from biomass in ecology where it encompasses all the organic matter in each habitat). More in detail, Directive (EU) 2001/77/EC on the promotion of the use of energy from renewable sources (always Article 2 Definitions, after repeated in Directives 2003/54/EC repealed by 2009/30/EC on biofuels and used by 2014/94/EU on alternative fuels infrastructure; and repeated in Directives 2003/54/EC repealed by 2009/28/EC and amended by 2018/2001) on RES [1] states that biomass refers to "the biodegradable fraction of products, waste and residues from biological origin from agriculture including vegetal and animal substances, from forestry and related industries, including fisheries and aquaculture, as well as the biodegradable fraction of waste, including industrial and municipal waste of biological origin".

Biomass is the fourth largest energy resource in the world (after oil, coal, and natural gas) and according to this definition includes a wide range of materials, such as, among others, wood chips and sawdust, straws, agricultural and forestry residues, municipal organic waste, bagasse generated in the agro-food industry, manures, sewage sludge, digestates, black liquor from the paper mill, etc. Indeed, they display very diverse morphological, structural, and physicochemical characteristics.

The RED II Directive 2018/2001 of 11 December 2018 is operative starting from 1st July 2021 for the biofuels, bioliquid and biomass fuels (i.e., gaseous, and solid fuels produced from biomass). In this directive, the definition of residues and waste can be found at the art.2:

- waste which means waste as defined in point (1) of Article 3 of Directive 2008/98/EC, excluding substances that have been intentionally modified or contaminated in order to meet this definition;
- residue which means a substance that is not the end product that a production process directly seeks to produce, not being a primary aim of the production process that has not been deliberately modified to produce it;
- agricultural, aquaculture, fisheries and forestry residues which means residues that are directly generated by agriculture, aquaculture, fisheries, and forestry and that do not include residues from related industries or processing.

Feedstocks produced from biomass wastes and residues for conversion to advanced biofuels may be considered in five separate categories (IEA):

- Wastes - materials which have no other useful purpose, and which otherwise have to be managed, usually incurring a cost.
- Processing residues and by products which arise part of an industrial process and are already available and pre-processed in quantity at a particular site (including for example sawdust to be used for pellet production or sugar bagasse).
  Locally collectable residues which are produced as part of a harvesting procedure, but which are dispersed, and which must be collected and brought to a central point and processed before they can be used, such as cereal straw, agricultural pruning, forestry residues or sugar cane straw.
- Internationally traded feedstocks, such as wood pellets, based on raw materials available at an industrial site, which are extensively processed to improve the energy density and then transported long distances to supply large scale conversion plants.
- Primary crops: grown principally to provide food, animal feed or other products which can also be used for energy production such as corn, sugar, and vegetable, with prices determined by commodity markets. Such crops often provide both an energy feedstock and a valuable by-product such as DDGS or press cake for animal feed. Energy crops may also be produced as part of a rotation scheme, thereby not affecting the food and feed production of the same land, or by using low-intensity cropping on marginal land no longer in active use by farmers. In these cases, all the production, harvesting, and pre-treatment costs must be met by the off-taker.

A second classification divides the Residual Biomass into primary or secondary residues:

- Primary residues are solid vegetal residues left in the field after harvest or pruning and manure;
- Secondary residues are the portion discarded during the processing phase (olive pits, nutshelling etc). Although they consist in a promising feedstock for bioenergy use and, in general, for EU bioeconomy, they are currently underutilised mainly because of logistics constraints and lack of incentives.

The following table presents a non-exhaustive list of primary and secondary agrobiomass feedstocks [OECD/IEA Report Sustainable production of biofuels] along with technical requirements for harvesting, benefits of mobilisation and seasonality.

Table 1 Primary and secondary biomass residues characteristics

Feedstocks examples	Harvesting requirements	Benefits of mobilisation	Seasonality
Straw, corn stover	Existing agriculture machinery (e.g., Baler)	No additional land required, considerate collection prevents pests, paying attention not to decrease SOC.	During crop harvesting season
Pruning	Agricultural machinery, usually modified for pruning	No additional land required, avoidance of pests / diseases, avoidance of emissions from open field burning In the case of pruning removals, harvesting and sale (or on-site use) significantly decreases management costs.	After the pruning season (usually winter – spring)
Plantation removal wood	Excavators, large shredders, etc.	No additional land required, clear-up of field for new plantations, avoidance of disposal costs	At the end of an orchard's lifetime
Pits and residues from crushing from olive shells/husks from seed/nut shelling, grape marc	No additional technical equipment; no additional infrastructure	By-Product; no additional land required; concentrated at processing site (no collection costs); avoids disposal costs (e.g., landfilling)	Year round

Biomass has many advantages as feedstock for energy generation. It is renewable, safe, and clean and produces little waste. It is continuously generated as a result of human, animal and plant activity, so its availability is assured. In addition, its price is lower than that of other fuels and the balance of CO_2 emissions to the environment is neutral if used in sustainable way. Not least, its use for energy provides additional economic and social benefits by simultaneously disposing degradable and pollutant wastes.

Nevertheless, the energy use of the organic substances is limited, to some extent, by their complexity, and low energy density, resulting therefore less efficient than fossil fuels. Additionally, the supply chain presents shortcomings because distribution channels are not yet as widespread as for other fuels. It should not be overlooked that biomass requires more space than other fuels and the storage and high local emissions of pollutants may be limiting drawbacks to be applied for bioenergy [2].

The use of biomass residues as feedstock would solve the long-standing drawback associated with the use of biomass as an energy source, i.e. competition with food, and would facilitate the simultaneous disposal and valorisation of highly degradable wastes. To fully exploit the biomass energy, small scale plants offering high reliability and efficiency and low environmental impacts must be developed, to overcome the low energy density and perishability of this fuel.

Indeed, the technical and economic potentials of biomass are higher than the current world energy consumption, thus, the challenge is in its viable and sustainable use and not in its availability (as long as there is life there will be availability of organic material, used "directly" by living organisms as their own source of energy and materials (food) or used "indirectly" like a source of external energy (biomass) and materials: (clothing, furniture, buildings, chemicals, etc.) [2,3]. Using biomass wastes as feedstock in reliable, efficient and low emissions micro to medium plants (as gasification-fuel cells) would solve all the old-actual drawbacks associated to biomass utilization as energy source (i.e. competition with food and materials avoided owing to the waste nature; low energy density and perishability not important owing to the micro to medium scale; low cost and emissions owing to the high efficiency and low emissions gasification-fuel cells coupling) [4].

The Joint Wood Energy Enquiry (JWEE) and the National Renewable Energy Action Plan (NREAP) progress reports provide information on the supply and use of woody biomass for energy estimated quantities (volume of weight).

Different biomass residues with large availability and low cost has been selected (description in DL2.1); under the aim of GICO they will be fully characterised and pre-treated in order to avoid detrimental effects on GICO (e.g. sorbents, catalyst and membrane): this will allow to widen the type of feedstocks that can be used developing solid intermediate bioenergy carriers with 5 €/MWh cost, including high humidity and ash content residual biomass and waste that, normally, are the one with greater potential and lower cost, so reaching applicability to around 678 Mt/y of EU residual biomass (i.e. around 2000 TWh that can produce around 30% of total electricity or 40% of total transport EU final energy consumptions).

Renewable energy in 2016 made up to 17% of the gross final energy consumption of the EU. Bioenergy constituted 59,2% of all renewable sources, and more than 60% of EU domestic biomass supplied for energy purposes was wood-based [4]. Heating and cooling represent about 75% of the bioenergy from biomass used in the EU today. The highest projections of the long-term strategy foresee an increase in bioenergy consumption by around 80% by 2050, compared with today. The strategy also shows that, especially regarding woody biomass, the current EU production trends would be insufficient for covering all future EU needs, so imports will likely be increasingly necessary [5].

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The primary energy processes of biomass can be divided into three main categories, according to the conversion pathways adopted: [6]

- Thermal: conversion using thermal energy (combustion; pyrolysis; gasification);
- Biological: conversion using microbial or enzymatic activity (aerobic and anaerobic digestion, fermentation);
- Mechanical: conversion using mechanical energy (oil extraction).

The direct combustion of solid biomass can supply only heat, which is converted into electricity at a low efficiency: a solid fuel is burned with low efficiency, and, only at large scale, it produces steam suitable for a Steam Turbine. The other processes transform the chemical energy of biomass into chemical energy of solid (low temperature pyrolysis e carbonization), liquid (fast pyrolysis, fermentation, oil extraction) and gaseous (gasification, anaerobic digestion) fuels. Three main conversion processes can be employed to produce fuel gas from biomass:

- Anaerobic digestion: is the conversion of biomass to primarily methane (CH_4) and carbon dioxide (CO_2) by micro-organisms in the absence of oxygen (typically between 10°C and 60°C).
- Pyrolysis: is the thermal decomposition (typically above 300 °C) of biomass in the absence of oxygen. The major products are char, bio-oil and gas that mainly contains CH_4, CO_2, carbon monoxide (CO) and hydrogen (H_2).
- **Gasification:** is the thermal decomposition (typically above 650°C) of biomass in the presence of gasification agents (e.g. air, oxygen, steam, CO_2, or a combination of them) that transforms the biomass into so-called bio-syngas that contains CO, H_2, CH_4, steam, CO_2, light hydrocarbons and, in case of air gasification, nitrogen (N_2). The fuel gas may contain a certain amount of impurities, e.g. tar, particulate matter, char, hydrogen sulphide (H_2S), hydrogen chloride (HCl) and ammonia (NH_3).

The GICO processes related to the gasification to produce syngas, electric and thermal energy (cogeneration) and biofuels are described in this deliverable.

1.2. Gasification

The gasification of biomass consists in its thermal decomposition (typically above 650 °C) in the presence of gasification agents, e.g. air, oxygen, steam, CO_2 or a combination of these.

Gasification does not need high (e.g. days as in anaerobic digestion) but low (e.g. seconds) residence time, and so have compact plants, furthermore, respect to other conversions, it offers high carbon conversion efficiency (e.g. 90% respect to 50% of anaerobic digestion) and flexibility by using different kind of feedstocks, including agricultural, forest, industrial residues and the biogenic fraction of municipal solid waste, like those addressed by GICO.

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Such a process transforms the biomass into the so-called bio-syngas. **Bio-syngas** (Bio Synthesis Gas) in fact is a mixture comprising hydrogen, carbon monoxide, carbon dioxide, and methane.

Air is the most used gasifying agent, due to the great availability and zero cost, but the large amount of nitrogen not only requires higher power on blowers and bigger equipment but especially lowers the heating value of the syngas produced. Pure O_2, avoiding the nitrogen content, increases the syngas heating value but also the operating costs due to the O_2 production. Steam, due to the great availability and about zero cost of water, increases the heating value and H_2 content of syngas, and can be produced using the excess of heat of the power plant [7]. Steam is a favourable gasification agent because it is available and at low cost as air but, as pure oxygen, it does not dilute (50% N_2) the gas (requiring higher blowers power, wider tubing and generating lowers HV syngas: 3-5 instead of 10-15 MJ/Nm^3) and maximizes the yield of hydrogen.

The type of solid feedstock has a significant impact on the best performing gasification technology: suitable biomass is typically characterised by significant scale availability (a few dozens to thousands t/year) and low cost (negative to maximum 100 €/t), but also by good physical (low water content and high bulk density) and chemical properties (high calorific value and carbon-to-nitrogen ratio, remarkable presence of volatile substances and low ash, chlorine and sulphur content).

Fluidized and Rotary bed gasifiers provide an intensive contact between the gas and the solid biomass which results in high reaction rates and carbon conversion efficiencies. Overall, this allows flexibility with respect to the feedstocks specification and thus the possibility to gasify a large variety of biomass, including low quality biogenic residues (e.g. OFMSW, digestate, sewage sludge). Biomass gasification is globally an endothermic process, so that it requires burning part of the fuels to allow auto-thermal process, but this can be done, without compromising the gas quality, recirculating hot material from a combustor (burning unreacted char) to the gasifier (indirectly heated gasification realised via double reactor configuration). Sorption Enhanced Gasification allows the sorbent regeneration and then reused within the cyclic process: the gasifier also become carbonator (e.g., $CaO+CO_2 \rightarrow CaCO_3$) and the combustor also calciner ($CaCO_3 \rightarrow CaO+CO_2$). Calcium oxide (CaO) is cheap and abundant. Additionally, CaO has the vital roles of not only CO_2 sorbent, but also tar cracking catalyst and bed material-based heat carrier. Removing CO_2 from the gasification reaction as soon as it is formed alters the equilibrium composition of the produced gas and promotes the production of gas rich in hydrogen. Similarly, it favours tar reforming, so not only reducing the tar amount in the product gas but also enhancing the yields of total gas and hydrogen as well as conversion efficiency. Hence, in order to create the crude energy feedstock basis, the SEG development plays a key role as backbone of the renewable energy vectors by 2030 and 2050. The

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new technologies developed in GICO, focused on residual biomass Steam Sorption Enhanced Gasification, can treat material with high humidity content (up to 50%), low ash melting temperature (the optimal gasification temperature, owing to the CO_2 sorption, is set around 650 °C), higher tar, sulphur and chlorine content. [8]

1.3. Syngas

Syngas, or synthesis gas, is the end-product of heating carbonaceous material with a limited amount of an oxidizing agent, typically oxygen, air, or steam; the process is called gasification. Most of the fuel energy in syngas is derived from its CO and H_2 content which are the main gas components; although with a significantly lower share, the contribution to the syngas energy content can also arise by CH_4 and light hydrocarbons (e.g. ethane, ethene and ethyne). When the starting material of gasification is considered renewable (e.g. woody and agricultural residues, organic fraction of MSW) it takes also the name of **Bio-syngas** to better emphasize the nature of the feedstock of origin.

Syngas composition varies widely with the biomass type and gasifier conditions. Typical composition of syngas produced by a gasifier using air as the oxidizer is by volume 18–20% H_2, 18–20% CO, 2% CH_4, 11–13% CO_2, traces of H_2O and balance N_2 [9]. The lower heating Value (LHV) of carbon monoxide is 10 MJ/kg, the LHV of hydrogen is 120 MJ/kg [10]. Thus, any process that generates syngas aims at maximizing the amount of carbon monoxide and hydrogen expressed in % by volume and the molar ratio of hydrogen to carbon monoxide in order to achieve a gas with as high as possible energy content. Typical LHV values of syngas produced in a gasifier using air or air/steam as the oxidizing agent are 4-6 MJ/kg [11]. Typical LHV values for gasoline and diesel fuel are 31.9 MJ/kg and 43 MJ/kg, respectively [12].

Based on the literature that has been reviewed in order to assess the feasibility of connecting a SOFC to a steam gasifier, it can be concluded that the longevity of the SOFC is likely to be at risk if no further gas cleaning will take place. Particularly problematic gas compounds are tars, sulphur, halogens (chlorine), and alkali metals (sodium and potassium). A gas conditioning system is always necessary before to exploit the producer gas into a power system. These systems normally have encumbrance and cost even greater the gasifier unit; they can be regarded as the unavoidable secondary unit in a gasification power plant.

The gas conditioning technologies can be primarily divided following the physical apparatus where they are applied:

- **pre-treatment conditioning**: (hydrothermal carbonization (HTC) in GICO): feedstock pre-treatments are generally aimed at improving the physical-chemical characteristics of the

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feedstock; indirectly, this can also lead to beneficial effects on the produced gas, particularly in terms of contaminant content;

- **primary conditioning** in the gasifier reactor: introducing a catalyst in the bed material during gasification brings a change in product gas composition, a decrease in tar amount, an increase in hydrogen and CO_2 production, and a decrease of CO, an overall increase in the gas yield. Ni-based catalysts, calcined dolomites, magnetite, and olivine promote char gasification, improve the product gas composition, and reduce the tar yield (High temperature inorganic removal sorbents, and Sorption Enhanced Gasifier (SEG) technology in GICO);
- **secondary conditioning** downstream the gasifier reactor (Hot Gas Conditioning (HGC) + Plasma enhanced catalytic oxidation PECO in GICO). The secondary methods can be subdivided into two main categories based on the working temperature: Cold and Hot methods.

Several biowaste pre-treatment technologies, which convert biomass into a coal-like substance by chemical processing, have been suggested: hydrothermal carbonization (HTC) is one of these. Hydrothermal carbonization, sometimes referred to wet torrefaction, is an artificial coalification process which takes place in hot pressurized water between 175 °C and 250 °C. It involves hydrolysis, decarboxylation, dehydration, condensation, and aromatization reactions.

GICO will use HTC on this biowaste evaluating optimal conditions (temperature and residence time) for the increase in energy density and reduction in humidity and ash and for, in a feedback procedure, the decrease in organic (tar) and inorganic (e.g. S, Cl) contaminants level of the SEG subsequent process in order to bring biomass with high humidity, ash and inorganic at least to the levels of the ”good” biomass.

1.4. Biofuels and Methanol

The biomass can be converted into liquid fuels, called “biofuels,” to help meet transportation fuel needs. The most common types of biofuels in use today are ethanol, biodiesel, and methanol, both of which represent the first generation of biofuel technology.

Ethanol (CH_3CH_2OH) is a renewable fuel that can be made from various lignocellulosic biomass feedstocks. Ethanol is an alcohol used as a blending agent with gasoline to increase octane, or plain in vehicles with specific designed engine, to cut down carbon monoxide and other smog-causing emissions.

The most common blend of ethanol is E10 (10% ethanol, 90% gasoline). Some vehicles, called flexible fuel vehicles, are designed to run on E85 (a gasoline-ethanol blend containing 51%–83% ethanol, depending on geography and season), an alternative fuel with much higher ethanol content than regular gasoline. Roughly 97% of gasoline in the United States contains some ethanol.

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Biodiesel is a liquid fuel produced from renewable sources, such as new and used vegetable oils and animal fats and is a cleaner-burning replacement for petroleum-based diesel fuel. Biodiesel is nontoxic and biodegradable and is produced by combining alcohol with vegetable oil, animal fat, or recycled cooking grease.

Like petroleum-derived diesel, biodiesel is used to fuel compression-ignition (diesel) engines. Biodiesel can be blended with petroleum diesel in any percentage, including B100 (pure biodiesel) and, the most common blend, B20 (a blend containing 20% biodiesel and 80% petroleum diesel).

Methanol is a key product in the chemical industry. It is mainly used for producing other chemicals such as formaldehyde, acetic acid, and plastics. Around 98 million tonnes (Mt) are produced per annum, nearly all of which is produced from fossil fuels (either natural gas or coal). Bio-methanol is produced from biomass [13]. The e-methanol is obtained by using CO_2 captured from renewable sources (bioenergy with carbon capture and storage and direct air capture, i.e. hydrogen produced with renewable electricity).

The methanol produced by GICO system will be Bio-methanol deriving from CO_2 recovered from residual biomass gasification plants. This makes it competitive with respect to current methanol and will allow for a significantly lower production cost (33 €/MWh vs 75 €/MWh).

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1.5. Cogeneration (CHP)

Combined heat and power (CHP) represent a very efficient use of biomass (> 80% of potential energy). These facilities capture the waste heat and/or steam from biopower production and pipe it to nearby buildings to provide heat or to chillers for cooling.

Cogeneration indeed provides:

- Decentralized generation (DG) of electrical and/or mechanical power;
- Waste-heat recovery for heating, cooling, or process applications;
- Seamless system integration for a variety of technologies, thermal applications, and fuel types into existing building infrastructure.

Syngas can be used as a fuel in a wide range of potential systems:

- Steam turbines: convert steam energy from a boiler or waste heat into shaft power.
- Gas (combustion) turbines, including microturbines: use heat to move turbine blades that produce electricity;
- Internal combustion engines (ICE) —Operate on a wide range of liquid and gaseous fuels but not solid fuels. The reciprocating shaft power can produce either electricity through a generator or drive loads directly;
- Stirling engines: operate on any fuel and can produce either electricity through a generator or drive loads directly;
- **Solid Oxide fuel cells (SOFC):** produce an electric current and heat from a chemical reaction rather than combustion. They require a clean gas fuel or methanol with various restrictions on contaminants;
- Polymer electrolyte membrane (PEM) fuel cells: it can also be treated to separate the hydrogen from the gas, and the hydrogen can be burned or used in fuel cells (PEM).

The CHP are divided in three main dimensions in relation to the electric production:

- **micro-cogeneration** unit means a cogeneration unit with a maximum capacity below 50 kWe.
- **Small scale cogeneration**: As per directive 2004/8/EC of 11 February 2004 on the promotion of cogeneration, “small scale cogeneration” means cogeneration units with an installed capacity below 1 MWe;
- **medium and large-scale CHP** installations with an electrical output > 1MWe: concern mainly the medium-large industrial sector and the electricity generation sector combined also with District Heating networks, which is a common practice in several European countries.

Typical fields of application for small-scale biomass CHP plants are wood-processing industries and sawmills, district heating systems (newly erected or retrofitted systems) as well as industries with a high process heat demand. These applications represent a great market potential in Europe. Due to the relatively low electric efficiency achievable with small-scale CHP plants, a basic requirement for an ecological and cost-effective operation of such plants is that not only the electricity but also the heat produced can be utilized as process or district heat (heat-controlled operation of the overall system).

The GICO activities aim at developing small to medium scale residual biomass plants (i.e. 2-20 t/day and 500-5.000 kWe, compatible with the standard residual biomass availability of few thousand tons per year) will change the actual social acceptance of the energy plants. They will no longer be seen as distant large consumers of resources and emitters of pollutants, but as local small/medium plants connected to communities (for waste, materials, and energy with negative/zero emissions) within the circular business model (industrial symbiosis with jointly located industries) that GICO promotes.

The installation of small-scale decentralized biomass power plants (Distributed Generation DG) is an economically viable and efficient solution. At this scale, gas engines and gas turbines suffer from lower efficiency (i.e., a reduction in power production capacity), compared with SOFCs. Moreover, SOFCs also have the advantage of operating at very high efficiencies in part-load windows. Furthermore, they are less susceptible to variations in fuel composition [9,10]. To accommodate the fluctuating electricity demands of both grid and off-grid installations, SOFC systems should be capable of operating within a wide part-load window.

2. MARKET ANALYSIS AND POTENTIAL

This chapter, after a description of the GICO concept and the technologies that is developed in the GICO project, focuses on the analysis (size, potential, barriers, CAGR) of potential markets.

2.1. GICO Concept

In order to overcome the main barriers that prevent renewable energy technologies from forming the backbone of the energy system, GICO develops:

- new materials: CO_2 capture sorbents; high temperature inorganic removal sorbents; catalytic filter candles; membranes for oxygen separation and Bio-methanol_production;
- new technologies: HydroThermal Carbonization (HTC); Sorption Enhanced Gasification (SEG); Hot Gas Conditioning (HGC); Carbon Capture, Storage and Use (CCST); Power To Gas via Plasma conversion.

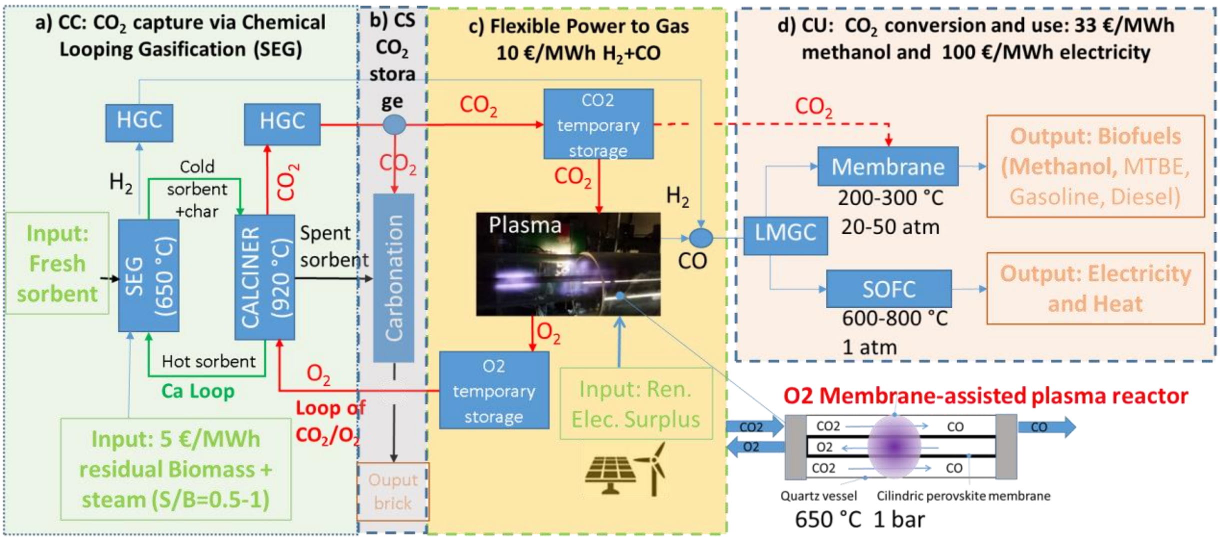

Figure 1. GICO concept

New technologies developed at GICO, i.e. *Steam Sorption Enhanced Gasification*, coupled with HTC pre-treatment, can allow the exploitation of residual biomass with high moisture content (up to 50%), low ash melting temperature (the optimal gasification temperature, due to CO_2 sorption, decreases from the typical 800 °C to 650 °C) and higher tar, sulphur and chlorine content [14].

The use of **CaO-sorbents** in the gasifier will shift the thermodynamic equilibrium towards a syngas with a H2 content up to 90%, 5% CO, 2% CO_2 and 3% CH_4 [15]. Following GICO process, CaO is converted into

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$CaCO_3$ during the gasification of biomass residues and the spent solid sorbent is regenerated by releasing CO_2 in a calcination step at ≥ 900 °C, thus producing a CO_2-rich flue gaseous stream.

GICO project raises the possibility of using hydrothermal carbonization to modify certain characteristics of the biomass wastes to make them more suitable for profitable gasification.

In recent years, **hydrothermal carbonisation (HTC)** has emerged as a very promising technology for the sustainable management of biomass waste [16]. Without prior drying, the HTC process takes place under temperatures between 160 and 250 °C and the respective autogenous vapour pressure. The lower dielectric constant of subcritical water favours the dissociation of biopolymers by reactions normally catalysed by acids and bases. It provides an excellent medium for the transformation of a wide variety of biomass residues into a C-enriched solid by-product (hydrochar) [16-20].

Within the GICO framework, HTC can be used to upgrade a wide variety of biomass and residues for gasification application. On the one hand, HTC produces energy densification (0,7-2) and enhances handling and drying properties of the material, resulting in significant cost savings if compared to the initial biomass. On the other hand, properties of subcritical water and production of organic acids during hydrothermal treatment increase the solubility of alkali and alkaline earth metals [22-22], leading to partial dissolution of inorganic components. Improved slagging, fouling or alkali indices and combustion properties have been reported for hydrothermally treated biomass wastes [23-24]. It has been reported that HTC enables nitrogen and chlorine removal from Municipal Solid Waste (MSW) [25].

The behaviour of biomass ash during hydrothermal treatment depends on the type of feedstock and the conditions under which the process takes place. In general, hydrochars from wood and algae, herbaceous and agricultural residues, compost, and faecal waste showed lower ash content than those derived from municipal solid waste (MSW), digestate and municipal and industrial sludge [26]. In addition, the ash yield for the first biomass set is lower, indicating differences in both the chemical composition and the solubility of the inorganic components. Generally, hydrochars derived from maize stubble, miscanthus, switch grass, rice husks and olive, artichoke and orange residues and empty fruit bunches have higher contents of K, Mg, S and Si compared to those obtained from industrial sludge. On the other hand, Al, Fe, P, Ca, and Si frequently show low solubility.

Thus, the integration of DBFBG, hot gas conditioning and SOFC will allow the conversion of a greater variety of low-cost biomass wastes at almost zero emissions to heat and power with high efficiencies, largely improving both the environmental impacts and its social acceptance.

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2.2. Market potential

The GICO project aims to create an integrated system, but in parallel there will be the development with related tests of materials and technology that could also potentially be marketed individually by the single partners. Market potential is the valuation of the sales revenue from all the supplying channels in a market. Market potential is the population that is interested in the product/ service that is being made or offered by an organization. In the specific case, the main reference markets have been identified where the technologies and materials described in GICO can be marketed. Market size, market potential, compound annual growth rate (CAGR) and critical factors were identified for each of them. The main market sectors are the following:

- Biomass segment
- Syngas and bio-syngas (biomass and renewable residues)
- Gasifier and Cogeneration
- Biofuel, Biomethanol
- Solid oxide fuel cells (SOFC)
- Carbon capture storage and utilisation (CCSU)
- Gas separation membranes

Table 2 Reference market size and CAGR

REFERENCE MARKET	Market Size	CAGR
Biomass	USD 51.2 Billion in 2020	5.9% (2020 to 2028)
Syngas	USD 43.6 Billion in 2020	10.6% (2020 to 2025)
Bio-syngas	USD 436 Million in 2020	20.0% (2020 to 2025)
Cogeneration	USD 9.4 Billion in 2020	3.1% (2021 to 2027)
Biofuel	USD 141.32 billion in 2020	8.3% (2021 to 2030)
SOFC	USD 403.3 million in 2019	30.0% (2020 to 2027)
Carbon capture, storage, and utilization CCSU	USD 1.75 billion in 2019	19.2% (2019 to 2027)
Gas separation membranes	USD 846 million in 2019	6.0% (2019 to 2024)

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2.3. GICO technology packages

The tables below represent for each material and for each technology (including the integrated GICO system) a short technical description, a list of end-users have been identified after a market survey, and the number of the task who will develop the system.

Table 3 GICO technology reference market

TECHNOLOGY	TECHNOLOGY Description	REFERENCE MARKET	Target end users	TASK
GICO integrated system	Integrated system to treatment of residual biomass to produce electric and thermal energy (CHP) and biofuel with near zero CO2 emissions. Installation in renewable energy companies or communities, connected to discontinuous renewable sources (solar, photovoltaic, wind), connected to the electricity grid (production of electricity for self-consumption or sale or storage) and to the thermal grid (district heating or drying of material). Simultaneous production of biofuels	Bio-syngas Biofuel Gasifier and CHP CCSU	Renewable energy communities, Agricultural, Forestry and Waste management companies	4.2
HydroThermal Carbonization (HTC)	Process to upgrade different organic waste materials, making them exploitable for energy purposes. Produce intermediate high-quality bioenergy carries (syngas).	Bio-syngas Gasifier and CHP	Farms, forestry companies, green management companies, renewable energy communities	2.1
High temperature inorganic removal sorbents	Sorbents for the reduction of inorganic species (like H_2S and HCl in gasifier and SO_x and NOx in combustor) generated during thermo-chemical conversion of waste materials	Bio-syngas Gasifier and CHP SOFC	Use in CHP power plants or combustors to increase the quality of syngas (ex. replacement of ICE with SOFC)	2.3
Sorption Enhanced Gasifier (SEG) technology	DFBG with sorbent to produce high H_2 and high CO_2 gases from residual biomass			2.5

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<table>
<tr><td>Hot Gas Conditioning (HGC) (WP2)</td><td>High temperature catalytic filters for both gasifier (650 °C) and combustor (950 °C) for the complete conversion of heavy hydrocarbons and particulate removal</td><td rowspan="2"></td><td rowspan="2"></td><td>2.3</td></tr>
<tr><td>Plasma enhanced catalytic oxidation PECO (WP2)</td><td>Plasma-Enhanced Catalytic Oxidation treatment (PECO) for the complete conversion of heavy hydrocarbons and particulate removal</td><td>2.4</td></tr>
<tr><td>CO_2 sorbents</td><td>CaO-based high temperature CO_2 sorbent and reforming catalyst materials for high H_2 and CO_2 production.</td><td rowspan="3">Gasifier
Gas separation membranes
CCSU</td><td rowspan="3">Use in after combustor or CHP to conversion of exhaust CO_2 Combination in plants with high CO_2 production: Incinerator, CHP plants and traditional combustor present in Ceramics, ferrous and non-ferrous metal industries Materials and chemical industries, EPC-Engineering companies</td><td>2.2</td></tr>
<tr><td>Membranes for oxygen separation</td><td>Novel perovskite membranes with plasma technologies (Dielectric Barrier Discharge, DBD) to increase the conversion of CO_2 into CO and produce pure O_2. Membranes with high CO_2 tolerance and resistant to plasma for oxygen separation</td><td>3.2</td></tr>
<tr><td>Plasma-assisted catalyst system for CO_2 conversion to CO</td><td>Flexible Power to Gas based on CO_2 dissociation via O_2 membrane-assisted plasma reactor powered by renewable</td><td>3.1</td></tr>
<tr><td>Innovative methanol synthesis reactor</td><td>Methanol synthesis membrane reactor with enhanced methanol yield per pass compared to conventional reactor. Produce methanol using syngas from residual biomass</td><td>Biofuel
Gas separation membranes
CCSU</td><td>Produce methanol from syngas by residual biomass</td><td>4.3</td></tr>
</table>

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2.3.1. Biomass

Favourable government regulations encouraging thermal power stations to switch from coal to cleaner fuels, such as biomass, are expected to play a vital role in the market growth over the forecast period. Biomass generates bioenergy that is used across several end-use markets to minimize dependence on fossil fuels, reduce Greenhouse Gas (GHG) emissions, and improve the security of energy supply. Moreover, the decline in coal usage along with the growing use of wood biomass for distributed electricity production is anticipated to positively influence the industry landscape.

The global biomass power market size was valued at USD 51.2 billion in 2020 and is expected to grow at a compound annual growth rate (CAGR) of 5.9% from 2020 to 2028 [26].

The solid biofuel segment accounted for the largest revenue share of 79.1% in 2020 [26].

In 2020, Europe accounted for the highest market share of 40.3% owing to the favourable environmental regulations implemented across the region to maximize the bioenergy potential in various countries.

The U.S. market is projected to witness a substantial growth owing to rising implementation of climate change laws requiring usage of renewable sources for power generation purposes. Biomass fuels are used as a primary energy source in the U.S. and are majorly sourced from wood-derived biomass and municipal waste biomass.

Asia Pacific is projected to be the fastest-growing region at a CAGR of 8.2% from 2020 to 2028 owing to the abundant availability and wide feedstock base of biomass across the emerging economies, such as China and India [27]. These data include all technologies than used biomass (combustor, boiler, gasification, biogas etc.).

The gasification segment is anticipated to attain the fastest growth rate over the forecast period owing to the high operational efficiency of the process.

In addition, new developments aimed at using more biomass for fuel are set to boost regional market growth. Biomass serves as a sustainable and low-carbon alternative to conventional fossil fuels while allowing local groups to use domestically available biomass sources. It makes efficient utilization of crop residues, the unused portions of urban waste, and wood manufacturing wastes. The government organizations are emphasizing on utilizing biomass for electricity production as a part of energy security and energy efficiency strategy. Such initiatives aim to augment the share of clean renewables in the overall energy mix of national economies.

Bioenergy is the energy produced through the burning of biomass or biomass fuels. According to the International Energy Agency (IEA), bioenergy power production rose by 5% in 2019 that is only a percent less than the 6% yearly rate required to meet the 2030 Sustainable Development Scenario goals. Market developments and recent policy changes in emerging nations are expected to further provide a positive outlook to the market growth [26].

2.3.2. Syngas and Bio-Syngas

The syngas cannot be burnt directly but is used as a fuel source. The other use is as an intermediate to produce chemicals. The production of syngas for use as a raw material in fuel production is accomplished by the gasification of coal or municipal waste. In this process several thermochemical reactions take place, giving rise to mainly carbon dioxide, carbon monoxide, and hydrogen. Syngas is used as an intermediate in the industrial synthesis of ammonia and fertilizer. During this process, methane (from natural gas) combines with water to generate carbon monoxide and hydrogen. The gasification process is used to convert any material that has carbon to longer hydrocarbon chains. One of the uses of this syngas is as a fuel to produce steam or electricity. Another use is as a basic chemical building block for many petrochemical and refining processes. The chemical industry is the largest application of syngas. The chemical industry tends to use feedstocks that are the most economical to procure or produce.

The syngas market is estimated at 245,557 MW_{th} in 2020 and is projected to reach 406,860 MWth by 2025. Global syngas market size was valued at USD 43.6 billion in 2020 and is projected to reach USD 66.5 billion by 2027 at a CAGR of 10.6% from 2020 to 2025. [27] Syngas capacity CAGR for gaseous fuels, liquid fuels and power generation are projected to be 20%, 12% and 15% after 2024. [29]

Global Syngas Capacity Share by Application: 74.5% of syngas capacity are employed in chemicals production –nitrogenous fertilizer, methanol, industrial chemicals, DME etc.; 10.6% of capacity provides substitute of natural gas and gaseous fuel. [29]

Global Syngas Capacity Share by Feedstock: Coal and natural gas are the two dominant feedstocks for syngas, refining residual such as pet coke, refinery residue and coke oven gas serves as 4.3% syngas feedstock; Biomass and waste constitute less than 1% of syngas feedstock [29].

Global Syngas Capacity Share by Product: 33.8% syngas capacities serve nitrogenous fertilizer production; 22% is used for methanol production; 11.6% is used for liquid fuels such as gasoline and diesel production; 10.6% produces substitute of natural gas and gaseous fuel [29].

Global syngas market, by gasifier: Based on gasifier, the fluidized bed gasifier segment held a significant share in 2019. These are commonly used to enhance turbulence for more complete gasification of low quality, low reactivity feedstocks. [28]

Global syngas market, by technology: By technology, the steam reforming segment is expected to lead the global market during the forecast period. Natural gas steam reforming is a reliable, cost-effective, and widely used method to produce hydrogen, with near- and mid-term energy protection and environmental benefits. [28]

2.3.3. Gasifier and Cogeneration (CHP)

The theoretical potential for applying GICO technology is seen as the 100% fuel switch to bio-fuels in existing CHP systems – in District Heating (DH) as well as in industry. The aim of this study is to project the EU specific penetration rate of biomass fuelled GICO system in the CHP markets by 2030. According to "European report on potential of BIO-ENERGY CHP in EU27", (Projected) heat demand from bio-energy CHP and DH in 2030 is equal to 17,664 ktoe or 205432 GWh. [30]

The global CHP installation market size was valued at USD 9.4 billion in 2019 and is expected to grow at a CAGR of 3.1% from 2020 to 2027 [29]. The shift in preference towards replacing conventional energy systems owing to operational cost and uninterrupted utility supply is expected to drive the market for CHP installations. Continuing demand for Distributed RES Generation (DG) coupled with consumer's inclination towards sustainable energy will propel market growth.

The European Commission published its latest national energy statistics, including European Union wide and national CHP data for 2017. Across the EU, cogeneration grew year-on-year by 3.3% in generated electricity and by 1.7% in installed electrical capacity between 2016 and 2017, reaching 371.7 TWh and 122 GW, respectively. Heat capacity and heat generation increased between 2016-2017 by 4.6% and 2.4% respectively. In terms of the cogeneration fuel mix, the growth in renewable cogeneration share (by 4.9%) is the most significant year-on-year development. Fuels used by CHP systems/plants use different sources of primary energy, such as solid fuels and peat, oil and oil products, natural gas, RES and other fuels (including industrial wastes and coal gases). Natural gas is the main fuel used for CHP. However, from 2009 to 2017, there is a slight decrease in the use of natural gas (from 48.3% in 2009 to 44.5% in 2017). In the same way, there is a significant decrease in the use of solid fossil fuels and peat (from 22.4% in 2009 to 16.2% in 2017), as well as in the use of oil and oil products (from 6.5% to 4.9%) and other fuels (from 9.2% to 6.3%). During the same period, the share of RES and waste has more than doubled in the total fuel mix (from 13.7% in 2009 to 28% in 2017). [31].

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In terms of CHP (fossil and renewable) capacity in 2017, Germany has the largest installed capacity from all European countries, with approximately 40 GW_e electrical capacity. Eurostat reports growth in generation between 2016-2017 in key EU countries, including Germany (7.3%), France (11%), Spain (4.6%), Italy (1.1%), Belgium (2.5%) and the UK (9%) [31].

A series of publications [32-37] finds that there is cost-effective potential for CHP as a key solution in a highly electrified, highly renewable, and low demand net-zero emissions energy system. When considering higher shares of bioenergy sources, CHP uptake is even more relevant fostering the efficient use of these fuels. Optimising CHP as part of integrated energy systems leads to energy system cost reduction of €4.1- €8.2 billion and allows to reduce remaining CO_2 emissions by 4-5 $MtCO_2$ annually in 2050, as part of a net-zero emissions Europe. CHP will displace less efficient power-only and heat-only generation, contributing 13-16% of total power and 19-27% of total heat production in 2050. Optimised CHP will operate flexibly and efficiently when and where needed, especially at times of peak demand by heat pumps and electrical vehicles and insufficient wind and sun generation.

Technologically, the next major development in the cogeneration market will be micro-cogeneration systems (below 15 kWe). These will be based on new prime movers: very small gas engines, Stirling engines and fuel cells. Their target markets will include individual houses, small groups of houses, small hotels, and retail establishments. The potential for this technology is vast. In the UK alone, the domestic gas boiler market is 12 million euros. If 25% of this is suitable for micro-cogeneration, the result could be 10,000 MWe of new installed cogeneration, or one-quarter of the UK's electricity demand [32].

Indeed, over the past 5 years, micro-CHP solutions have consolidated their presence on EU markets and growth has intensified in some key markets. Today there are close to 100,000 micro-CHP systems installed across Europe (around 60,000 in the 0-5.5 kWe segment and more than 20,000 between 5.5-50 kWe [33].). Annual sales in both domestic and small commercial segments are estimated at 9,500-10,000 units for 2017 [34]. Product cost reductions have already been achieved in the sector, as key manufacturers [34] are concentrating resources on scaling up and standardizing they manufacturing processes especially for ICE and fuel cells technologies, while developing the market via the heating sector supply chain. Given the increasing market awareness and expected additional cost reductions, annual sales are likely to grow further in the coming decade, with projections estimating an installed micro-CHP stock of 5 – 30 million by 2030. [35]

The use of biomass in CHP plants is common in Scandinavia and also in Austria. The frontrunner is Sweden, where solid biomass accounted for over 60% of the CHP fuel inputs in 2017, followed by Finland and Denmark. In Denmark, the use of solid biomass in CHP plants has grown substantially during the last

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decade, from around 13% in 2010 to 33% in 2017. Sweden and Finland are also leading in terms of the absolute solid biomass use for combined heat and power generation, and Germany follows as the third largest biomass consumer for CHP [36,37].

2.3.4. Biofuel - Bio-methanol

Limited availability of fossil fuel-based resources and growing awareness regarding curbing carbon emissions are some of the factors that are likely to drive the market. Also, the presence of various supporting regulatory policies and tax incentives across the world on the utilization of biofuels is anticipated to enhance their demand majorly in the transportation sector.

However, the traditional biofuels are manufactured from sources such as corn, sugarcane, soybeans, and oil palms which are basically food crops. Further, large scale utilization of these crops to generate biofuels can create a scarcity of food products made from them. It can affect the prices of food and also pose questions regarding food security. This will hinder the growth of the market in the forecast period in some regions or countries around the world.

The biomass-to-methanol process may play an important role in introducing renewables in the industry chain for chemical and fuel production.

The use of residual biomass, not deriving from the categories described above, therefore allows a drastic reduction in the cost of the raw material, making the development of biofuels very favourable, becoming competitive with respect to both fossil fuels and traditional non-residual biomass.

The global biofuels market size is expected to be worth around USD 307.01 billion by 2030 from USD 141.32 billion in 2020 (compound annual growth rate (CAGR) of 8.3% from 2021 to 2030 over the forecast period [38].

The liquid biofuel form segment held the largest revenue share of 73.4% in 2019 owing to rising focus towards energy security and application of liquid biofuels in flexible-fuel vehicles. In addition, bioethanol blending mandates set in various countries has driven the utilization of liquid biofuels [39].

By 2050, most of the literature sources claim that the biofuel contribution to the transport sector could range from 0 to 50–100 Mtoe/year (i.e. from 0 to 30% of the expected transport fuel demand in the EU by 2050), and will mainly be focused on the aviation, maritime and long-haul road transport segments.

Bio-ethanol consumption grew from 6.5 Mtoe in 2000 to 53 Mtoe in 2013 and biodiesel consumption went from only 0.4 Mtoe in 2000 to 15 Mtoe in 2010 and 20 Mtoe in 2013. The current global production of biofuels consists roughly of 72% bioethanol and 28% biodiesel. Mind that in the EU the balance of liquid biofuels consumption is completely different with 79% (10.7 Mtoe) biodiesel and 20% (2.7 Mtoe) ethanol in 2013 as a result of the high share of diesel fuel in the European transport sector. For that reason, Europe dominates global biodiesel production, whereas the US and Brazil dominate global ethanol production. [90].

In 2020, North America dominated the global market with a market share of more than 36%. U.S. and represented the highest share in the North American region primarily due to availability of abundant feedstock for the production of biofuels, along with the favourable government policies for the biofuel production in the region.

Europe was the second important market in biofuel. The growth of the biofuel industry in the countries of the Europe is attributed to growing adoption of the biofuels in the road transportation applications. Further, supporting policies for the use of biofuels by the European government in the European region is also expected to boost the demand for biofuels market in the near future.

In GICO's project, systems to produce a specific biofuel, methanol, will be carried out. In particular, it will be Bio-methanol deriving from CO_2 recovered from residual biomass gasification plants.

Most methanol is currently produced from natural gas or coal, with estimated annual life-cycle emissions of 0.3 Gt CO_2, around 10% of the total chemical and petrochemical sector's CO_2 emissions. Addressing emissions from methanol production is therefore a key component of the decarbonization of the chemical sector and could contribute to the transport sector where the methanol can be used as a fuel [13].

Worldwide annual production of methanol nearly doubled over the past decade to reach about 98 Mt in 2019. A large part of that growth came from China through methanol production from coal. With current global demand for methanol at close to 100 Mt per year and growing, there is a large potential market for renewable methanol. Methanol demand is expected to continue increasing to reach more than 120 Mt by 2025 and 500 Mt by 2050 in IRENAs Transforming Energy Scenario [13].

In 2050, 135 Mt of bio-methanol are estimated to be produced annually; this is an ambitious, yet realistic transformation pathway built on renewable energy and steadily improving energy efficiency [13].

2.3.5. SOFC market potential

Fuel cells (FCs) will play a significant role in the efficiency improvement/emission reduction strategy. FCs are clean (no combustion), efficient (direct conversion of chemical to electrical energy), and modular (independent scaling between power and capacity).

The future fuel cell market has huge potential. The global solid oxide fuel cell market size was valued at USD 900.3 million in 2020 and is expected to grow at a compound annual growth rate (CAGR) of 25.3% from 2021 to 2028. These are promising numbers, which suggest an industry on the verge of a commercial breakthrough [40].

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As described in the previous pages, biomass residues are an abundant and carbon-neutral feedstock for energy recovery. A potential approach to improve the efficiency of waste-to-energy conversion is the application of a fuel-cell-type reactor to the treatment system to generate electricity from the feedstock, with high power and energy density.

Compared with liquid or solid acid fuel cells, solid oxide fuel cells (SOFCs) are more compatible with biomass gasifiers because they both operate at high temperatures, which enables the integration of these systems, which shows advantages in a variety of fuels, quiet operation, low or zero emission and high efficiency.

The enhancement of SOFC technology reliability accompanied by cost reduction, could present further opportunities. The CHP market appears to be an opportunity for the SOFC systems in the longer term, primarily due to the lack of near-term market opportunity, which is exacerbated by the relatively high capital cost anticipated with the initial SOFC systems. Nevertheless, a considerable Distributed Generation (DG) market opportunity can be projected for SOFCs in the next ten years, which should increase as overall demand increases [41].

2.3.6. Carbon Capture, Utilization, and Sequestration (CCUS)

Carbon capture, utilization, and storage (CCUS) contributes to the transition to net zero in multiple ways. These include tackling emissions from existing energy assets, providing solutions in some of the sectors where emissions are hardest to reduce like cement, supporting the rapid scaling up of low-emissions hydrogen production, and enabling some CO_2 to be removed from the atmosphere.

The global carbon capture and sequestration (CCS) market is set to gain traction from the increasing partnerships between industry giants to commercialize the CCS technology by completing large scale production facilities.

CO_2 Utilization differs from prevalent carbon capture and storage (CCS) solutions in one basic way. CCS captures CO_2 emissions exclusively for storage, usually reinjecting them into geological formations; the goal of CCU is to convert CO_2 into end products that in turn are emissions neutral or negative.

The development of CO_2 utilization technologies is being promoted for three key reasons:

- It can be used for mitigation to meet internal or external standards for CO_2 emissions for carbon dioxide producers.
- It would allow for carbon dioxide to be used as an alternative to fossil-fuel-derived feedstocks.
- It can contribute to achieving national or global aims for decreasing carbon emissions.

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The global carbon capture, utilization, and sequestration market size (Figure 2) is projected to grow from USD 1.6 billion in 2020 to USD 3.5 billion by 2025, at a CAGR of 17.0% during the forecast period. [43]

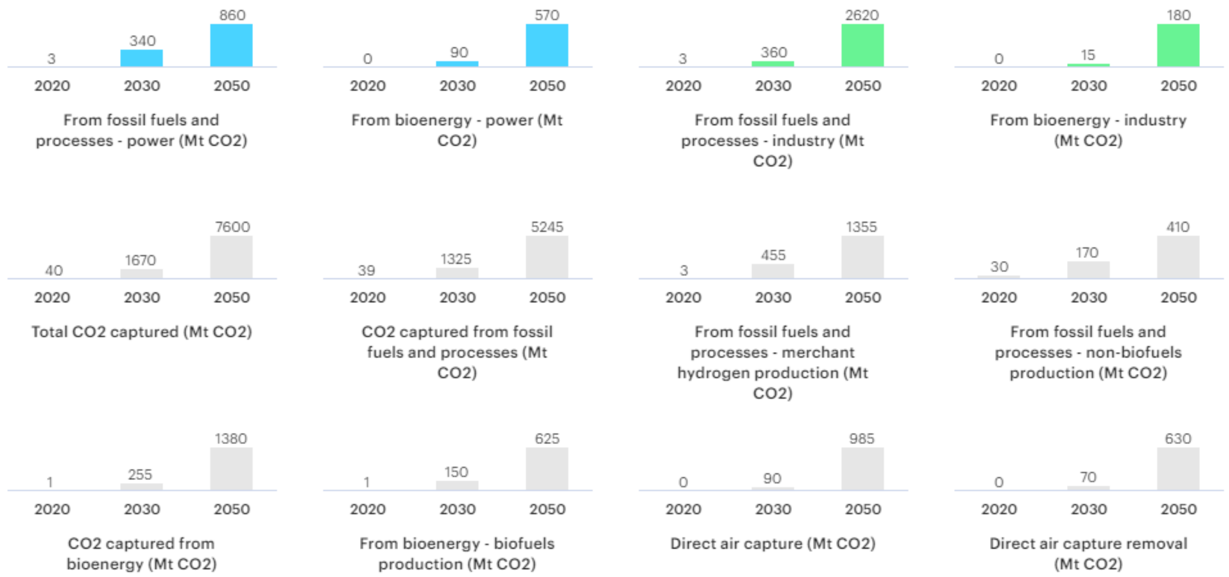

Figure 2 Carbon capture, utilisation, and storage (CCUS) prevision [42]

In GICO the Capture of CO_2 is performed using CaO-based adsorbents, the Utilization is performed through the conversion of CO_2 in CO using the plasma catalysis and Oxygen membranes, and re-utilization of the $CaCO_3$ (circular economy).

Combination of membranes with plasma technologies not only will allow better turnkey process but overall will synergistically increase the conversion of CO_2 into CO.

Carbon dioxide capture using CaO-based adsorbents has recently attracted intense attention from both academic and industrial sectors in the last decade due to the high theoretical capacity of CO_2 capture, low cost, and potential use in large-scale.

At full scale, CO_2 utilisation products has the potential of utilizing 7 billion metric tons of CO_2 per year by 2030 – the equivalent of approximately 15% of current annual global CO_2 emissions. CO_2 utilisation can create new business opportunity and simultaneously contribute to CO_2 reduction. Both conclusions are consistent with an earlier market study that the GCI, the Global CO_2 Initiative, commissioned concluding that CO_2 utilisation can remove over 10% of the emitted CO_2 and represents an annual market opportunity of USD 0.8-1.1 Trillion. The market for CO_2-based fuels can be quadrupled by 2025 (from USD 50b to USD 200b), increasing the CO_2 reduction by 15-fold (from 0.03b tons to 0.5b tons) [44].

A series of studies show that there are a wide range of technology pathways (Figure 3): Catalytic conversion (in GICO using non thermal Plasma technologies), mineralization and electrochemical conversion are the most widely studied pathways based on number of developers. Time-to-commercialization depends heavily on this concentration of research efforts. Catalytic conversion and mineralization are the most well-developed pathways for the CO_2 conversion and utilization.

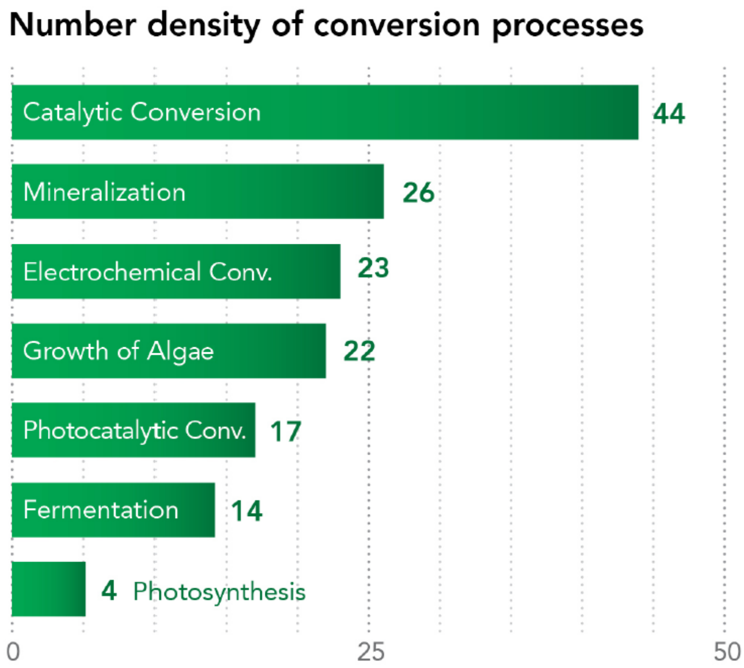

Figure 3 Number of developers by CO2U technology pathway [44]

2.3.7. Gas separation membranes

In the GICO project it will developed and tested:

- membranes for oxygen separation: Perovskite membranes can provide an economical solution for oxygen production because of low energy input.
- membranes for methanol production.

Both types of membranes can be included in the gas separation membranes sector.

The market size of gas separation membranes is estimated at USD 846 million in 2019 and is projected to reach USD 1,131 million by 2024, at a CAGR of 6.0% [45]. The growing demand for syngas and biogas in the emerging countries and cost-effectiveness of membrane separation are factors fueling the growth of the market. The growth of this market is attributed to the increasing demand for carbon dioxide removal in emerging countries such as China, India, Indonesia, and South Korea. However, regulations related to plasticization of polymeric membranes are restraining the growth of the gas separation membranes market.

On the basis of material type, the gas separation membranes market is segmented into polyimide & polyaramid, polysulfone, cellulose acetate, and others. Polyimide & polyaramide is the largest as well as

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the fastest-growing gas separation membrane material owing to its superior selectivity & permeability, high chemical & thermal stability, mechanical strength, and good film forming properties.

Most of the gas separation membranes developed by researchers are tested only in laboratories. Upscaling of new membranes technology will ensure reliability and durability. Upscaling also ensures the safe designing and operation of the membrane in real operating conditions through stress analysis in the field. However, testing the new membranes in the pilot plant and analyzing their performance is highly time-consuming and involves high installation cost. Therefore, most of the membranes developed in recent years are yet to be tested under real-time conditions, thus delaying their commercialization.

The high cost and time consumption involved with upscaling and commercializing new products is a major challenge for the players in the market.

3. PESTLE ANALYSIS

3.1. Methodology

The PESTLE analysis will be used to evaluate the external influences on the GICO potential development (Table 4).

PESTLE stands for Political, Economic, Social, Technological, Legal, and Environmental. It provides a broad view of the complete environment of the biomass and biofuel industry. The analysis will determine the factors for the economic, environmental, socioecological, and geopolitical sustainability facets. It provides the framework for the correlation with the production technologies to determine the strength and weaknesses of the different production pathways.

The PESTLE analysis is developed by using the concept of Design Thinking. Design thinking offers a structured framework for understanding and pursuing innovation in ways that contribute to organic growth and add real value to end-users. The design thinking cycle involves observation to discover unmet needs within the context and constraints of a situation, framing the opportunity and scope of innovation, generating creative ideas, testing, and refining solutions.

The New Green Deal and various European directives implemented at national levels have set binding targets on countries to reduce their GHG emissions and import of energy. The ambition of this project is to enable Europe to move closer towards greater independence of fuel supplies and to achieve this domestically at local levels across Europe, while reducing emissions. Therefore, GICO is fitting perfectly in the current and future political and regulatory environment. Indeed, widespread deployment of biomass plants is limited not only by the OPEX and CAPEX (hence efficiency, cost, reliability) but by the overall impacts (space required, bed smells, emissions). GICO, in developing the most efficient, reliable, low-cost, high-density power and zero emissions process, will overcome these limitations: the goal for the next future is that small to medium biomass CHP/biofuel plants will be recognized as clean and efficient power plants unlike.

Table 4 PESTLE analysis

P	E	S	T	L	E
Political	**Economic**	**Social**	**Technological**	**Legal**	**Environment**
Directive 2018/2001 on renewable energy (REDII)	Cogeneration and Biomass subsidies	Biomass acceptance	Electrification	National procedure for installation	Circular economy: Residues from the process: ash, char, exhausted catalysts
European Green Deal (EGD)	SOFC cost trend roadmap	Biofuel acceptance	Distributed RES generation (DG)	Electricity market rules	CO_2 emissions and European Emissions Trading System (EU ETS)
Transport policies	Trend of price of energy: biomethanol and electricity	Renewable energy community (REC)	SOFC and membrane technological evolution	Certification of supply chain sustainability	Sustainability of the residual biomass
Fit for 55	Energy taxation	Carbon Capture and Storage (CCS) Social Acceptance			The Industrial Emissions Directive (IED) 2010/75/EU

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3.2. Political

Several relevant regulations and legislations, including support schemes (subsidies and loans, etc.) and financial incentives have contributed to encourage the market related these technologies (Gasifier, CHP, Fuel cells, CCS, CCU). **To have a simple overview we consider the GICO integrated system as an innovative zero emission cogenerators with CCSU and bio-methanol production.**

The regulatory sectors that will be taken into consideration are related to renewable sources, cogeneration, and biofuels.

Since the founding CHP Directive published in February 2004, European policies and legislation focused on encouraging the wider use of CHP. The main scope of this Directive was to promote high-efficiency cogeneration (minimum share of 10% of primary energy savings). In 2012, the Energy Efficiency Directive 2012/27/EC (EED) was issued and replaced Directive 2004/8/EC, introducing more specific measures related to CHP development in the EU countries.

3.2.1. Directive 2018/2001 on renewable energy (REDII)

The political and legal aspects of the biomass and biofuel industry in the EU are driven by directives developed by the European Commission such as the Renewable energy directive (RED).

The Directive 2018/2001 on renewable energy (REDII) is a step forward in the governance of environmental sustainability of bioenergy used in the EU, and it provides tools that can be already used to limit or minimize several of the high-risk pathways identified in this report. One of the main goals of the sustainability criteria of REDII (2018/2001) is to ensure that forest biomass used in the EU energy sector is sourced in ways that minimize negative impacts on forest ecosystems and their services.

Bioenergy operators need to provide evidence that the forest biomass is subject to national or sub-national legislation or management systems at the sourcing area level ensuring: (i) legality of harvesting, (ii) forest regeneration, (iii) protection of nature protected areas, (iv) maintenance of soil quality and biodiversity; and (v) maintenance or improvement of the long-term production capacity of the forest. Applied on the consumption side, these criteria affect both to domestic and imported biomass feedstocks [46].

The sustainability criteria set by the EU in the RED II should help ensure that the use of biomass is compatible with long-term emissions reduction objectives by limiting the use of biomass types where indirect land use changes can occur. Likewise, the directive stipulates that biomass can only count towards renewables targets if specific emissions reductions are guaranteed.

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3.2.2. European Green Deal (EGD)

The European Green Deal (EGD) establishes the objective of becoming climate neutral in 2050 in a manner that contributes to the European economy, growth, and jobs. This objective requires a greenhouse gas emissions reduction of 55% by 2030 as confirmed by the European Council in December 2020. This in turn requires significantly higher shares of renewable energy sources in an integrated energy system. The current EU target of at least 32% renewable energy by 2030, set in the Renewable Energy Directive (REDII), is not sufficient and needs to be increased to 38%-40%, according to the Climate Target Plan (CTP). At the same time, new accompanying measures in different sectors in line with the Energy System Integration, the Hydrogen, the Offshore Renewable Energy and the Biodiversity Strategies are required to achieve this increased target.

Launched in 2019, the Green Deal is Europe's new growth strategy that aims to transform the EU into a modern, resource-efficient, and competitive economy, where:

- there are no net emissions of greenhouse gases by 2050;
- economic growth is decoupled from resource use;
- no person and no place are left behind.

The use of sustainable biomass will play a considerable role in meeting the 2030 target to reduce greenhouse gas emissions, as well as the objective of climate neutrality by 2050 in the European Green Deal.

In the context of the European Green Deal, biomass in its different forms might be a versatile component of a climate-neutral economy. Biomass can directly supply heat, it can be transformed into biofuels and biogas/BioSyngas, it can substitute carbon-intensive materials and products, and it can be used in power generation, potentially attaining negative emissions if coupled with a carbon capture technology. At the same time, it is crucial to ensure that its sourcing and use take place in a sustainable manner that is in line with the EU's climate and environmental agendas. For current and potential uses, the production and consumption of biomass are subject to numerous sectoral policies, such as energy, environmental, agricultural and climate policies. The combined effect of these policies can have a significant impact on the availability and use of biomass today and in future.

Unavoidable biowaste can be converted into energy including biofuels for sectors in which electrification will remain challenging (aviation, maritime).

While biomethanol would qualify as a renewable fuel of nonbiological origin, RED II places barriers to the purchasing of renewable electricity from the grid that must be overcome. The specification of a direct correlation in time and geography of synthetic fuel production and renewable electricity generation is a barrier to both investment and biofuel uptake. Guarantees of origin and purchase power agreements should be adequate proof that renewable electricity from a wind turbine or solar farm in one location has been purchased by a producer of biomethanol in another location connected by the transmission grid. Concepts such as "virtual power plants" can allow for real-time monitoring and validation of both manufacturers and consumers to avoid double counting of the renewable power feedstock.

3.2.3. Transport Policies and recommendations [47]

The policymakers at the EU and national levels will need to create an appropriate regulatory framework, both to encourage and enable investments, so that private companies will recognize the business case for investing in e-fuels technologies.

Legislation and standards for methanol used as a fuel for road transport are already in place or being put in place in many countries. While these were initially intended for fossil fuel-based methanol, they also apply to renewable methanol and will ease the transition. [48]

The 2018 review of the Renewable Energy Directive (RED II) recognized this challenge for the transport.

In order to be counted towards the target biofuels must meet certain sustainability criteria, irrespective of whether they were produced using raw materials cultivated inside or outside the EU.

The proportion of the target which can come from biofuels produced crops grown on agricultural land is limited to 7%. This limit was introduced in 2015 to address concerns related to Indirect Land Use Change (ILUC). Advanced biofuels fall outside the 7% limit as well as biofuels produced from used cooking oil and animal fats. There is an indicative target of 0.5% for advanced biofuels, and advanced biofuels, as well as biofuels produced from used cooking oil and animal fats, are double counted towards the 10% target. A revised RED-II (2018/2001 EU Directive, 2018) was adopted on 11 December 2018 and the Member States will have to transpose the RED-II by 30 June 2021 and the original RED will be repealed as from 1 July 2021. The RED-II sets a binding overall target to ensure that the share of energy from renewable sources in 2030 is at least 32%. Member states do not have mandatory individual targets for their overall renewables' contribution. Under RED-II, Member States have to require fuel suppliers to ensure that the share of renewable energy supplied for final consumption in the transport sector is at least 14% by 2030. This share is calculated as the sum of all biofuels (subject to fulfilling the sustainability and GHG emissions saving criteria set out in the directive) and renewable transport fuels of non-biological origin used in the transport sector. However, biofuels from oil, sugar and starch crops are limited to 7%, or to 1% higher than the level of use of such biofuels in the member state in 2020 (whichever is lower).

The RED-II defines advanced biofuels as biofuels that are produced from feedstocks listed in Part A of Annex IX of the directive (Algae if cultivated on land in ponds or photobioreactors, Biomass fraction of mixed municipal waste, but not separated household waste subject to recycling targets under point (a) of Article 11(2) of Directive 2008/98/EC, Bio-waste as defined in Article 3(4) of Directive 2008/98/EC from private households subject to separate collection as defined in Article 3(11) of that Directive, Biomass fraction of industrial waste not fit for use in the food or feed chain, including material from retail and wholesale and the agro-food and fish and aquaculture industry, Straw, Animal manure and sewage sludge, Palm oil mill effluent and empty palm fruit bunches, Tall oil pitch, Crude glycerin, Bagasse, Grape marcs and wine lees, Nut shells, Husks, Cobs cleaned of kernels of corn, Biomass fraction of wastes and residues from forestry and forest-based industries, i.e. bark, branches, pre- commercial thinnings, leaves, needles, tree tops, saw dust, cutter shavings, black liquor, brown liquor, fiber sludge, lignin and tall oil, Other non-food cellulosic material as defined in point (s) of the second paragraph of Article 2, Other ligno-cellulosic material as defined in point (r) of the second paragraph of Article 2 except saw logs and veneer logs, Renewable liquid and gaseous transport fuels of non-biological origin, Carbon capture and utilization for transport purposes, if the energy source is renewable in accordance with point (a) of the second paragraph of Article 2, Bacteria, if the energy source is renewable in accordance with point (a) of the second paragraph of Article 2.

It provides that biofuels and biogas produced from these feedstocks shall equal to at least 0.2% in 2022, 1% in 2025 and 3.5% in 2030, gradually increasing their share over time. Furthermore, the contribution of advanced biofuels will be double counted towards the 14% target. The Commission can add feedstocks to Part A of Annex IX, but only those that can only be processed with advanced technologies. There is also a limitation for waste lipid-based fuels (Part B of Annex IX) to 1.7 %, but these are also double counted.

Member states are responsible for putting in place measures to give effect to the requirements of the RED and are using a variety of different mechanisms. For example, Germany has had a biofuel mandate in place since 2009 with a 6.25% target for biofuels in road and rail transport. Biodiesel constituted 59% of all biofuels, followed by ethanol (35%). In 2017 legislation introduced a sub-target for advanced biofuels, increasing it from 0.05% of energy used in road and rail transportation (for companies supplying more than 20PJ of fuels), up to 0.5% for all suppliers by 2025. Conventional biofuels are capped at 6.5% of the energy used in transportation. In 2015, Germany moved from an energy mandate to a GHG reduction quota with the goal of achieving a 6% GHG reduction in the transportation fuel mix by 2025.

Until 2014, fuel suppliers failing to meet the mandate were subjected to penalties of 0.7 EUR/liter of diesel equivalent for biodiesel and 1.55 EUR/liter of diesel equivalent for ethanol. Beginning in 2015, the penalty switched to 470 EUR/per ton of CO_2eq of GHG savings not achieved.

Italy has had a transportation biofuel obligation in place since 2006. In 2011, it began to transpose the RED, setting a minimum mandate of 5% blending by energy by 2014. In 2014 the biofuel mandate was amended to achieve 10% blending by 2022 and introduced a specific mandate for advanced biofuels. The country’s biofuel sector is almost completely dominated by diesel substitutes (97%), mostly biodiesel (FAME) as well as a small share of HVO produced from palm oil. Italy has been consuming less palm-based biofuel over time and has increased consumption of biofuels produced from wastes and residues that can be double-counted towards the RED target, while decreasing the physical amount of biofuels consumed.

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3.2.4. EU Fit for 55 Package

On 14 July, the European Commission passed a crucial milestone by adopting the EU "Fit for 55" package to transform the European economy.

The package of interconnected legislative proposals will align the EU's climate, energy, land use, transport, and taxation policies with the target of reducing net greenhouse gas emissions by at least 55% by 2030, compared to 1990 levels. The "Fit for 55" package proposes an unprecedented set of ambitious objectives and plans to be implemented by 2030. A key component is the significant revision and strengthening of the EU Emissions Trading System (ETS) targets and carbon pricing signals in line with the proposed 2030 ambitions. The overall emission would be further lowered, and its annual rate of reduction increased from 2.2% to 4.2%.

In particular the main measures and goals that directly affect the GICO business plan and that will need to be monitored including:

- an increase of the renewable energy target from 32% to a 40% share, with plans to simplify certain permitting processes and to address other barriers;
- new 2030 energy efficiency targets of 36% for final and 39% for primary energy consumption respectively and an obligation for the public sector to annually renovate 3% of its buildings;
- implementation of a new energy taxation principle that taxes electricity and energy products based on energy content and environmental performance;
- minimum tax rates for motor and heating fuels and electricity as well as aviation, boat, and ship fuels;
- climate neutrality for land use, forestry, and the agriculture sector by 2035;
- creation of a nature-positive economy which protects and restores degraded ecosystems and increases the EU natural carbon sink to 310 megatons (Mt) by 2030.

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3.3. Economic

External economic factors affect the GICO market from both a CAPEX and OPEX perspective:

- CAPEX and OPEX: the presence and type of subsidies for the installation of residual biomass plants.
- CAPEX: cost trend of some technologies present in GICO (SOFC);
- OPEX: sales price trend of electricity and biomethanol; energy taxation;

3.3.1. Cogeneration and biomass subsidies

Most EU countries, in order to meet their clean energy goals and to increase the share of CHPs fuelled by RES in total electricity generation, have developed new regulations or updated their existing ones in support of CHP. The support schemes existing in various EU Member include:

- Investment subsidies for potential demonstration projects, (Belgium, Greece, and Hungary)
- Feed-in-tariff (FiTs) and feed-in premium schemes (FiPs), (Germany, Hungary, Italy)
- Loans or grants, e.g. in Finland, Germany, Slovenia
- Green certificates scheme, e.g. in Belgium, Romania
- Tax mechanisms, e.g. in Belgium, Poland, Greece.

The implementation of policy support schemes and mechanisms was the main reason for the CHP market growth in several countries. Such countries are Belgium (subsidies, green certificate scheme, tax reduction), Luxembourg (feed-in-tariff, grants), Denmark (tax exemption, feed-in-tariffs and feed-in-premiums, grants), Germany (loans, premium tariff) and Italy (premium tariff).

Based on a series of study in 15 European countries to inventory the subsidies provided to solid biomass production, investment, and demand. The subsidies covered included tax expenditures (exemptions and reductions, tax allowances, tax credits and others), direct transfers (grants, soft loans) and indirect transfers (feed-in tariffs, feed-in premiums, renewable energy quotas, tradeable certificates, and others). The work covered the period 2015-2018 and focused on biomass used for electricity or heat [31].

The compilation of subsidy data across 15 countries of interest leads to a total of 46 policy instruments with a total value of just over €6.5 billion in 2017. Over the period 2015-2017 the total value of the subsidies provided to the use of solid biomass for energy purposes increased. The lion's share of this growth came from Italy (>607 M EUR), the UK (>255 M EUR) and the Netherlands (88 M EUR). A large (57 M EUR) decrease took place in Poland, relating to a reduction in the prices of green certificates. In 2018, the total amount of subsidies for those for which data is available shows a small decline from 2017 levels. However, when data from the other countries is available, we expect the total to grow again [31]. In seven of the case study countries subsidies for energy from solid biomass represent less than 10% of the total financial support given to renewables, in only three countries does it account for more than 20% of the total support given to renewables. There is generally a clear correlation between countries with high share of the renewables support going to biomass and the share of biomass in gross electricity generation. For the use of solid biomass in final energy consumption the relation with government subsidies seems to be less pronounced. It should be noted though, that in many countries the use of biomass for heating is less heavily taxed than the use of other energy carriers, and in many cases no energy taxes apply at all. China is promoting the use of agricultural residues for bioenergy (as an alternative to uncontrolled in-field burning that deteriorates air quality); both Energy-from-Waste (EfW) and solid biomass-based electricity generation currently receive feed-in tariff support. Plus, China has announced a pilot project for coal power stations to begin co-firing biomass. In Brazil, the federal RenovaBio plan, due to come into force in 2020, will boost the production of transport biofuels and in turn will result in additional bagasse-based electricity generation from both existing facilities and new mills. In India, fiscal support and capital subsidies underpin capacity expansions of existing plants and greenfield investments, mainly in bagasse co-generation plants utilising by-products of the sugar and ethanol industries. Mexico and Turkey also show signs of expanding bioenergy deployment, especially for EfW and biogas. [49]

3.3.2. SOFC cost trend roadmap

The learning or experience curve is a standard method [50] used in the industry to project production costs for SOFC unit based on the cost of the first unit. Forecasting models rely on this curve to predict future costs [51]. It is based on cost reductions observed with the increase in installed capacity due to repetitive reproductions of a unit of the same technology. The most commonly used curve is based on the premise that cost reductions take place every time the cumulative production is doubled. [52]

The ratio of the cost after doubling the capacity to the original cost is termed the learning rate (LR) and generally varies directly with the maturity of the technology. The lower the maturity of the technology, the lower the LR, implying a higher cost reduction percentage with each doubling in capacity. While there is limited data on the LRs that can be associated with SOFC technology, the H.C. Starck SOFC production experience, discussed in the study of Rivera-Tinoco [52] indicate that LRs as high as 80% are realizable due to the relatively low maturity of the fuel cell technology, along with the molten carbonate fuel cell (MCFC) experience (1995–2012) depicted Exhibit in 5-4 [53] [54], indicate that LRs as high as 80% are realizable due to the relatively low maturity of the fuel cell technology. Learning curves showed that the SOFC system becomes cost competitive with traditional technologies after 25-90 MWe of installed capacity, around 2025, and is consistent with the technology development plan.

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The estimated development timeline shows that, a significant number of 1 MWe systems, a building block for larger scale systems, would have been successfully demonstrated to operate reliably by 2030.

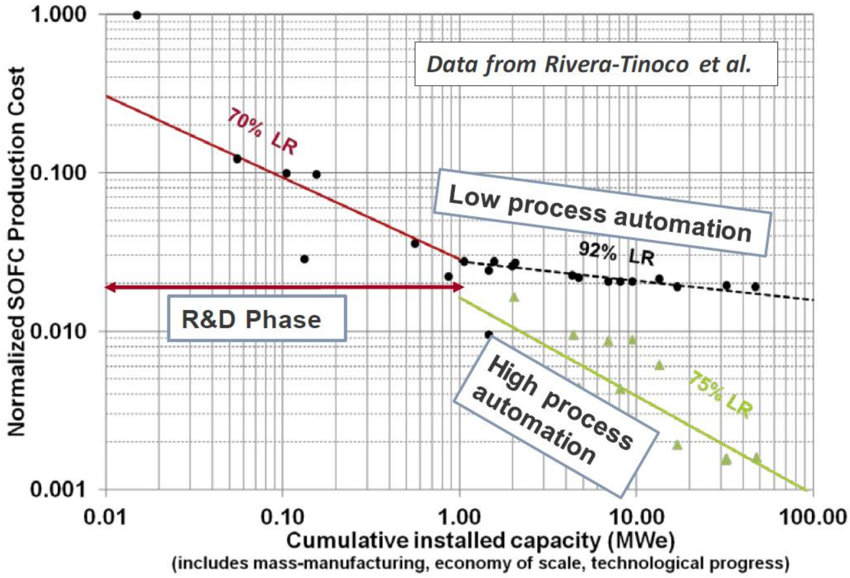

Figure 4 SOFC production learning curve [55]

3.3.3. Trend of Feedstock cost

Based on the results of eight Integrated Assessment Models, the biomass residues might cost-competitively play a large role in the twenty-first century bioenergy supply. At high bioenergy demand biomass residues could meet 7–50% of bioenergy demand towards 2050 and 2%–30% towards 2100. When also considering literature-estimated residue availability, residues could provide around 55 EJ/year by 2050 [56].

- In Europe, the estimated biomass residues cost range is between 11 €/MWh and 18 €/MWh. [57].
- In the United States resource could be supplied at cost of between 12 €/MWh and 20 €/MWh, the upper feedstock price level used in the production cost analysis above. [57].

The theoretical availability and cost modelling indicate that large volumes of feedstock could be made available to users at costs between 5 to 10 €/MWh. [57].

3.3.4. Trend of price of electricity

The price of energy in the EU-27 depends on a range of different supply and demand conditions, including the geopolitical situation, the national energy mix, import diversification, network costs, environmental protection costs, severe weather conditions, or levels of excise and taxation. Note that prices presented in this article include taxes, levies, and VAT for household consumers, but exclude refundable taxes and levies for non-household consumers. Contrary to the price of fossil fuels, which are usually traded on global markets with relatively uniform prices, electricity prices vary widely among EU-27 Member States. The price of primary fuels and, more recently, the cost of carbon dioxide (CO_2) emission certificates influence, to some degree, the price of electricity.

For household consumers in the EU-27, (defined as medium-sized consumers with an annual consumption between 2500 kWh and 5000 kWh), electricity prices in the second half of 2020 were highest in Germany (EUR 0,3006 per kWh), Denmark (EUR 0.,2819 per kWh) and Belgium (EUR 0,2702 per kWh). The lowest electricity prices were in Bulgaria (EUR 0,0982 per kWh), Hungary (EUR 0,1009 per kWh) and Estonia (EUR 0,1291 per kWh). The price of electricity for household consumers in Germany was more than three times as high as the price in Bulgaria [58].

The EU average price in the second semester of 2020, a weighted average using the most recent (2020) data for electricity by household consumers, was EUR 0,2134 per kWh [58].

Primary energy and CO_2-prices are relevant for the development of average, unweighted electricity prices for the years 2020 to 2040. From 2040, electricity prices will stagnate despite rising gas and CO_2-prices. High feed-in from wind and photovoltaic power plants increasingly lead to low and often even negative electricity prices. The actual developments in the individual countries differ considerably from each other. This is shown by the deviation ranges shown above. In particular, countries with a low expansion of renewable energies are seeing a steady increase in electricity prices (due to the development of commodity prices).

If we have a glance at electricity prices on a monthly basis, the seasonality and volatility of the electricity market can be noticed. For winter season, the analyses demonstrate rising prices due to the temperature sensitivity of electricity demand. By contrast, electricity prices are usually much lower in summer. This effect is exacerbated by the rising share of solar power generation, which has a dampening effect on electricity prices.

In the scenario various factors lead to a significant increase in price volatility. On the one hand, the generation costs of controllable fossil power plants rise in hand with the development of commodity prices. On the other hand, the expansion of fluctuating renewable energies has a price-lowering effect.

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As a result, extreme prices are more frequent from today's perspective and have become a normal part of the electricity price structure of the day-ahead market [59].

3.3.5. Trend of price of biofuels

The political aspect influences the economics of the biofuel industry by providing subsidies and creating import tariffs to protect and support the market. The biofuel industry will be affected by changes in the economic environment which are, among others, tax, interest, and exchange rates. However, specifically for the long-term sustainability of the biofuel market, the factor that will be addressed is the demand and supply of biofuel. The production cost of the different biofuels relates to the price, which affects the demand and therefore influences the supply [60].

As a replacer of fossil fuels, the competitiveness of biofuels does not only depend on its own production cost but even more so on the price of fossil fuels. Moreover, the current subsidies largely influence the competitiveness of the biofuel production cost. Biodiesel, bioethanol, and biomethane all have their own economic sustainability, influenced by factors including the feedstock, the type of conversion technologies, and the number of required processing steps.

The cost of biomethanol and e-methanol depends to a large extent on the cost of biomass, hydrogen, and CO_2. The cost of CO_2 depends on the source from which it is captured.

Methanol from non-renewable sources such as natural gas and coal is already competitive from a cost perspective with gasoline and diesel fuel.

In 2019 non-household natural gas in Europe had an average price of about EUR 35/MWh (USD 10.8/GJ). According to data provided to the SGAB report, typical biomethane production costs are in the range of 70-80 €/MWh when based on anaerobic digestion [61].

The value of Methanol increased 129 CNY or 5.34% since the beginning of 2021, according to trading on a Contract For Difference (CFD) that tracks the benchmark market for this commodity.

It is also an essential feedstock for numerous chemicals, materials, and plastics. Hybrid systems using both renewable and fossil fuels with fewer or no CO_2 emissions to produce low-carbon-methanol (LCM) could be used during the transition period to a sustainable future. LCM could thus be part of a bridge towards renewable methanol. Once the infrastructure for the distribution and use of methanol and LCM is in place, it could be seamlessly shifted to sustainable renewable methanol in the future. Fossil methanol and renewable methanol are the same from a chemical point of view. Renewable methanol can be a sustainable feedstock for many of the chemicals and products currently obtained from petroleum, including aromatic compounds (BTX) and plastics (polyethylene, polypropylene) [62].

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3.3.6. Energy taxation

The taxation of energy products and electricity plays an important role in the area of climate and energy policy. The harmonized rules set under the Directive 2003/96/EC of 27 October 2003 restructuring the Community framework for the taxation of energy products and electricity ("Energy Taxation Directive" or "ETD") aim to ensure the proper functioning of the Internal Market.

In the EGD the Commission committed to review the ETD focusing on environmental issues and to ensure that energy taxation is aligned with climate objectives. Taxation plays a direct role in supporting the green transition by sending the right price signals and providing the right incentives for sustainable consumption and production.

The rates have been set according to a ranking that takes into account the environmental performance of energy products and electricity:

- conventional fossil fuels, such as gas oil and petrol, and non-sustainable biofuels will be subject to the highest minimum rate of €10.75/GJ when used as a motor fuel and €0.9/GJ when used for heating;
- The next category of rates applies to fuels such as natural gas, LPG, and non-renewable fuels of non-biological origin, which, differently from fossil-based, can still lend some support to de-carbonisation in the short and medium term. Two thirds of the reference rate will apply to this category for a transitional period of 10 years – i.e. a minimum rate of €7.17/GJ when used for motor fuel and €0.6/GJ when used for heating - before being taxed at the same rate as conventional fossil fuels.
- The next category is that of sustainable, but not advanced biofuels. To reflect these products' potential in supporting decarbonisation, half of the reference rate applies – i.e. a minimum of €5.38/GJ when used as motor fuel and €0.45/GJ when used for heating.
- The lowest minimum rate of €0.15/GJ applies to electricity - regardless of its use -, advanced sustainable biofuels and biogas, and renewable fuels of non-biological origin such as renewable hydrogen. Low-carbon hydrogen and related fuels will also benefit from that same rate for a transitional period of 10 years. The rate applicable to this group is set significantly below the reference rate as electricity and these fuels can significantly support the EU's clean energy transition towards achieving the objectives of the European Green Deal and, ultimately, climate neutrality by 2050.

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3.4. Social

3.4.1. Biomass acceptance

Bioenergy projects involving energy crops can make a significant contribution to rural income or employment increment. Energy crops lead to changes in agricultural labor patterns and give positive contributions to rural economic diversification [63]. Results of surveys on local public opinion of a proposed biomass gasifier in the UK indicate that potential employment impact was the most highly confirmed benefit [64]. A specific study [65] recognizes the generation of direct and indirect jobs as one of the main benefits of biomass. The adoption of land for the production of energy crops should be considered as a possible solution to problems such as the abandonment of land, rising unemployment and an exodus of rural areas. However, perceived negative impacts should not be forgotten. The transport and infrastructure requirements and associated emissions of new biomass capacity may also result in an adverse reaction from sections of the local community [63]. Some studies [66] presents some examples demonstrating that a major barrier to promote biomass energy is frequently local opposition. An example is the Journal Acceptance Rate Feedback System. The definition of journal acceptance rate is the percentage of all articles submitted to Waste and Biomass Valorization that was accepted for publication. Based on the Journal Acceptance Rate Feedback System database, the latest acceptance rate of Waste and Biomass Valorization is 75.0%.

3.4.2. Biofuel acceptance

The development of traditional biofuel production has a significant impact on the world's agricultural market and food security [67]. The cultivation of the biofuel feedstock competes directly for land with other food crops such as coffee beans or rice. The feedstock that is also used for food and feed production including corn, wheat, sugar cane, soybean, rapeseed, and sunflowers are denoted as the first-generation feedstock.

The aspect of land-use incorporates the essential difference between the restoration of degraded farmlands or removing forests for biofuels [68]. The term indirect land-use change (ILUC) describes the change of natural environments to croplands to grow crops that replace the feedstock used for biofuels. Essentially, it is the effect of competing with the same resources as the food industry. The ILUC leads not only to a loss in biodiversity but also increases the GHG emission and impacts the prices of food [69].

The feedstock used in GICO necessary for the production of biofuel and energy, includes residual biomass and organic waste, considered completely RES, does not go to use land with potential for food production.

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3.4.3. Renewable energy communities

Community energy refers to a wide range of collective energy actions that involve citizens' participation in the energy system. The Clean Energy Package recognizes certain categories of community energy initiatives as 'energy communities' in European legislation. Energy communities can be understood as a way to 'organize' collective energy actions around open, democratic participation and governance and the provision of benefits for the members or the local community.

Energy communities are defined in two separate laws of the Clean Energy Package. The revised Renewable Energy Directive (EU) 2018/2001 sets the framework for 'renewable energy communities' covering renewable energy. The revised Internal Electricity Market Directive (EU) 2019/944 introduces new roles and responsibilities for 'citizen energy communities' in the energy system covering all types of electricity. The primary purpose is to generate social and environmental benefits rather than focus on financial profits. The directives frame energy communities as non-commercial type of actors that use revenues from economic activities to provide services/benefits for members and/or the local community.

Within the context of an energy transition to a low carbon economy, new roles for local communities are emerging, whereby they are transitioned from being passive consumers to active prosumers with the possibility of local generation, demand response and energy efficiency measures. The energy transition will require significant mainstreaming of niche social and technical innovations to succeed at the community level, for example sustainable vehicles (bio-methanol GICO), heat pumps, smart meters, sustainable energy communities, CHP powered by residual biomass (GICO), and RES energy storage (GICO).

There are a few examples of biomass community-owned schemes in Sweden, Denmark, Germany, Poland, and Belgium.

Community projects can be vital for stimulating renewables growth. Germany is a forerunner of citizen-led investments in renewables. In 2016, citizens including households and farmers owned 42% of the installed renewable energy capacity. Investment funds, banks, project providers and other investors owned another 41.2%, while the four biggest power utilities accounted for only 5.4% [70]. In total, there were about 1.750 citizen-led initiatives, with about 855 cooperatives founded since 2006 (DGRV, 2016). More than 180.000 people are involved in cooperative projects, from production and supply to (heat) network operation and marketing. The vast majority of projects concern generation (mostly solar and wind with shares of about 43% each, bioenergy at 6.2% and hydropower at 0.7%); with the rest engaging in distribution and energy services [71].

Bioenergy villages represent an example of communities using biomass from local agriculture and forestry resources. For instance, Bioenergiedorf Jühnde is Germany's first village to produce heat and electricity through renewable biomass and combined heat and power (CHP) system, with a local heat network delivering heat to households [72].

In the Netherlands, about 8% of final energy consumption comes from renewables [73]. Energy communities could ramp up this share by investing in vast amounts of solar panels and windmills. In 2018, 74.5 MW of solar power and 159 MW of wind was collectively-owned in the country. The number of cooperatives rose to 484, with about 70,000 members; and the first cooperatives for heat and biogas appeared [74].

The UK is another example where community projects have made fast progress in renewables investments over the past 20 years. In 2017, the UK community energy sector owned a total electrical generation capacity of 249 MW, including Scottish community renewables (Community Energy England, 2018). In Denmark, 60% of the heat consumption supplied in district heating systems has historically been consumer- and municipality- owned [75].

District heating cooperatives using wood fuel for heat and combined heat and power are particularly common in Denmark (about 300) and Germany. In Denmark, Marstal Fjernvarme, a citizens-owned district heating network uses solar heat collectors and heat pumps to provide hot water on the island of Ærø [76]. Some multi-utility cooperatives such as Enercoop in France, EWS Schönau in Germany and Som Energia in Spain are also investing in or purchasing biogas.

Energy communities can also advance energy efficiency at the household level and alleviate energy poverty by reducing consumption and supply tariffs. Several case studies are addressing socially vulnerable households experiencing energy poverty to some degree. Enercoop supports Énergie Solidaire, a solidarity fund that encourages micro-donations from consumers and renewable energy producers to donate their surplus production. Enercoop consumers can donate 1 cent per kWh from their energy bills. EnergieSolidaire then allocates the funds to associations that fight against fuel poverty [77].

For the example of SAS Ségala Agriculture et Energie Solaire, a company created by the local agricultural cooperative Fermes de Figeac to specifically carry out the installation of solar PV on agricultural buildings, trust in the local cooperative was a crucial aspect. This made it possible for farmers to embark on a solar photovoltaic project with a well-recognised local actor rather than engage in PV projects alone or with unknown firms.

The Fermes de Figeac' success created additional value to the community: profits to reinvest, networks and expertise in the field of renewable energy, new competencies in negotiating large-scale projects. Of special interest is what mutualisation of the solar resources through the cooperative achieved. In this way, a farm (Fermes de Figeac, agricultural cooperative) emerged as a new player in renewable energy development. It also contributed to the revitalisation of rural areas where agricultural activities are on decline. Innovation in this case supported preservation and conservation, instead of replacement and change (farm roofs of agricultural cooperatives gaining an extra role) [78].

GICO's development model for rural areas could be inspired by this modality. The GICO plant stands as a fulcrum in the nascent energy micro communities. The members of the energy community thus become prosumers, supplying the raw material (residual biomass, CaO, waste CO_2) and purchasing electrical, thermal and biomethane energy for the vehicles. The electricity produced and self-consumed within the community is also subject to OPEX incentives (€ 119/MWh in Italy) which allow for a reduction in the investment payback time.

3.4.4. Carbon capture, storage, and utilisation acceptance

In addition to the technical–economic, ecological, and political aspects, the question of social acceptance is a decisive factor for the implementation of CCSU technologies.

Before an analysis of social acceptance, a distinction must be made between the two CCs and CCU technologies that are both developed in GICO:

- CCS is a CO_2 mitigation strategy; its objective is to deal with large volumes of CO_2 emissions by capturing and sequestering the gas in geological formations for periods of hundreds of years.
- CCU on the other hand uses CO_2 as a feedstock for the creation of new, value-add products; it can promote sustainability and a circular economy, encourage industrial symbiosis and economic growth, and enable the storage of renewable energy.

In GICO the Capture of CO_2 is performed using CaO-based adsorbents, the Utilization is performed through the conversion of CO_2 in CO using the plasma catalysis and Oxygen membranes, and re-utilization of the $CaCO_3$ (circular economy).

The use of CO_2 capture processes is feasible both in fossil-fired power plants for electricity generation and in energy-intensive industrial processes (for example, steel or cement plants) and could enable a significant reduction in CO_2 emissions in these applications. According to the International Energy Agency [79], fossil-fired power plants accounted for about 42.5% of total global CO_2 emissions in 2013. In comparison, the share of CO_2 emissions caused by industrial activities was around 25%. The IEA estimates that CCS in the cement, iron and steel, and chemicals sectors will need to deliver around 28 $GtCO_2$ of emission reductions between now and 2060 to meet the climate target of the Paris Agreement. To achieve these reduction goals globally, strategies for robust and timely market introduction of CCS technologies need to be developed.

The introduction of CCS technologies in some countries (e.g., Germany) has been stymied by a strong resistance to the concept among stakeholders and the general public. A series of studies after a detailed explanation of the functions of the CCU has yielded very positive public acceptance results due to its potential role in climate change mitigation, as revealed by mean values and standard deviations [80,81]. On the other hand, in the case of people with little knowledge of the subject the awareness of the use of CO_2 is currently low and while there is some scepticism about the long-term environmental benefits of the technology, there is an attempt to support. to the concept of "bridge technology" in the fight against climate change [82]. The key factor for a positive social acceptance of CCSU technologies is therefore directly related to the quality and dissemination of the communication activities that will be carried out within the GICO project to the entire chain of stakeholders.

3.5. Technological

3.5.1. Electrification

Based on the "Sustainable Development" scenario of the IEA's World Energy Outlook 2020 the global electricity demand recovers and surpasses pre-Covid-19 levels in 2021. Electricity demand growth in India outpaces other regions to 2030, after which growth is most pronounced in Southeast Asia and Africa. China sees the largest absolute increase in demand, accounting for over 40% of the global growth to 2030. Electricity demand growth globally outpaces all other fuels. Electricity meets 21% of global final energy consumption by 2030.

Above all, population growth and higher electrification in households increase the demand for electricity. Most of the economic growth in the European Commission's plans takes place in the tertiary services sector, which also needs more electricity. In the industrial sector, increased efficiency prevents a significant increase in electricity consumption. This scenario conservatively assesses how sector coupling between the electricity, heat and transport sectors will develop. In passenger transport, hybrid cars will reduce the consumption of commodities, such as oil.

In advanced economies, electricity demand recovers to pre-crisis levels by 2023 and then rises by 0.8% per year through to 2030, driven by the electrification of mobility and heat. In developing market and emerging economies, rising levels of ownership of household appliances and air conditioners, together with increasing consumption of goods and services, underpin strong growth, exceeding pre-crisis levels by 2021. A handful of countries including Ghana, Kenya, Senegal, Ethiopia, and Rwanda are on track to achieve universal access to electricity by 2030, but in the STEPS – 660 million people still lack access in 2030 – including 33% of all people in Africa [83].

Renewable sources of electricity have been resilient during the Covid-19 crisis and are set for strong growth, rising by two-thirds from 2020 to 2030 in the STEPS. Renewables meet 80% of global electricity demand growth during the next decade and overtake coal by 2025 as the primary means of producing electricity. By 2030, hydro, wind, solar PV, bioenergy, geothermal, concentrating solar and marine power between them provide nearly 40% of electricity supply. China leads the way, expanding electricity from

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renewables by almost 1500 TWh to 2030, which is equivalent to all the electricity generated in France, Germany and Italy in 2019 [83].

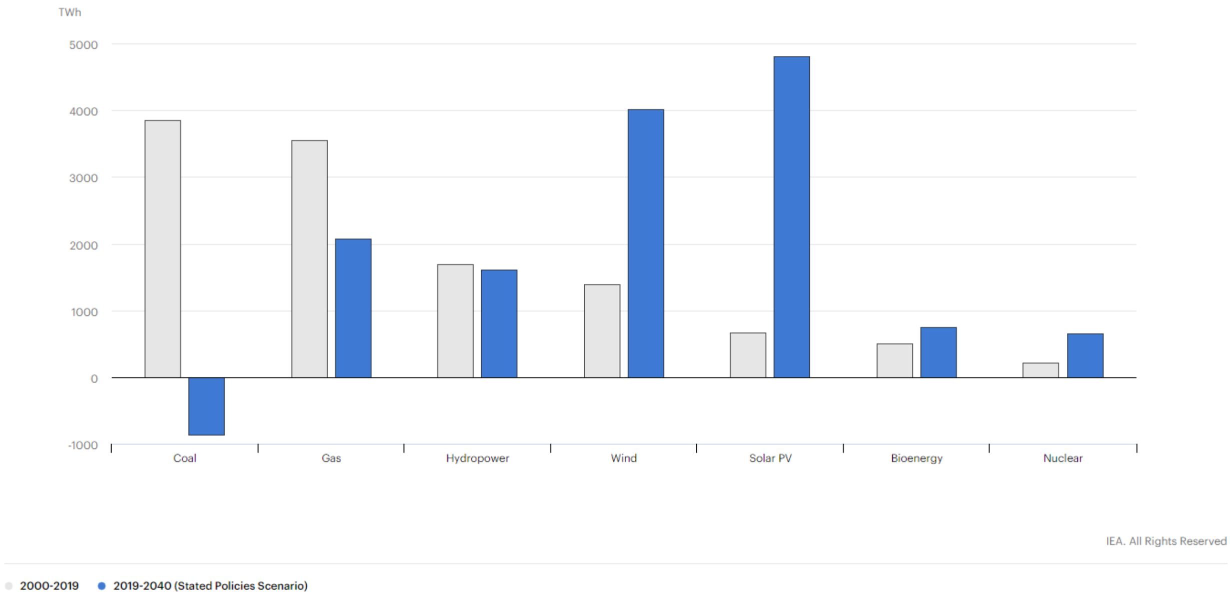

Figure 5 Change in global electricity generation by source in the Stated Policies Scenario, 2000-2040 [83]

In 2019, bioenergy electricity generation increased by over 5%, just below the 6% annual rate needed through 2030 to reach the Sustainable Development Scenario level. Recent positive policy and market developments in emerging economies indicate an optimistic outlook for bioenergy, supporting its “on track” status [84].

In the transport sector: electrification is not an effective solution for all transport sectors. The production of biofuels is not as energy efficient as the direct supply of electricity for battery electric vehicles (BEVs), it still offers an important opportunity to produce very low-CO_2 fuels with a significant opportunity to reduce GHG emissions in transport. There are certain transport modes, where direct electrification is not technically feasible. Deep sea shipping and aviation are two areas, where fuels with a higher energy density (compared to the energy density of lithium-ion batteries) will continue to play a role. To achieve full decarbonisation for ships and planes by mid-century, their fuels will need to be decarbonised. Even within the light-duty segment, biofuels can offer an alternative route to carbon neutrality target and has the advantage that it can be deployed across the whole existing fleet without modifications to the engine, using much of the current distribution infrastructure.

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3.5.2. Distributed RES generation (DG)

Distributed generation (DG) refers to a variety of technologies that generate electricity at or near where it will be used, such as solar panels and CHP. Distributed generation may serve a single structure, such as a home or business, or it may be part of a microgrid (a smaller grid that is also tied into the larger electricity delivery system), such as at a major industrial facility, a military base, or a large college campus. When connected to the electric utility's lower voltage distribution lines, distributed generation can help support delivery of clean, reliable power to additional customers and reduce electricity losses along transmission and distribution lines.

DG production is the opposite of centralized electricity production. The power systems in Europe have mainly been built to accommodate central power plants, meaning large fossil fuel condensing plants, nuclear plants and hydro power stations. This is changing, more and more distributed energy resources are being introduced into the power system. The distributed energy resources concern the power system and are seen to include not just distributed generation, but also energy storage and demand response. End users are becoming not only producers but also active participants in network balancing operations.

EU Directive 2009/72/EC defines DG as generation plants connected to the distribution system where the distribution system is the high-voltage, medium-voltage and low-voltage network as opposed to the extra high-voltage and high-voltage transmission system. Decentralized generation is not defined per se in the recent directives as it is used more in the descriptive sense. There are more precise and restricting definitions for DG, but these vary. However, a broad consensus is that DG units are connected to the distribution grid and are not large-scale units. They usually have one or several strong local dependencies: they are connected to the distribution network, not the very high voltage transmission grid; the energy source is produced locally (wind, solar, biomass, biogas, geothermal, ocean energy, hydro); electricity production in combined heat and power plants is dependent on local heat demand; production is used by the producer; or the owner is a relatively small actor on the electricity market (e.g. a municipality, an end-user, a private investor or consortia, a land owner).

The promotion of renewable energy technologies contributes to the development of decentralized energy production. However, easy access to the energy grids (electricity and gas infrastructure) remains a problem, not only in technical but administrative terms, as well. Operators of electricity or gas grids in most cases are/were at the same time energy producers, as well. They were therefore not interested in offering easy access for renewable energy producers and made network access difficult and costly, making renewable energy investments unfeasible or unprofitable. The European Union decision makers recognized this problem and after a long procedure established the so-called third energy package.

The Increasing rural electrification rate, particularly in developing countries, has escalated the demand for decentralized electricity generation, which is majorly driving the global biomass gasification market toward growth.

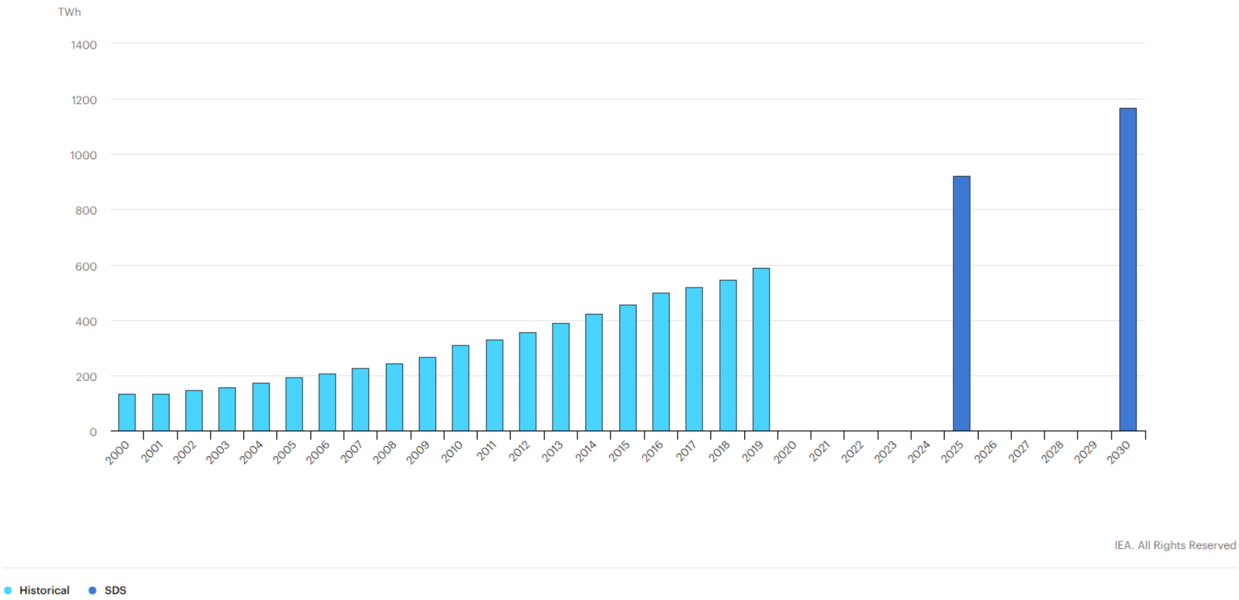

Figure 6 Bioenergy power generation in the Sustainable Development Scenario, 2000-2030 [84]

Besides this, the widespread acceptance of these systems for waste processing as a replacement of conventional techniques, such as incineration and landfill, is further fuelling the market growth. Moreover, the leading market players and governments of various nations have been consistently investing in the development of advanced technologies, which is contributing to the market growth. For instance, the United States Depart of Energy (USDOE) is developing innovative and flexible modular designs through the Gasification Systems Program. This aids in the conversion of different types of US domestic coal blends, waste plastics, and municipal solid waste (MSW) into clean synthesis gas. Furthermore, the rising development and commercialization of small- to large-scale biomass gasification systems combined with power generation equipment is positively influencing the market across the globe.

3.5.3. SOFC technological evolution

Solid oxide fuel cell is now an attractive potential option due to its promised benefits in helping to keep people away from environmental pollution and providing clean and efficient power supply. SOFC is used as a highly skilled energy conversion device that directly converts chemical energy to electrical energy by numerous electrochemical reactions.

Solid Oxide Fuel Cells are gradually evolving from the laboratory stage to technology being introduced to the market. New products address real consumers, though in first niche areas only. In European SOFC development planar designs prevail. Several companies are already offering cells, stack components, stack modules and complete units, at least at a pre-competitive level, e.g. for demonstration projects.

Recently, researchers showed their keen interest in developing suitable and low-cost materials, especially electrodes, to the commercialization of SOFC. Therefore, their primary aim to overview different perovskite-type materials doped with copper, which are prospective for electrode materials in SOFCs, as copper is a much cheaper material in the periodic table and has availability on earth [85].

3.6. Legal

3.6.1. National procedure for installation

In relation to the type and characteristic of plant, GICO integrated system can be assimilated to a cogeneration system (this factor will need to be investigated according to the state of installation). The installations procedure is in relation to the size of CHP power plants:

- **micro-cogeneration** unit means a cogeneration unit with a maximum capacity below 50 kWe
- **medium and large-scale CHP** installations with an electrical output > 1MWe: concern mainly the medium-large industrial sector and the electricity generation sector combined also with District Heating networks, which is a common practice in several European countries.
- **Small scale cogeneration**: As per directive 2004/8/EC of 11 February 2004 on the promotion of cogeneration, "small scale cogeneration" means cogeneration units with an installed capacity below 1 MWe

Connecting a cogeneration system to the electricity grid requires careful consideration of the available options, including the following:

- generator connection point;
- generator and connection voltages (low voltage (LV) or high voltage (HV));
- if export of power to the grid is required;
- if operation in island mode is required.

The selection of the connection method can significantly affect the complexity, timeframe and costs associated with the grid connection and can therefore affect the overall feasibility of cogeneration for the particular site.

Most cogeneration schemes operate in parallel to the grid but do not export electricity to it. Generally, the cogeneration plant is sized to operate continuously at high load to satisfy the base load requirements for the site, with load variations above the base load being met by electricity imported from the grid. This configuration is generally the most economic.

If the capacity of the cogeneration plant is greater than the customer's on-site load demand, it may be possible for any excess of electricity generated to be exported to the grid. This arrangement would be subject to agreement for the additional technical requirements with the Distribution Network Service Provider (DNSP) and negotiation of a satisfactory energy purchase agreement with the retailer.

3.6.2. Electricity market rules

The EU has recently adopted a number of new laws that will make the EU electricity market fit for the challenges of the clean energy transition – better connected, better protected against black-outs, better able to integrate renewable energy, more market-based and more consumer-oriented.

The Directive on common rules for the internal market for electricity (EU) 2019/944, which replaces Electricity Directive (2009/72/EC), and the new Regulation on the internal market for electricity (EU) 2019/943, which replaces the Electricity Regulation (EC/714/2009) on January 1 2020, introduce a new limit for powerplants eligible to receive subsidies as capacity mechanisms (confirming the phasing out of subsidies to generation capacity emitting 550gr CO_2/kWh or more).

The EU will need to issue directives and apply rules to ensure fair play for all in the rapidly liberalizing electricity and gas markets. Nonetheless, cogeneration has come to stay, and its widespread increase can only be delayed, not prevented. There is no doubt that investment in cogeneration plants across Europe, including central and eastern Europe, will soar in the next decade or two, though the rate of activity will of course vary by country.

The new rules include the revised electricity market regulation, the revised electricity market directive, a new risk preparedness regulation and an enhanced role for the Agency for the cooperation of energy regulators (ACER). These changes will adapt current EU market rules by:

- allowing electricity to move freely throughout the EU energy market through cross-border trade, more competition and better regional cooperation;
- enabling more flexibility to accommodate an increasing share of renewable energy in the electricity grid;
- fostering more market-based investments in the sector, while decarbonizing the EU energy system;
- introducing a new emissions limit for power plants eligible to receive subsidies;
- improving planning to anticipate and respond to electricity market crisis situations, including through cross-border cooperation.

The regulations require prosumers to be provided with a smart meter and a dynamic price contract that allows them to be rewarded for moving consumption / production in times when energy is widely

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available and cheap. The configuration of GICO allows to "store" the surplus of discontinuous RES through the conversion of CO_2 and therefore to obtain economic rewards on dynamic price contract.

3.6.3. Certification of supply chain sustainability

The sustainability of the supply chain is certified thanks to a traceability of the biomass. Traceability is defined as the ability to discern, identify, and follow the movement of a product or substance intended to be or expected to be incorporated into a product, through all stages of production, processing, and distribution.

In particular, implementing a traceability system within a supply chain requires that all parties involved will link the physical flow of products with the flow of information about those products. Adopting regulations and industry standards for traceability processes ensures agreement about identification of the traceable items. This supports the visibility and continuity of information across the supply chain.

A traceability system is the totality of data and operations that is capable of maintaining the desired information about a product and its components through all or part of its production and utilization chain. Therefore, it records and follows the trail as products and materials come from suppliers and are processed and distributed as end products. In fact, the basis of all traceability systems is the ability to identify things that move along the supply chain. The basic characteristics of traceability systems are

- identification of units / batches of all ingredients and products;
- registration of information on when and where units/batches are moved or transformed;
- a system linking these data and transferring all relevant traceability information with the product to the next stage or processing step.

In practice, traceability systems are record keeping systems that show the path of a particular product from suppliers through intermediate steps to consumers. As well as identifying the product, traceability systems may identify other information (e.g. country of origin, species and best by date) that is associated with the product.

The traceability has to be assured for each subject of the chain: farms and plantations, points of origins, first gathering points, central offices, collecting points, traders, storage facilities and processing units. Transport and any modes of transport (e.g. road, rail, air, river, or sea) are not subject to certification. All relevant information regarding the transport of sustainable materials (e.g. delivery documents, means and distance of transport, etc.) are covered by the certification of the aforementioned economic operators. In the case of residues directly deriving from or generated by agriculture (e.g. straw, bagasse, husks), the point of origin is a farm or plantation where sustainable biomass is cultivated and harvested. Farms or plantations do not need to be certified individually, but anyway have to conduct a selfassessment and complete and sign a self-declaration which must be provided to the certified first gathering point.

In order to assure the traceability and consequently the point of origin of the residues, the farm/plantation has to be clearly and transparently identified. For the farm identification it is necessary to use the Business Identification (BID) or an alternative Farm ID. The BID is allocated by the Ministry of Agriculture or any other designated government agency which maintains the National Farm Registry FAO 2017.

Farmers have to identify all the plots in every farm they manage and if possible, all the crops in every plot. This shall give the opportunity to confirm the quantities of the residues and to verify the respect of the sustainability criteria (see RED II). All the information related to the previous conditioning (e.g. shredding, baling, etc.) and harvesting from plots must be recorded. These records should be organized chronologically by dates in a Farm Book (e.g. electronic or paper notes, etc.). The Farm Book is a simple notebook (e.g. a copybook) wherein a farmer records cultural practices, plant protection treatments and additional information that may be considered of importance in relation to crop/residues management.

3.7. Environmental

3.7.1. CO_2 emissions and European Emissions Trading System (EU ETS)

Carbon pricing is an instrument that captures the external costs of greenhouse gas (GHG) emissions—the costs of emissions that the public pays for, such as damage to crops, health care costs from heat waves and droughts, and loss of property from flooding and sea level rise—and ties them to their sources through a price, usually in the form of a price on the carbon dioxide (CO_2) emitted. A price on carbon helps shift the burden for the damage from GHG emissions back to those who are responsible for it and who can avoid it. Instead of dictating who should reduce emissions, where and how, a carbon price provides an economic signal to emitters, and allows them to decide to either transform their activities and lower their emissions or continue emitting and paying for their emissions. In this way, the overall environmental goal is achieved in the most flexible and least-cost way to society. Placing an adequate price on GHG emissions is of fundamental relevance to internalize the external cost of climate change in the broadest possible range of economic decision making and in setting economic incentives for clean development.

The European Emissions Trading System (EU ETS) has been the cornerstone of the EU's strategy for reducing greenhouse gas (GHG) emissions from industry, electricity, and heat production since 2005. It contributes significantly to achieve the overall EU target of cutting GHG emissions by 20% from 1990 levels by 2020, which the EU is on track to surpass. the Commission's Communication on the 2030 Climate Target Plan2 proposed to increase the EU's 2030 GHG emissions reductions target from 40% to at least 55% compared with 1990 levels.

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The EU ETS currently operates in the 27 Member States of the EU, Iceland, Liechtenstein, and Norway, as well as in the United Kingdom until the end of 2020.

The EU ETS and ETD (see cap 3.3.6.) have co-existed since 2005 and are complementary. While the ETD is a tax on output fuels/energy content for all sectors of the economy, across industry, transport, and households, the ETS limits greenhouse gas emissions in the sectors it covers and puts a price on these emissions. For this reason, it was included among the points related to the environment. While both subscribe and contribute to our environmental objectives, the economic sectors and energy uses they cover can be subject to both at the same time. As long as a particular sector or energy use is taxed with ETD for fuel consumption and charged under ETS for CO_2 emissions, no overlap or double taxation can occur.

In this context, the proposed introduction of emissions trading to the road transport and building sectors will be complementary to the proposed revision of the ETD. Emissions trading will tackle CO_2 emissions while ETD will ensure that fuel taxation incentivises an efficient use of energy and the consumption of more sustainable energy products, while not including a CO_2 specific tax component.

In 2019, greenhouse gas emissions from EU ETS-covered installations marked a historical fall of 9.1% compared to 2018. This was mainly driven by a reduction of almost 15% in emissions from electricity and heat production, with a strong penetration of renewable sources of energy, increased use of natural gas and a reduction of coal of around 19%. Emissions from industry also marked their strongest decrease in phase 3 so far, of close to 2%.

Emissions from biomass used by ETS installations increased by 4% in 2019 compared to the previous year, while emissions from coal declined by 19%, contributing to the significant 15% reduction in emissions from the power sector. Regarding only fuels, and as was the case in previous years, the fuels combusted within the EU ETS in 2019 remained overwhelmingly fossil. However, twenty-nine countries also reported biomass use in connection with 2197 installations (20.8% of all installations). The highest percentage of emissions from biomass compared to emissions covered by the EU ETS per country was reported by Lithuania: 68%. Two countries (LI and MT) did not report any use of biomass. Total emissions from biomass in 2019 amounted to approximately 170 million tonnes CO_2 (11% compared to ETS reported emissions), a clear increase from the 145 million tonnes CO_2 in 2018 (8% compared to ETS reported emissions). Out of these, 99.2% were zero-rated. In the EU ETS, the emission factor of biomass is set to zero if the definition of the term “biomass” is fulfilled and – where biofuels or bio-liquids are concerned – the sustainability criteria pursuant to Article 17 of Directive 2009/28/EC (the Renewable Energy Directive) are met. No allowances have to be surrendered for zero-rated emissions. In the 2020 Article 21 submissions, two participating countries (LV and DK) only reported the energy content of zero-rated biomass, and not the actual emissions. Their emissions are therefore not taken into account in the total provided. In 2019, for the first time a small amount of biofuel was reported to be used.

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Despite the difficult economic situation for industry and aviation due to the COVID-19 crisis, the carbon price signal remained stable between January 2019 and end June 2020, with a short exception in March/April. The total revenues generated by the EU ETS from the auctions between 2012 and 30 June 2020 exceeded EUR 57 billion, with total revenues to Member States of more than EUR 14 billion in 2019 and EUR 7.9 billion in the first half of 2020. A large part of these revenues is used by the Member States for climate action. [86]

3.7.2. Circular economy

As a basic building block for hundreds of chemicals that touch our daily lives, the transition towards renewable methanol can contribute to the circular economy and the adoption of green chemicals.

Furthermore, the carbonation–calcination looping cycle of calcium-based sorbents is considered as an attractive method for CO_2 capture from combustion gases because it can reduce the cost during the capture steps compared to conventional technologies.

The carbon capture with calcium-based sorbents uses relatively abundant cheap materials with several outlet markets for spent sorbents (iron, steel, aggregates, and cement industries) making the SEG process a fully circular and economically viable process where the CO_2 sorbent ($CaCO_3$) can be reused in other industrial sectors.

The calcium carbonate market size was estimated at over 90 million ton in 2020, and the market is projected to register a CAGR of over 5% during the forecast period (2021-2026) [87]. By application, the market is segmented into raw substance for construction material, dietary supplement, additive for thermoplastics, filler and pigment, component of adhesives, desulfurization of fuel gas, neutralizing agent in soil, and other applications. By end-user industry, the market is segmented into paper, plastic, adhesives and sealants, construction, paints, and coatings, pharmaceutical, automotive, agriculture, rubber, and other end-user industry.

A series of possible application are:

- **cement industry:** Shell $CaCO_3$ is a sustainable biomaterial that could partly replace the presently dominating non-renewable mineral sources in some applications. A possible solution to the environmental problem linked to the cement industry could be to capture the CO_2 present in flue gases and re-use it within the cement industry to develop a circular economy in cement manufacturing. CO_2 could be recycled in the cement industry to produce valuable chemicals e.g. cement additives and concrete nanofillers to improve cementitious product quality. Nearly zero CO_2 cementitious composites could be developed by adding a $CaCO_3$ nanofiller produced via innovative recovery systems of carbon dioxide in cement manufacturing [88]. The $CaCO_3$ particles were added to the cementitious composites in different percentages according to the cement

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weight. A series of studies showed that after 7 days of curing, the flexural and compressive strength improved by increasing $CaCO_3$ content even if the optimal additional percentage proved to be 2%. Within the framework of these criteria, research in this area is attracting widespread interest due to the possible development of a circular economy in the cement industry. Nano $CaCO_3$ particles are additive materials with high potential for cementitious composites. They could be produced via an innovative CO_2 emissions recovery system in cement manufacturing. Results from mechanical tests so far have been very encouraging [88].

- **brick industry:** The use of calcium carbonate as additive for the elaboration of red bricks, has been studied by several authors [89,90,91], in those cases, such addition is generally reported at high rates for burning temperatures, ranging from 900 to 1000 ºC. It was demonstrated that the addition of calcium carbonate into the clay admixture in amounts ranging from 2 to 5% improves bricks compressive strength at temperatures close to 900ºC and, it also improves sintering periods from 1 to 3 hours. Such effect is explained by the modification of reactions occurring in clays during a thermal treatment, due to the presence of calcite mineral, which enables the sintering process at lower temperatures in studied clays, which mineralogical composition is mainly montmorillonite mineral [92]
- **packaging industry:** One way that you can help to reduce the environmental footprint of packaging is through the use of a mineral filler with Calcium Carbonate. Not only does the use of this mineral offer a cost savings through the displacement of resin but adding calcium carbonate to plastic has also been shown to offer added benefits such as faster heating and cooling, significant energy savings as a result of improved productivity, and higher outputs. The use of $CaCO_3$ in plastics has been steadily increasing over the years. Studies conducted by Heritage Plastics have shown that using a 40% loaded calcium carbonate filled polypropylene can generate a Green House Gas savings of approximately 23% - and this is before taking into consideration the increased productivity mentioned.

3.7.3. Sustainability of the residual biomass and supply chains

According to RED methodology (Dir. EU 2018/2001, Annex V, Part C), compared with ‘conventional’ first generation feedstock, the use of these residual materials would imply greater sustainability and less competition for land used for food and feed production.

Sustainability needs specific emphasis, because it is both a transversal driving force and a challenge for guaranteeing long-term biomass strategies.

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Criteria involved to define the Sustainability of the final products (energy and biofuels) are

- biomass sustainability;
- supply chains sustainability certification;
- greenhouse gas saving.

The definition of sustainable biomass value chains should not represent an unmanageable obstacle for farmers and industries to develop supply chains.

Concerning the sustainability criteria, the RED II assumes that:

- biofuels, bioliquids and biomass fuels produced from waste and residues, other than agricultural, aquaculture, fisheries, and forestry residues, are required to fulfil only the greenhouse gas emissions saving criteria;
- biofuels, bioliquids and biomass fuels produced from waste and residues derived not from forestry but from agricultural land shall be considered only where operators or national authorities have monitoring or management plans in place in order to address the impacts on soil quality and soil carbon.

Biofuels, bioliquids and biomass fuels produced from agricultural biomass shall not be made from raw material obtained:

- from land with a high biodiversity value, namely land that had one of the following statuses in or after January 2008, whether or not the land continues to have the status of primary forest and other wooded land, highly biodiverse forest and other wooded land, areas designated for nature protection or conservation purposes, highly biodiverse grassland spanning more than one hectare (Art. 29, point 3);
- from land with high-carbon stock, namely land that had one of the following statuses in January 2008 and no longer has the status of wetlands, continuously forested areas spanning more than one hectare with trees higher than five meters and a canopy cover of more than 30 %, land spanning more than one hectare with trees higher than five meters and a canopy cover of between 10 % and 30 % (Art. 29, point 4);
- from land that was peatland in January 2008, unless evidence is provided that the cultivation and harvesting of that raw material does not involve drainage of previously undrained soil (Art. 29, point 5).

3.7.4. The Industrial Emissions Directive (IED) 2010/75/EU

Industrial production processes account for a considerable share of the overall pollution in Europe due to their emissions of air pollutants, discharges of wastewater and the generation of waste.

Directive 2010/75/EU of the European Parliament and the Council on industrial emissions (the Industrial Emissions Directive or IED) is the main EU instrument regulating pollutant emissions from industrial installations. The IED was adopted on 24 November 2010. The IED aims to achieve a high level of protection of human health and the environment taken as a whole by reducing harmful industrial emissions across the EU, in particular through better application of Best Available Techniques (BAT).

Best Available Techniques Reference Documents (BREFs) are reference reports developed in the European Union to describe industrial processes, emission and consumption levels of applied techniques, and best available techniques for integrated prevention and control of pollution from industrial activities.

BREFs provide descriptions of a range of industrial processes, where also regular comparisons with sector, national or regional benchmarks are provided.

The IED is based on several pillars, in particular an integrated approach, use of best available techniques, flexibility, inspections, and public participation.

The integrated approach means that the permits must take into account the whole environmental performance of the plant, covering e.g. emissions to air, water and land, generation of waste, use of raw materials, energy efficiency, noise, prevention of accidents, and restoration of the site upon closure.

The documents refer to plants with bigger size than GICO. However, the documents can give some of the published documents can give us useful information about the key environmental issues to consider, together with some emission levels to benchmarked with GICO in order to quantify the impact reduction of our process.

4. MARKET PORTER'S ANALYSIS

4.1. MARKET PORTER'S Table

Porter's Five Forces Model is a comprehensive yet easy-to-use market analysis tool that helps companies gain understanding of their industry's customers. It is based on five forces that shape industry competition.

- **Competitive Rivalry**: The current intensity of industry competition, as determined by the number of existing competitors and what each player is capable of doing. Rivalry is high when companies in the industry are numerous or are roughly equal in size and power (thus equally selling a product or service), when the industry is growing, and when customers can easily switch to a competitor's offering.
- **Supplier Power:** How much power and control suppliers have over the potential to raise prices of the products and service provided. Sources of supplier power include the number of available suppliers, switching costs from one supplier to another, the presence of available substitutes, and how critical the inputs are to the industry.
- **Buyer Power:** The power of customers to affect pricing and quality. Customers have power when there are large numbers of sellers and when it is easy to switch between different sellers. In contrast, customers have low power when they purchase products in small quantities and the seller's product is very different from any of its competitors' products.
- **Threat of new entrants:** Barriers to entry into the marketplace in the industry. These can include patents, economies of scale, capital requirements, and government policies.
- **Threat of substitute products or services:** The availability of products or services that can serve the same purpose. This is measured by the amount of available substitute products or services, the level of switching costs, and the likelihood of customers switching to alternatives in response to price increases. This differs from bargaining power of customers in that the emphasis is switching to different products rather than to different suppliers.

Table 5 MARKET PORTER'S Table

Threat of New Entrants - MEDIUM

High initial capital intensity

Complex and different authorization rules between states

Presence of many supports scheme offered by the government.

Low market maturity

Supplier Power - LOW

Large number of small biomass suppliers

Dependence on a low number of suppliers of consumables products (membranes, catalyst materials)

The fast advancement in technology has helped in reducing the cost of manufacturing (SOFC) and increased competition

Competitive Rivalry - HIGH

High due to the presence of new emerging companies globally specialized in alternative RES (CHP, SOFC, biofuels plants).

Very small number of competitors already on the market able to combine all the technologies present in GICO

High competition of electric vehicle with biofuels

Buyer Power - LOW

High switching costs

Low market maturity

Complex installation and authorization procedures

Incentives more reward decentralized and continuous production over time, this lowers the risk of exchange of the source of production

Threat of Substitutes - MEDIUM

High number of low costs fossil substitutes

High number of alternative traditional RES for electricity (solar, wind, biomass CHP) and transport (electric vehicles)

Reduced number of substitutes capable of producing biomethanol from residual CO_2

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4.1.1. Competitive Rivalry

The presence of incentives and subsidies focused on RES has given it a boom for new companies to enter into the market. The presence of global warming has also increased the companies to focus on clear energy. These factors create a high level of competitiveness on the market both in relation to the existing company (Competitive Rivalry) and for the possible entry of new companies (Threat of New Entrants).

Even if, on the other hand, there are few competitors with a high level of development able to enter the market within a few years and a very small number of competitors already on the market able to combine all the technologies present in GICO.

In other hand, there will be a high competition of biomethanol with electric vehicle. The overall energy efficiency of electricity use in battery electric vehicles (BEVs) is 4-6 times higher than for e-fuels in combustion engines. The battery electric vehicle has a total overall efficiency (from the power generation point to the final user) of around 69%, while a fuel cell vehicle has an efficiency of around 26% - 35%, and a liquid e-fuel car has an efficiency of around 13–15% [89].

In the transport sector, much of the policy focus is on electromobility and support for increasing the share of EVs, especially for passenger cars. Batteries and hydrogen fuel cells may be challenged in meeting the energy demands of long-haul trucking, shipping, and aviation. Further, the legacy fleet of combustion engines will continue to power cars, trucks, buses, ships, and aircraft for years to come even as electromobility makes market inroads and charging infrastructure expands.

4.1.2. Supplier Power

It can be considered that the supplier power is low due to the fast advancement in technology has helped in reducing the cost of manufacturing (SOFC) and increased competition. In other hand there are a number of threats mainly due to High Dependence on a low number of suppliers of consumables products (membranes, catalyst materials). The presence in the consortium of specialized producers of these products reduces this risk and allows good control of the market.

A large number of small biomass suppliers allows to increase competition and obtain affordable prices of the raw material (residual biomass). The "local" nature of the system, especially in relation to its nature of distributed generation, allows the creation of a chain of local suppliers which therefore reduces the risk of volatility in the purchase of residual biomass and low-cost absorbents (CaO)

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4.1.3. Buyer Power

In this sector, customers have a relatively modest power above all due to the nature of the product (high initial costs and low sales numbers due to the low number of vendors on the market compared to traditional and fossil micro-plants). Furthermore, incentives more reward decentralized and continuous production over time, this lowers the risk of replacement of the source of production.

The selling price of the product is therefore not very influenced by the buyers' market, it is instead more dependent on the variation of the incentives on the CAPEX which could cause volatility.

In fact, CAPEX incentives (normally limited to a time period of 3-5 years) can create a speculative bubble with an increase in sales prices during the incentive period and zero sales at the end of the incentive.

4.1.4. Threat of New Entrants

The presence of manufacturing companies specialized in renewable energy makes the GICO consortium well established in the potential market. The threat of the entry of new competitors in the market area where you want to go to insert GICO can be evaluated as Medium.

The technologies, even if of medium size, have a high initial capital intensity (CAPEX) compared to traditional fossil fuel or traditional renewable technologies. This also entails a higher initial investment for the manufacturing companies to build the plants, reducing the number of potential competitors heading towards this market.

In parallel the complex and different authorization rules between states constitutes considerable barriers for new entrants (higher costs of legal advice and authorization in the initial phase).

However, technologies related to process CO_2 storage and its conversion into renewable fuel, sectors which have numerous support schemes offered by the government, can have a high opportunity for new entrants.

4.1.5. Threat of Substitutes

The threat of subsidies for the production of electrical and thermal energy is divided into two broad categories:

- replacement with RES: in this case the threat is given by the low cost of some RES (photovoltaic, solar) even if they are discontinuous and require storage systems. This makes the replacement risk medium

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- replacement with fossil fuels: these technologies have now reduced initial costs due to their wide diffusion but are increasingly subject to taxation for the emissions and are not subject to incentives on CAPEX and OPEX. This makes the replacement risk very low.

At the same time, however, there is a limited number of substitutes capable of producing biomethanol from residual CO_2. Competitors in fact produce methanol from biomass or fossil, less advanced technologies, and dependent on "fuels".

There are also possible innovative substitutes considered renewable such as hydrogen, which however still have problems that make the risks of a substitution low. Hydrogen gas has been proposed as an energy storage medium and produces, besides energy, only water when combusted. In practice, however, because of its low volumetric density hydrogen requires either compression to high pressures (350-700 bar) or liquefaction at very low temperature (-253°C), making its storage problematic and energy-intensive. It is also highly flammable and explosive and can diffuse through many commonly used metals and materials [98].

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5. SWOT ANALYSIS

A SWOT analysis is a common tool used to plan and understand the four major categories involved in a project, business, or technology. For using such a tool, it is needed to specify the objective of the project and identify the internal and external factors that are supportive or unfavourable to achieving that objective. A SWOT analysis is often used as part of a strategic planning process.

SWOT analysis helps to identify the internal and external factors to analyse and evaluate factors that favour or deter the planned objectives:

- internal factors: an advantage over others (Strength) or deficiencies (Weakness).
- external factors could be categorized as an advantage (Opportunity) or concern (Threats).

Internal and external factors which are of relevant for evaluation are prioritized based on their significance and used for decision-making.

Starting from the PESTLE analysis it was realized a complete SWOT. The results of a SWOT analysis are summarised in a SWOT matrix. In the following paragraphs (5.1, 5.2, 5.3, 5.4) all the factors are described in more detail.

Table 6 Structure of a SWOT matrix

	Success factors	Failure factors
Internal	STRENGTHS	WEAKNESSES
External	OPPORTUNITIES	THREATS

To increase the chances of success of the GICO technology, short-term and long-term countermeasures against the identified negative factors need to be scrutinized. In this way, the stakeholders can apply these countermeasures to limit the negative factors that may limit the commercial success of this technology. Paragraphs 5.5 and 5.6 present the main countermeasures against the negative factors identified.

Table 7 SWOT final table

	Success factors	Failure factors
	STRENGTHS	**WEAKNESSES**
Internal	**Modularity:** The system consists of modules that can be marketed integrated or individually.	**Level of development:** Immature (TRL4-5) technology for commercialization. Large-scale production could present other drawbacks compared to those found in laboratory experiments.
Internal	**Residual Biomass:** Use of low-cost residual biomass with constant production and currently considered as waste	
Internal	**Circular economy:** reuse of CO_2 sorbent in other industrial sectors	**O&M:** presence of consumable materials, such as catalysts and membranes to be replaced periodically to ensure the correct functioning of the system, with high costs due to a still restricted market.
Internal	**Biomethanol flexibility:** used in transport sector in alternative to fossil fuels and electric mobility	
Internal	**Near zero GHG Emission:** by combining the CO_2 plasma conversion system and SOFCs to produce electric and thermal energy and biomethanol	**Technical installation requirements:** GICO requires significant space for gasifier, GCU, SOFC, fuel storage.
	OPPORTUNITIES	**THREATS**
External	**Rural regeneration:** creation of additional income for farms or small forestry companies, creation of a series of high skill green jobs in the area	**Market competition:** lower prices of conventional fossil energy technologies and presence of new renewable competitors
External	**Green retrofitting:** the installation of individual technologies can be integrated into existing CHP plants, improving efficiency (SOFC vs ICE), reducing emissions (CO_2 plasma conversion), expanding treatable waste (SEG)	**RES Competitor incentives:** presence of incentives on competing RES technologies (solar, batteries, wind)
External	**Energy community:** increase the local green prosumers, increase in the efficiency of the electricity grid and reduction of the energy costs (self-consumption incentives)	**Complex and instable Subsidy schemes:** in the future may pose a risk if the technology cannot decrease the investment costs.
External	**Electrification:** The trend to electrification in the future will be an opportunity for fuel cells which can achieve higher power-to-heat ratios than other CHP technologies.	**Installation rules:** unclear national installation regulations could slow down the spread of the system
External	**Green Electric storage and grid flexibility:** indirect storage of energy from discontinuous RES through the use for CO2 conversion	**Biomass acceptance and supply chain:** the use of biomass to produce biofuels and biochemicals is a relatively new activity and meets the resistance. The supply chain is not organized like that of fossil fuels.

5.1. STRENGTHS

The main STRENGTH of the GICO project is the **modularity** of the system, which consists of modules that can be marketed integrated or individually. In fact, this modularity also allows the marketing of single products, which are inserted in highly developed markets (Syngas cleaning technologies CAGR 20%, Gas separation membranes CAGR 6%, CCUs CAGR 19.2%).

The other major strengths are related to the environmental aspect. The system, in fact, allows to produce energy from **residual biomass** waste that is not discontinuous as the other RES (sun, wind, hydroelectric), storing CO_2 and reusing the residue in the cement, plastic and construction industries. The process is carbon neutral.

Residual Biomass is one of the few RES whose availability does not depend on weather conditions, seasonal or diurnal variations and can be stored, for use on demand. This represents an important advantage, allowing electricity generation from biomass to be highly predictable and contributing to base load capacity. This will allow to widen the type of feedstocks that can be used developing solid intermediate bioenergy carriers between 5 to 10 €/MWh cost, including high humidity and ash content residual biomass and waste that, normally, are the one with greater potential and lower cost, so reaching applicability to around 678 Mt/y of EU residual biomass.

The carbon capture with calcium-based sorbents uses relatively abundant cheap materials with several outlet markets for spent sorbents (iron, steel, aggregates and cement industries) making the SEG process a fully circular and economically viable process where the CO_2 sorbent ($CaCO_3$) can be reused in other industrial sectors in optical of **Circular economy.**

Biomethanol is very flexible fuels and has several advantages compared to some other renewable energy carriers, including hydrogen, CNG/LNG, ammonia, and batteries. The liquid state makes it easy to store, transport and distribute by ship, pipeline, truck, and rail. Requirements for methanol storage and transport are similar to other flammable liquids such as gasoline, jet fuel, and ethanol. Methanol can be used in combustion ignition (diesel) engines. Methanol used as an automotive fuel can be dispensed in regular filling stations, requiring only minimal and relatively inexpensive modifications.

Another application of methanol in the transport sector is in combination with Fuel cell electric vehicles (FCVs). FCVs represent a strong potential for a decisive reduction of the greenhouse gas emissions from road transport but that these technologies are still far from being technologically reliable and

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economically competitive. Methanol-based FCEVs are less technologically mature than those fueled by hydrogen, and they are notably more pollutant and more expensive. They can however represent a good compromise between security of supply and environmental concerns, bypassing, at the same time, the economic barriers and the safety concerns related to hydrogen distribution and dispensing. In this framework, the use of blends of biomethanol with gasoline, along with the development of Flexible Fuel Vehicles, could represent an immediate and viable option that can also favor the transition towards methanol based FCVs.

The production of electricity and biomethanol at the same time from natural and anthropogenic sources, including residual biomass and the conversion with plasma technologies (powered by a discontinuous renewable source) of CO_2 from fumes, could be the first step towards an anthropogenic carbon cycle. The removal of even a fraction of the CO_2 from industrial emissions would result in the availability of huge amounts of CO_2. Using the CO_2 captured from fossil fuel sources or other industrial process to produce energy and bio methanol instead of simply releasing the CO_2 to the atmosphere could potentially halve the emissions. **This type of energy carrier can therefore be considered a near zero-carbon fuel.**

5.2. WEAKNESSES

The main weaknesses are related to the **Level of development** of the GICO integrated system. The integrated system is in fact composed of technology with TRLs between 4 and 6 (at the end of 48 months). Still commercially immature technology – not many large-scale companies in production. This can lead to directly related weakness: a large-scale production (TRL9) could present many other drawbacks compared to those found in laboratory experiments (TRL6).

In this period the regulations and subdivisions now present could in fact change and move towards alternative systems and already in the marketing phase (electric cars versus biofuels, wave motion vs. residual biomass etc ...)

The presence of innovative materials (membranes, catalysts) allows the project to increase efficiency and distinguish itself from more traditional competitors. At the same time, however, these materials have a limited duration of time (4000 - 7000 hours) and must be replaced to ensure the correct functioning of the system. This involves, especially in the initial phase of commercialization**, an increase in OPEX costs due to high costs of catalysts and membranes** due to a still small market; absence of an organized distribution chain and with reduced procurement times.

Another weakness about the system is related with the **technical installation requirements.** The integrated system containing all the technologies in fact occupies an installation space that can be between 100 and

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150 square meters. The plant also requires areas for the storage of residual biomass to be treated (possibly also a space for shredding). Current cogeneration plants also have a very large footprint. Traditional fossil systems (methane cogenerators, combustors, etc.) occupy a much more limited space as they are mainly powered by the network (they do not require fuel storage).

5.3. OPPORTUNITIES

The greatest opportunities that GICO can provide are related to its "local" configuration for the production of Distributed Generation electricity and fuels, especially in energy communities.

The capacity of agriculture to mobilise further unexploited potential will be crucial to meet the EU long term emissions reduction target. To this end, bioenergy-oriented agriculture development will be a key driver to determine the long-term potential available. With 95% locally produced biomass, the growth potential of bio-energy relies essentially on the potential of sustainable biomass resources available in Europe. They positively contribute to **Rural regeneration**, representing a possible income for farmers, and if used as bioenergy feedstock they contribute to climate change mitigation strategies [94]

Biomass residues used in GICO is a domestic energy source and contributes to the green transition of local economy and diversification of the fuel mix and to the security of supply and reduction of the energy import dependence (fossil fuels). The expected increase of electricity demand from biomass sources in the industry sector of every target country will give higher market opportunities for biomass technologies.

The transition to the circular economy and the fulfilment of the objectives to become climate neutral will require the full mobilization of the industry and will bring new business processes and changes in the manufacturing and new technologies. On the way, the EU is working hard to balance economic growth with the need to protect the environment and has set itself challenging targets for reducing greenhouse gas emissions, increasing energy efficiency, and promoting renewable energy, and reducing waste.

The bioenergy sector in Europe employs **(green jobs)** more people than all other renewables combined, with employment concentrated in rural areas. In parallel, it contributes with €60 billion to Europe's economy (2019) across a diverse value chain from forest management to cutting edge manufacturing.
This has given rise to a wide range of "green jobs." One of the definitions of "green jobs" set by the EC is *"…covering all jobs that depend on the environment or are created, substituted or redefined (in terms of skills sets, work methods, profiles greened, etc.) in the transition process towards a greener economy." [99].* GICO can be installed to replace existing fossil plants or as a **green retrofitting** of existing cogeneration plants: the installation of single technologies can be integrated into existing CHPs (ICE

replacement with SOFC, CO_2 conversion, CO_2 sorbents in existing gasifiers) reducing the initial CAPEX compared to a completely new plant and reducing the amount of existing plant to be disposed of.

Installation in **energy communities** can bring many opportunities: electrification, stimulation of the local economy, increase in local places generated by the creation of prosumers, increase in the efficiency of the electricity grid and reduction of the energy costs of the participants. Local energy allocation can reduce local peak demand and the payment for grid services. If more prosumers use the electricity produced locally in the community and aggregate their consumption profiles, the energy flows from the main grid will decrease. Self-consumption in a community will therefore reduce the recovery of distribution network costs and policy charges and taxes.

The grid costs are distributed equally among the users of the system as the same type of network guarantees the same costs distribution.

Many studies have shown that end use **electrification**, especially when applied to heating buildings, will significantly increase peak demand. Even when maximising demand efficiency and meeting heating and cooling demand with highest efficiency heat pumps, it is expected that peak demand in winter will more than double in many European countries. The challenge of matching increasing peak demand with variable renewable energy requires an integrated systems approach. A mix of efficient and renewable solutions is needed to address it. GICO will be key to complement electrified demand and help support security of supply cost-effectively.

The possibility of **green electric storage** of discontinuous electric RES (wind, hydro, or solar energy) through the use of energy for conversion of CO_2 contained in exhaust fumes in chemical energy vectors (e.g. liquid and gaseous biofuel) will be an alternative to alleviate many of the problems associated with the intermittency and peak in the electric grid. The system will be able to Provide **flexibility for the grid.** By generating biofuel and power at times of peak demand, GICO can significantly improve the stability of the grid and strengthen its resilience. Estimates based on whole electricity system modelling for the EU show that an additional kW of installed CHP will reduce grid reinforcement costs between € 1.500 – 2.500 up until 2050 [96].

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5.4. THREATS

The main threat for GICO technology is the **Market competition,** related to the presence of fossil fuels with low initial cost (high diffusion) able to compete on CAPEX and OPEX of renewable systems.

Recently crude oil prices have been relatively low compared to historical levels with somewhat reduced demand and plentiful supply, including from the USA. This trend is expected to continue, although some price volatility is always to be expected due to short term supply and demand imbalances.

Global oil prices have ranged between 22 USD/MWh and 40 USD/MWh (19-30 EUR/MWh) [6] over the last five years. Prices of gasoline and diesel fuels follow closely the trends in oil prices but are on average some 35% higher than crude oil prices on an energy content basis. These data suggest that it is appropriate to take a fossil fuel price range of 30-50 EUR/MWh as a current benchmark for the basket of fossil fuels for which advanced biofuels are being considered.

In parallel there is a **competition with renewable fuels** (electricity from solar, "conventional biofuels").

The current and projected costs of the green biofuels considered (methanol derived from residual biomass and CO_2 conversion) are compared with those of "conventional biofuels" such as bioethanol and biodiesel, with a range of current prices for fossil fuel, and with longer term cost energy price projections. The need for financial support to "bridge the gap" between today's costs and those of fossil fuels is estimated.

Through the RES LEGAL Europe Comparison Tool, they compared parameters and contents of different support schemes for the countries and energy sectors of your choice [97]. Support to renewable energy, at USD 166 billion in 2017, was almost 19 times smaller than the subsidies to fossil fuels in the same year [97]. Four types of support schemes were mainly in place in Europe:

- Feed-in tariffs (FiTs);
- Feed-in premiums (FiPs);
- Green Certificates (GCs); and
- Investment grants.

In eight EU countries subsidies for energy from solid biomass represent less than 10% of the total financial support given to renewables, in only three countries they account for more than 20% of the total support given to renewables. There is generally a clear correlation between countries with high share of the renewables support going to biomass and the share of biomass in gross electricity generation. For the use of solid biomass in final energy consumption the relation with government subsidies seems to be less pronounced. It should be noted though, that in many countries the use of biomass for heating is less heavily taxed than the use of other energy carriers, and in many cases no energy taxes are applied at all.

Figure 7 Overview of the share of biomass in total renewable energy subsidies in 2015 and 2016 [98]

Country	Bioenergy subsidies (EUR million)		RES subsidies (EUR million)		Bioenergy as % of total	Bioenergy as % of total
	2015	2016	2015	2016	2015	2016
Finland	79	47	229	194	35%	24%
Austria	283	275	1 096	1 179	26%	23%
Belgium	279	309	1 395	1 378	20%	22%
United Kingdom	1 384	1 399	9 391	8 658	15%	16%
Sweden	60	53	381	368	16%	14%
Slovakia	52	67	474	464	11%	14%
Spain	781	948	9 261	8 179	8%	12%
Portugal	86	80	963	1 137	9%	7%
Germany	1 724	1 746	25 544	26 199	7%	7%
Italy	242	740	12 169	11 877	2%	6%
Poland	79	39	1 019	636	8%	6%
Ireland	4	9	97	160	4%	6%
Denmark	60	59	1 117	1 107	5%	5%
The Netherlands	29	57	863	1 159	3%	5%
France	256	319	5 544	6 497	5%	5%
Total	**5 399**	**6 147**	**69 541**	**69 192**	**8%**	**9%**

Several countries have not developed a legislative and institutional framework and tooling for the CHP sector development. Despite the fact that countries promote renewable energy investments, they often exclude CHP installations, or suddenly interrupt support for new renewable energy power plants. As a result of this **lack of regulations and support schemes they reach a low CHP share in total electricity generation.**

Although, at European level, there is a large set of regulations and Directives, which aim to promote the CHP sector, at state level, governments follow different approaches, impeding the development of adoption CHP facilities. Another important factor for developing such large and complicated systems, is the existing legal, regulatory environment as well as the institutional arrangements and the permitting procedures.

Other aspects to be considered as a threat are related to **the social acceptance of using residual biomass for energy purposes and the related supply chain:**

- biomass use for producing biofuels and energy is a relatively new business and it faces resistance: for many citizens who are scared by its "environmental unfriendliness" and the generally "high" emissions of particulates linked with biomass technologies, as well as by the concern that not only biomass but also waste can be directed to the same plants, the latter being considered even more environmentally impactful than biomass;
- lack of technical and non-technical know-how, concern about soil depletion due to residues collection;
- lack of information regarding successful business cases.
- the different steps in the biomass supply chain are complex, and logistics, organisation and management are recognised as main challenges. Together with the actual biomass availability it is necessary to consider some aspects related to the supply chain such as the collection from the origin places, the transformation in the products useful for the energetic valorisation and the transfer to the place of final use. The dispersed nature of biomass resource involves complex transportation problems within the supply chain. It is widely assessed that if each step of the whole bioenergy chain is not optimised, the final cost of the produced biofuel may result not competitive in comparison with the fuel from traditional fossil source. The costs of the fuel from residual biomass are mainly: biomass collection, treatment, storage, transport, and conversion costs. One of the most important problem in using biomass as a fuel in fact is the spreading out of supplies together with the low territorial density, in comparison with the traditional fossil fuels. Moreover, the biomass supply is also in most of the cases seasonal, namely variable in time, thus creating the need of a temporarily stockpiling before and after the delivery to the GICO plant.

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5.5. Possible countermeasures

To increase the chances of success of GICO's technology, short-term and long-term countermeasures against the identified negative factors need to be scrutinized.

Table 8 Countermeasure for Weaknesses

Weaknesses	Countermeasure
Level of development	The presence of high European funds for the development of technologies aimed at reducing CO_2 emissions can be an excellent driving force for speeding up development activities in order to bring GICO to be marketable within 10 years after the end of the project. The EU offers a set of funding programs to help finance European energy projects, including for CCS and CCU. These cover the full range of technology development levels, from research under Horizon 2020 and Horizon Europe to commercial scale projects in the Innovation Fund. EU funding schemes and innovation networks are vital in supporting early deployment of CCS and CCU. The Connecting Europe Facility (CEF) is a European Commission funding initiative which has a series of calls aimed at developing cross-border CO_2 infrastructure.
O&M costs	Using Condition-based maintenance (CBM) strategy, combined with the improvement of the performance of membranes and reagents (tests during the project period) allow an optimization of maintenance operations. The replacement of high-cost materials with materials deriving from circular economy (CaO, iron oxides etc.) allows to reduce ordinary maintenance costs (syngas filtration, CO_2 conversion).
Installation	Promote the use of locally sourced fuels to reduce biomass storage volume. Optimization of SOFCs and non-thermal plasma generator with reduction of overall dimensions.

Table 9 Countermeasure for Threats

Threats	Countermeasure
Market competition:	Introduce a carbon tax on fossil fuels to promote the use of renewables and biomass fuels. Introduce policies to mobilise agricultural and forest residue biomass for fuel production to increase availability and reduce costs.
Competitor incentives:	Revise/implement national support schemes to support technologies based on their overall environmental and energetic performance. Revise/implement national support schemes for biomass to incentivize the use of locally-sourced agricultural or forest residue biomass, thereby helping to stimulate fuel supply chains, enhance energy security and develop regional economies.
Complex and instable Subsidy schemes	Standardization of technology (consumption, dimensions, emissions, residues) to easily comply with all national regulations and speed up the authorization procedures. Provide together with the sale of the "GICO system" also the authorization procedures by personnel specialized in such authorizations. Governments could fund the certification and testing of CO_2-based products (biomethanol, CaO etc..) by organizations such as UL, ASHRAE, ASME and others. These accreditation processes can accelerate and simplify the adoption of new technologies into existing supply chains but do require funding in order to conduct the necessary testing and certification steps.
Installation rules:	Simplification and European standardization of the installation rules for the small-medium power plants with zero CO_2 emissions.
Social acceptance and supply chain	Develop a regional roadmap for the usage of locally available agriculture and forest biomass residue. Provide together to the customer also a preliminary contract with the biomass supplier. Carry out communication activities capable of training the population on the different types of biomasses (primary and residual) and on the different technologies present and related emissions (ICE, combustor vs GICO with SOFC)

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6. CONCLUSIONS

The detailed market analysis carried out allowed to define how the sectors in which GICO is inserted have a high growth potential (CAGR between 6% and 30%). In particular the highest projections of the long-term strategy foresee an increase in bioenergy consumption of around 80% by 2050 compared with today.

GICO's main success factor is in its modularity and simultaneous production of four energy carriers (bio-syngas, electricity, heat, biomethanol) with reuse of waste CO_2, starting from low-cost residual biomass of local origin. The use of local biomass residues solves the inconvenience linked to the use of biomass as an energy source, and the competition with food (primary energy crops), facilitating the simultaneous disposal and enhancement of highly degradable waste.

The bio-syngas from thermal biomass gasification processes is an outstanding energy carrier. It can be used as a stand-alone fuel (heat and power applications), or it can be further treated and transformed into another energy carrier by chemical upgrading and synthesis.

The production of electricity, heating, and biomethanol at the same time from natural and anthropogenic sources, including residual biomass and the conversion with plasma technologies (powered by a discontinuous renewable source) of CO_2 from fumes, could be the first step towards an anthropogenic carbon cycle.

The PESTLE analysis made it possible to have a clear overview of all the external factors that can affect the success of the GICO project:

- the use of sustainable and residual biomass will play a considerable role in meeting the 2030 target to reduce greenhouse gas emissions, as well as the objective of climate neutrality by 2050 in the European Green Deal. The theoretical availability and cost modelling indicate that large volumes of biomass residues could be made available to users at costs between 5 to 10 €/MWh.
- the adoption of a new energy taxation rules, which taxes electricity and energy products on the basis of energy content and environmental performance, allows us to be competitive with respect to traditional fossil fuels and also to RES.
- the presence of regulations that require prosumers to be equipped with a smart meter and a dynamic price contract allows them to be rewarded for moving consumption / production in times when energy is widely available and cheap. The configuration of GICO allows to "store" the surplus of discontinuous RES through the conversion of CO_2 and therefore to obtain economic rewards on contract at a dynamic price;
- the electrification, in particular with Distributed RES generation, of the energy market plays a key role in the energy policies of the European Union, but also of developing countries: electricity

meets 21% of global final energy consumption by 2030. The Increasing rural electrification rate, particularly in developing countries, has escalated the demand for decentralized electricity generation, which is majorly driving the global biomass gasification market toward growth.

- In the transport sector electrification is not an effective solution for all sectors. Deep sea shipping and aviation are two areas, where fuels with a higher energy density (biofuels) can offer an alternative route to carbon neutrality target and has the advantage that it can be deployed across the whole existing fleet without modifications to the engine, using much of the current distribution infrastructure.
- The key factor for a positive social acceptance of biomass residues utilisation for energy uses, biofuels, and CCSU technologies is directly related to the quality and dissemination of the communication activities that will be carried to the entire chain of stakeholders. Social acceptance is also directly related to the system's ability to create a circular economy: reusing process waste materials in other sectors allows both to have a second source of income and to reduce the CO2 and waste footprint.

Porter's model of the five forces made it possible to better define the key points that characterize GICO's success on the market:

- the market sees a high level of competitiveness between residual biomass and other traditional renewable sources more incentivized and with lower initial investment costs: GICO's winning key lies in its ability to produce decentralized low-cost electricity and simultaneous production of methanol, exploiting of waste CO2 (CCSU);
- technologies related to process CO2 storage and its conversion into renewable fuel have numerous support schemes offered by the governments. This is a positive factor for the marketing of GICO but increases competition by favouring the entry of new entrants into the market;
- the power of the customers is low as the incentives on OPEX reward decentralized and continuous electric production over time, the installation procedures are complex: these factors reduce the risk of switches between production plants
- the transport market sees a high level of competition from methanol with electrical systems. Much of the political focus is on electromobility and support for increasing the share of electric vehicles, particularly for passenger cars. Biomethanol, however, has a number of advantages: the liquid state makes it easy to store, transport and distribute it by ship, pipeline, truck, and rail, and it can be used in combustion ignition (diesel) engines and dispensed in regular filling stations, requiring only minimal and relatively inexpensive modifications.

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The SWOT analysis highlights that the successful of GICO system depends decisively on the following main factors:

- the modularity of the GICO system to enter different market sectors;
- complete development times of the GICO (TRL in 10 years) to anticipate any competitors;
- streamlining of the regulatory framework (plant, incentives, biomass certification);
- presence of subsidies and incentives capable of rewarding the generation of distributed generation and energy communities;
- communication campaign to promote the acceptance of biomass residues as a green and clean energy source and methanol as a transport fuel capable of integrating electrical systems and being an alternative to fossils in sea or air transport;
- cost trend of SOFCs and catalysts and membranes to be competitive with traditional solutions (ICE, filters);
- "local" configuration for the production of Distributed Generation electricity and fuels, especially in energy communities.

Having established the strong competition from today until 2030 in the sectors of energy production from renewable sources and in the transport sector (electric mobility), the GICO configuration with the greatest potential has the following main characteristics:

- small and medium-scale plants (2-20 t/day and < 5.000 kWe) near sites with high production of waste CO_2 that are reconfigured to green companies. The small size is a winning factor both for the smaller space required and for the containment of authorization times;
- use of a wide spectrum of residual biomass deriving from local and certified supply chain. A certified and local supply chain allows to have a high level of social acceptance and a reduction of emissions in certified and certain logistics;
- use the methanol produced in the local area to reduce emissions from the transport chain, especially for powering heavy vehicles which are not convenient for electric power supply;
- decentralized energy production in renewable energy communities. The GICO plant stands as a fulcrum in the nascent energy micro communities. The members of the energy community thus become prosumers, supplying the raw material (residual biomass, CaO, waste CO_2) and purchasing electrical, thermal and biomethane energy for the vehicles. The electricity produced

and self-consumed within the community is also subject to OPEX incentives (€ 119 / MWh in Italy) which allow for a reduction in the investment payback time;

- integrate the installation with communication activities capable of training the population on the different types of biomasses (primary and residual) and on the different technologies present and related emissions (ICE, combustor vs GICO with SOFC).

In this configuration, the system allows to create local added value, a high number of green high-quality jobs throughout the supply chain (recovery of waste biomass, decentralized energy production, distribution of the energy products) and to have a positive social impact (reduction in the import of fossil fuels, reduction of use of lithium batteries, reduction of net GHG emissions). At the same time, distributed generation makes it possible to stabilize the grid (increase the self-consumption rate, peak shaving, increase grid efficiency, improve load shifting and valley filling strategies) and obtain the CAPEX and OPEX incentives connected to the self-consumed energy. The CO_2 conversion system allows to store the energy produced by other discontinuous RES producing four types of renewable energy carriers with almost zero emissions without the problems associated with the production of lithium batteries.

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