Monitoring Reporting and Verification	*Document information* **MRV 001 - A**	*Date* April 2023
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DRAFT INTERNAL METHODOLOGY FOR MRV

LIMENET + DAC

Abstract

This MRV methodology outlines LIMENET internal procedure to count the total GHG emission avoidance for LIMENET + DAC system, the monitoring system (calculation and measurement approach) all the uncertainty present in the ocean alkalinization system to permanently remove CO_2 and the possible implementation of Blockchain as internal tracking tool for negative emission.

Methodology Information

BASIC INFORMATION	
Methodology Name	DRAFT INTERNAL METHODOLOGY FOR MRV LIMENET + DAC
Version	MRV 001 - A
Date of Issue	26/09/2022
Sector	Direct Air Capture + Ocean Alkalinity Enhancement
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Summary

CARBON SEQUESTRATION & STORAGE LIMENET-DAC

1 Introduction

To cope with the climate goals of 2015 Paris Agreement, a lot of solutions has come to te market with negative emission technology. However, during the past years it has been difficult to precisely count the positive impact of those technologies. Because of that, a specific procedure must be followed to precisely count each impact of each technology and see the total final benefits in respect to a reference scenario. LIMENET S.R.L. BENEFIT is developing its own MRV (Monitoring, Reporting and Verification) procedure to deliver its best precise information about all LIMENET + DAC technology emissions.

This is done referring to ISO 14064-2:2019 Standards for quantifying greenhouse gas emissions, REGULATION (EU) 2018/2066, REGULATION (EU) 2015/757 and its amendments.

In summary this is done with four steps:

a) Preliminary LCA analysis done by a third-party evaluator.

The AWARE ICRC – AWARE (polimi.it) research group of Politecnico di Milano Home: polimi will complete a full Life Cycle Assessment of LIMENET-PCC-DAC process according to ISO 14040 and 14044. The potential environmental impacts will be evaluated using the software SimaPro with a "cradle to grave" approach and international databases such as Ecoinvent will be used for the Life cycle inventory. Other impact categories (e.g., Acidification, Resource depletion - water, Resource depletion - mineral, fossil) will be considered as suggested by PEF guidelines in addition to Climate change impact category that is necessary for verifying the effectiveness and the efficiency of the process in removing CO_2 from the atmosphere using a life cycle approach.

b) Monitoring:

A specific measuring procedure is established for assessing the net carbon removal footprint of LIMENET plant. This is ensured using measurement-based approach utilizing specific sensors (i.e. pH, Turbidity, suspended solid, Conductivity, CO_2 ppm detector) that can detect, in real time, if the LIMENET process works as expected. With these precautions it is possible to know exactly how much CO_2 has been captured and sequestrated in a certain period of time.

c) Reporting and Verification:

The reporting of data will be done automatically by LIMENET internal software. The Verification is performed by a third part certification company that will evaluate and verify the compliance of the process to the plant's SPECS. The net negative emission will be calculated as the gross negative emission minus the LCA performed by the third part and the uncertainties of the specific project.

d) Blockchain:

In addition to the MRV LIMENET-DAC procedure, LIMENET S.R.L. BENEFIT is evaluating a new platform for confirmation and validation of data based on a blockchain tracking system that will be implemented to support MRV validator for ensuring traceability, transparency, and integrity of production data. All data coming from the monitoring sensors will be processed and collected by an Ethereum second layer that will make it possible for everyone at any time to control sensible process data about the generation of "real" negative emissions. The blockchain carbon footprint will be evaluated in the LCA.

1.1 Definition

Accuracy: means the closeness between the result of a measurement and the true value of the particular quantity or a reference value determined empirically using internationally accepted and traceable calibration materials and standard methods, taking into account both random and systematic factors.

Atmospheric carbon dioxide: Carbon dioxide in the atmosphere at respective concentrations (concentration can vary across daytime, month and year. For indicative purposes, the global monthly mean in August 2020 was 409.50 ppm according to NOAA (2020))

Batch: means an amount of material representatively sampled and characterised, and transferred as one shipment or continuously over a specific period of time.

Bicarbonate: means a salt characterized by the presence of anion HCO_3^-. Bicarbonate includes calcium bicarbonate ($Ca(HCO_3)_2$), magnesium bicarbonate $Mg(HCO_3)_2$.

Blockchain: The Blockchain is a technology that allows saving digital information (defined as blocks) in a secure and totally transparent way through a decentralized computer system. It is like a public and "immutable" register that offers the certainty of the entered information.

Calibration: means the set of operations, which establishes, under specified conditions, the relations between values indicated by a measuring instrument or measuring system, or values represented by a material measure, or a reference material and the corresponding values of a quantity realized by a reference standard.

Carbon Dioxide Removal (CDR): means anthropogenic activities that seek to remove CO_2 from the atmosphere and durably store it in geological, terrestrial or ocean reservoirs, or in products. CO_2 is removed from the atmosphere by enhancing biological or geochemical carbon sinks or by direct capture of CO_2 from air and storage (DAC+S).

Carbonate Minerals: means minerals characterized by the presence of the carbonate ion (CO_3^{2-}) in their structure. Carbonate minerals include calcite ($CaCO_3$), aragonite ($CaCO_3$), magnesite ($MgCO_3$), siderite ($FeCO_3$), ankerite ($Ca(Fe,Mg,Mn)(CO_3)_2$), and dolomite ($CaMg(CO_3)_2$).

CO_2 Capture: means the capture of CO_2 from a process stream or from the atmosphere to produce a stream of CO_2 amenable for conversion or storage.

CO_2 Storage: means the storage of CO_2 into the sea in the form of bicarbonates.

CO_2 Leakage: means any release of CO_2 from the storage complex and/or the injection facility after the last monitoring point.

CO_2 Stream: means a flow of concentrated CO_2 in gaseous or liquid (liquified or water-dissolved) form that results from a CO_2 capture process.

Conservative: means that a set of assumptions is defined to ensure that no under-estimation of annual emissions or over-estimation occurs.

Continuous Measurement: means a set of operations having the objective of determining the value of a quantity by means of periodic measurements, applying either measurement in the discharging pipeline and other parts of the projects with a measuring instrument. This is in line with the Regulation (EU) 2018/2066.

Crediting Period: The period during which the Direct Air Capture project is eligible to achieve removals, the lifespan of the Direct Air Capture Facility.
Emission source: means a separately identifiable part of an installation or a process within an installation, from which relevant greenhouse gases are emitted.
Energy balance method: means a method to estimate the amount of energy used as fuel in a furnace, calculated as the sum of utilizable heat and all relevant losses of energy by radiation, transmission and via the flue gas.
ETS: The Emission Trading System (ETS) is the European Union CO_2 emission trading system.
Fugitive emissions: means irregular or unintended emissions from sources that are not localised, or too diverse or too small to be monitored individually.
GHG: means greenhouse gases, gases that cause the greenhouse effect, such as CO_2, CH_4, N_2O, CH_4, and N_2O.
ID TSC: Identity Document Tracking Smart Contract is our internal tool that can write the information on-chain about the specific batch of material utilized. It can associate the batch of material to the specific LCA analysis.
LCA Analysis: LCA is a methodology for assessing environmental impacts associated with all the stages of the life cycle of a commercial product, process, or service.
Leakage: means leakage as defined in Article 3(5) of Directive 2009/31/EC.
Mint an NFT: Minting an NFT means converting digital data into crypto collections or digital assets recorded on the blockchain.
Monitoring: means the quantification of GHGs entering or leaving the project boundary (CO_2 Capture and CO_2 Storage). It provides data and parameters to be monitored over the duration of the storage continuous period.
Monitoring Period: The period evaluated to verify that CDR was produced according in compliance with methodology.
NFT: NFTs (Non-Fungible-Token) are "digital certificates" issued through the Blockchain technology. Each NFT has the characteristic of being unique, as if it is a digital brand that guarantees its authenticity and uniqueness.
Payload: means the total mass of freight, mail, passengers, and baggage carried onboard an aircraft during a flight.
Process emissions: means greenhouse gas emissions other than combustion emissions occurring as a result of intentional and unintentional reactions between substances or their transformation, including the chemical or electrolytic reduction of metal ores, the thermal decomposition of substances and the formation of substances for use as product or feedstock.
Project Proponent(s): means an individual(s) or organization(s) that has overall control and responsibility for the project, or an individual or organization that together with others, each of which is also a project proponent, has overall control or responsibility for the project. The entity(s) that can demonstrate project ownership in respect of the project.
Project Operator(s): One of the above (Direct Air Capture Operator, Transport Operator, Storage Operator) or a combination of two or three of them.
Plant Lifetime: The (estimated) lifetime of the Direct Air Capture and post-capture treatment facilities.

Reference scenario: The reference scenarios should reflect the current state-of-the-art in the different sectors.
Smart Contract: Smart contracts (SC) are IT protocols that facilitate, verify, or enforce, the negotiation or execution of a contract, sometimes allowing the partial or total exclusion of a contractual clause.
Tonne-kilometre: means a tonne of payload carried a distance of one kilometre;
Tier: means a set requirement used for determining activity data, calculation factors, annual emission and annual average hourly emission, and payload.
Tonnes of $CO_{2(e)}$: means metric tonnes of CO_2 or $CO_{2(e)}$.
Uncertainty: means a parameter, associated with the result of the determination of a quantity, that characterises the dispersion of the values that could reasonably be attributed to the quantity, including the effects of systematic as well as of random factors, expressed in per cent, and describes a confidence interval around the mean value comprising 95 % of inferred values taking into account any asymmetry of the distribution of values.
Virtual wallet: The virtual wallet is a digital wallet that allows users to store and manage their assets (i.e. NFT).

1.2 Applicability

This document is applicable to any project in which LIMENET technology is used. This comprises:

- LIMENET + LIMENET S.R.L. BENEFIT DAC facility;
- LIMENET + third part DAC facility;
- LIMENET used for production of carbon free slaked lime or PCC:

1.3 Scope of methodology

The scope of the following methodology, as described in Figure 1, is to encompasses the CO_2 carbon and capture DAC facility, the CO_2 storage, the bicarbonate discharging and the possible implementation of the Blockchain for negative emission traceability and transparency to third party verificatory.

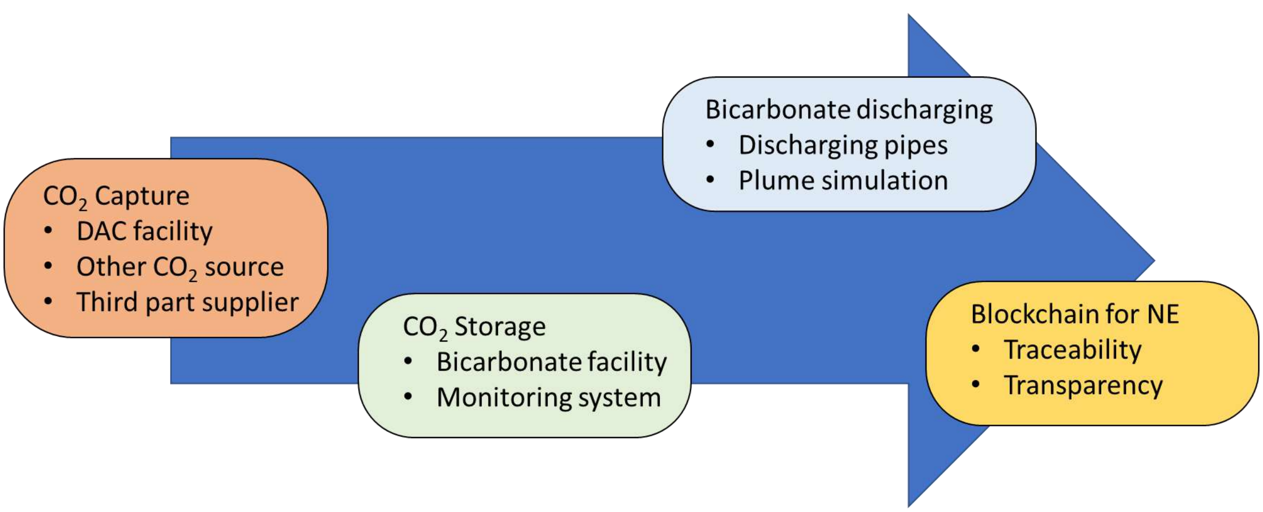

Figure 1 Scope of LIMENET S.R.L. BENEFIT methodology.

Here is described a resume of the different source of GHG in all LIMENET + DAC process.

Table 1 Sources and GHGs.

	Emission Source	GHG Gas	Included	Justification/Explanation
Baseline	Because it is additional, no activity is considered as baseline			
Project activity	Electricity for DAC	CO_2eq	Yes	Utilizing possibly 100% of renewable energy we assume CO_2 as major source
	Electricity for CO_2 capturing	CO_2eq	Yes	Utilizing possibly 100% of renewable energy we assume CO2 as major source
	Electricity for CO_2 storing	CO_2eq	Yes	Utilizing possibly 100% of renewable energy we assume CO2 as major source
	Electricity for limestone calcination	CO_2eq	Yes	Utilizing possibly 100% of renewable energy we assume CO2 as major source
	Electricity for Blockchain	CO_2eq	Yes	Utilizing possibly 100% of renewable energy we assume CO_2 as major source
	Embedded GHGs in limestone raw material	CO_2eq	Yes	∓ Major emission from source
	Embedded GHGs in construction and disposal	CO_2eq	Yes	Major emission from source

1.4 Additionality

LIMENET S.R.L. BENEFIT is still studying the additionality of LIMENET + DAC technology with the UNFCCC CDM (Clean Development Mechanism) “Tool for the demonstration and assessment of additionality”. However, it seems from a first preliminary analysis that the full LIMENET + DAC project with the both negative emission offset + ocean alkalinity enhancement + blockchain tracking system seems to be the first of a kind.

2 Monitoring Reporting & Verification

2.1 Preliminary LCA analysis done by a third-party evaluator

2.1.1 GHG definitions and parameters

2.1.1.1 Absolute GHG emission avoidance

The absolute GHG emission avoidance represents the difference, over a defined period, between all the emissions that would occur in a reference scenario in the absence of the proposed project, and all the emissions from the project activity. The absolute GHG emission avoidance is calculated based on the expected emissions avoided in each year from the entry into operation over a 10 years' period, using the equation below.

$$\Delta GHG_{abs} = \sum_{y=1}^{10} (Ref_y - Proj_y)$$

Where:
ΔGHG_{abs} = Net absolute GHG emissions avoided thanks to operation of the project during the first 10 years of operation, in tCO_{2e}.
Ref_y = GHG emissions that would occur in the absence of the project in year y, in tCO_{2e}.
$Proj_y$ = GHG emissions associated with the project activity in year y, in tCO_{2e}.

2.1.1.2 Relative GHG emission avoidance

The relative GHG emission avoidance potential is calculated by dividing the absolute emission avoidance (ΔGHG_{abs}) by the reference emissions (Ref_y) cumulated over a 10 years' period.

$$\Delta GHG_{rel} = \frac{\Delta GHG_{abs}}{\sum_{y=1}^{n^{10}} (Ref_y)}$$

Where:
ΔGHG_{rel} = Relative change in GHG emissions avoided due to operation of the project cumulated over 10 years of operation, in percent.
ΔGHG_{abs} = Net absolute change in GHG emissions avoided due to operation of the project cumulated during the first 10 years of operation, in tCO_{2e}.
Ref_y = GHG emissions that would occur in the absence of the project in year y, in tCO_{2e}.

2.1.1.3 GHG considered and global warming potentials

The greenhouses gases that must be taken into account in emissions calculations are at least those listed in the EU Emissions Trading System (EU ETS) Directive 2003/87/EC, Annex II: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulphur hexafluoride (SF_6). Emissions factors for methane and nitrous oxide, when given, may be converted into CO_2 equivalents ("CO_{2e}").

2.1.1.3.1 *Reference scenario*

The calculations of GHG emission avoidance as well as relevant costs should comprehensively cover the impacts from the changes in inputs, processes, and outputs between the project and the reference scenario. The reference scenarios should reflect the current state-of-the-art in the different sectors, as shown in Table 2.

Table 2 Reference Scenarios[1].

Sector	*GHG emissions are based in the reference scenario (among others) on:*
Energy-intensive industries CCS	EU ETS benchmark(s)
Renewable electricity	Expected 2030 electricity mix
Renewable heat	Natural gas (NG) boiler
Energy storage	Single-cycle NG turbine (peaking power)

2.1.1.3.2 *Calculation of GHG emission avoidance: reference scenario*

The calculations of GHG emission avoidance covers the impacts from the changes in inputs, processes, and products between the reference scenario and the project. The reference scenarios reflect the current state-of-the-art in the ETS sectors, as shown in Table 3.

Table 3 Emission sources included from the reference and project boundaries.

Emission sources	
Reference (Ref)	CO2 that would be available in the atmosphere in the absence of the project activity
Project (Proj)	CO2 capture activities. Includes emissions from fuel and input material use for compression and liquefaction of the CO2, as well as fugitive and venting pre-injection. (Projcapture)
	Transport of CO2 by pipeline. Includes emissions from combustion and other processes at installations functionally connected to the transport network such as booster stations; fugitive emissions from the transport network; vented emissions from the transport network; and emissions from leakage incidents in the transport network. (Projpipeline)
	Transport of CO2 by road, rail and maritime modal. Includes emissions from combustion at tank trucks, sea tanker and other vehicles. (Projtransport road; Projtransport rail and Projtransport maritime)
	Injection at the geological storage site. Include emissions from fuel use by associated booster stations and other combustion activities including on-site power plants; venting from injection or enhanced hydrocarbon recovery operations; fugitive emissions from injection; breakthrough CO2

[1] https://climate.ec.europa.eu/system/files/2020-05/20200605_annex_a_en.pdf

	from enhanced hydrocarbon recovery operations; and leakages. (Projinjection)

2.1.1.4 Monitoring, reporting and verification of performance for disbursement and knowledge-sharing

During operation, LIMENET S.R.L. BENEFIT will demonstrate GHG emission avoidance obtaining, recording, compiling, analysing, and documenting the monitored data, including assumptions, references, activity data and calculation factors in a transparent manner that enables the checking of performance achieved during the operation of the project. LIMENET S.R.L. BENEFIT will ensure that the operational data determination is neither systematically nor knowingly inaccurate. In selecting a monitoring methodology, the improvements from greater accuracy will be balanced against additional costs.

2.1.2 GHG emissions avoidance

2.1.2.1 Absolute and relative GHG emissions avoidance

The absolute emissions avoided by the project are the emissions of the reference scenario minus the emissions of the project scenario. The relative emissions avoidance is then calculated by dividing the absolute emissions avoided, by the emissions of the reference scenario.

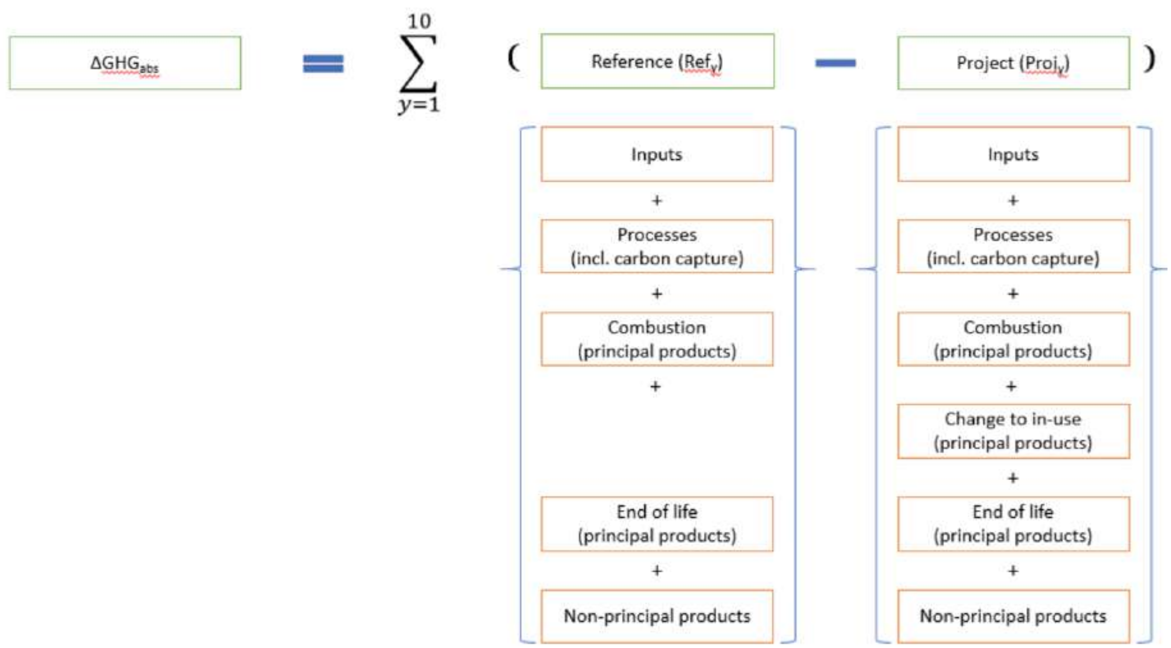

Figure 2 Diagram of GHG emission avoidance related to LIMENET projects[2].

[2] EU Grants: InnovFund GHG emission avoidance methodology: V1.0 – 15.03.2022

2.1.2.2 Emissions from processes (incl. carbon capture)

For the **project** scenario, LIMENET S.R.L. BENEFIT will include in the “processes” box all the emissions expected within the system boundary of LIMENET FOAK associated with the processes required to produce negative emissions DAC.

The **reference** scenario of LIMENET S.R.L. BENEFIT process includes in the “processes” box all the emissions from processes (See Table 2) associated with producing the same quantity of negative emission.

2.1.2.3 CO_2 capture DAC technology

The DAC system will be used by LIMENET S.R.L. BENEFIT to capture and store carbon dioxide in the form of PCC. For the purposes of the GHG calculation LIMENET S.R.L. BENEFIT will bring the CO_2 use within the system boundary of the project even if the CO_2, in form of PCC, is sequestrated in different location and/or is operated by a third party that gives to LIMENET S.R.L. BENEFIT a sequestrated CO_2.

Referring to the European standard, the negative emissions attributed to the capturing process, plus any emissions from transporting the CO_2 in LIMENET storing facility, will be reported in the “processes” box of the project scenario. Any emissions associated with incorporation of the CO_2 into PCC will also be fully accounted in the “processes” box of the project scenario. Having accounted for all relevant emissions, a credit for incorporation should then be included as a negative emission term in the “processes” box of the project scenario equal to the amount of CO_2 incorporated in products, thereby reducing the overall emissions in the project scenario.

2.1.2.4 Emissions from inputs

LIMENET S.R.L. BENEFIT will specify the inputs that enter the system boundary associated with the “processes” box of the project and the reference scenarios. This should include both energy and material inputs such as calcium carbonate raw material etc.

2.1.2.4.1 RIGID inputs

The emission avoidance calculations take account of processes which divert materials from other uses. Therefore, it is necessary to consider whether an input is “rigid”. If the input has a fixed supply, then it is considered “rigid”.

2.1.2.4.2 SEMI-ELASTIC inputs

Some inputs are one of several co-products produced in fixed ratios from an existing process, but with less value than other co-products. In such cases, it may not be clear whether the input should be characterised as rigid or elastic. To simplify the assessment of these cases, any input that represents less than 10% of the economic value of products from a process is considered rigid, any input that represents more than half of the economic value of products from a process is considered elastic, and any input with a value from 10% to 50% of the economic value of products from a process is considered semi-elastic. The emissions of a semi-elastic material shall be assessed as the weighted combination of the emissions if it was entirely rigid and the emissions if it was entirely elastic.

2.1.2.4.3 ELASTIC inputs

If the supply of the input can be varied in order to meet the change in the demand, then the input is considered "elastic", and its emission factor is found from the emissions involved in supplying the extra quantity of that input.

The emissions intensity of a rigid input is based on the elastic input that replaces the rigid input in its existing use. The provisions in this section also apply to elastic inputs identified as substitutes for diverted rigid inputs: they are considered on the same basis as the other elastic inputs for project and reference scenarios.

2.1.2.5 Data and parameters

LIMENET S.R.L. BENEFIT will calculate the GHG emission avoidance with the monitoring of different process parameter. Those includes, for example, inline process sensors such as pH or Turbidity meter that must remain constant throughout the duration of the project.

2.1.3 LCA analysis (GHG SCOPES)

LCA is a technique to assess the environmental aspects and potential impacts associated with a product, process, or service, by:

- Compiling an inventory of relevant energy and material inputs and environmental releases
- Evaluating the potential environmental impacts associated with identified inputs and releases
- Interpreting the results to help you make a more informed decision[3]

[3] https://web.archive.org/web/20120306122239/http://www.epa.gov/nrmrl/std/lca/lca.html

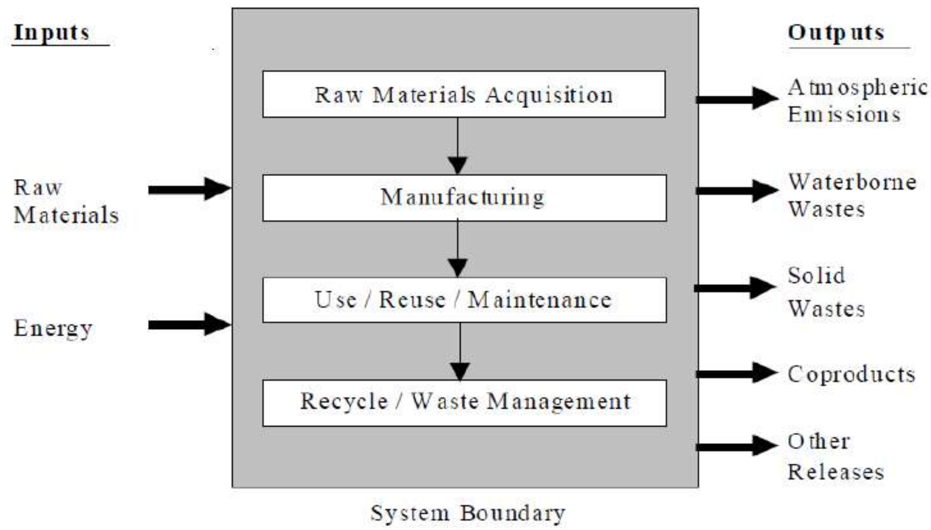

Figure 3 Life Cycle Stages (Source: EPA,1993) [4].

LCA evaluates all stages of a product's life from the perspective that they are interdependent, meaning that one operation leads to the next. LCA enables the estimation of the cumulative environmental impacts resulting from all stages in the product life cycle, often including impacts not considered in more traditional analyses (e.g., raw material extraction, material transportation, ultimate product disposal, etc.). By including the impacts throughout the product life cycle, LCA provides a comprehensive view of the environmental aspects of the product or process and a more accurate picture of the true environmental trade-offs in product and process selection[5].

As described above, LIMENET S.R.L. BENEFIT will do with the aware research group of Politecnico di Milano the complete Life Cycle Assessment of the LIMENET -DAC process according to ISO 14040 and 14044. The potential environmental impacts will be evaluated using the software SimaPro with a "cradle to grave" approach and international databases such as Ecoinvent will be used for the Life cycle inventory. Other impact categories (e.g., Acidification, Resource depletion - water, Resource depletion - mineral, fossil) will be taken into account as suggested by PEF guidelines in addition to Climate change impact category that is necessary for verifying the effectiveness and the efficiency of the process in removing CO_2 from the atmosphere using a life cycle approach.

2.1.3.1 Capture and storage of CO_2

LIMENET S.R.L. BENEFIT negative emission technology consists of the union of a DAC system to LIMENET carbon free slaked lime production. This both leads to negative emissions. CO_2, in then

[4] LIFE CYCLE ASSESSMENT: PRINCIPLES AND PRACTICE, EPA/600/R-06/060 May 2006
[5] LIFE CYCLE ASSESSMENT: PRINCIPLES AND PRACTICE, EPA/600/R-06/060 May 2006

stored in two different ways. Or in a solid form as calcium carbonate (PCC) or in an aqueous form in the sea in form of calcium bicarbonate.

2.1.3.2 LIMENET LCA Analysis

According to Politecnico of Milano work, the complete LCA analysis of LIMENET + DAC can be summarized in the following Table 4.

Table 4 Total of all impact categories.

	Impact category	Unit of measure (UOM)	Total (UOM/FU)	
			Italy	**Norway**
1	Climate change	kg CO_2 eq	1054	57
2	Ozone depletion	kg CFC-11 eq	1,44E-04	2,31E-06
3	Ionising radiation, HH	kBq U_{235} eq	145	45
4	Photochemical ozone formation, HH	kg NMVOC eq	2,30	0,14
5	Respiratory inorganics	disease inc.	1,75E-05	2,27E-06
6	Non-cancer human health effects	CTUh	5,76E-05	8,54E-06
7	Cancer human health effects	CTUh	6,38E-06	3,15E-06
8	Acidification terrestrial and freshwater	mol H^+ eq	4,78	0,20
9	Eutrophication freshwater	kg P eq	0,238	0,021
10	Eutrophication marine	kg N eq	0,74	0,05
11	Eutrophication terrestrial	mol N eq	8,2	0,5
12	Ecotoxicity freshwater	CTUe	222	51
13	Land use	Pt	5409	1054
14	Water scarcity	m^3 depriv.	710	67
15	Resource use, energy carriers	MJ	16069	1061
16	Resource use, mineral and metals	kg Sb eq	1,02E-03	4,08E-04

As it is possible to see, climate change impact varies a lot changing country and so its energetical mix. In LIMENET - DAC example, Italy and Norway renewable % are 39.87% and 98.86% respectively[6].

[6] https://ourworldindata.org/energy/country/norway

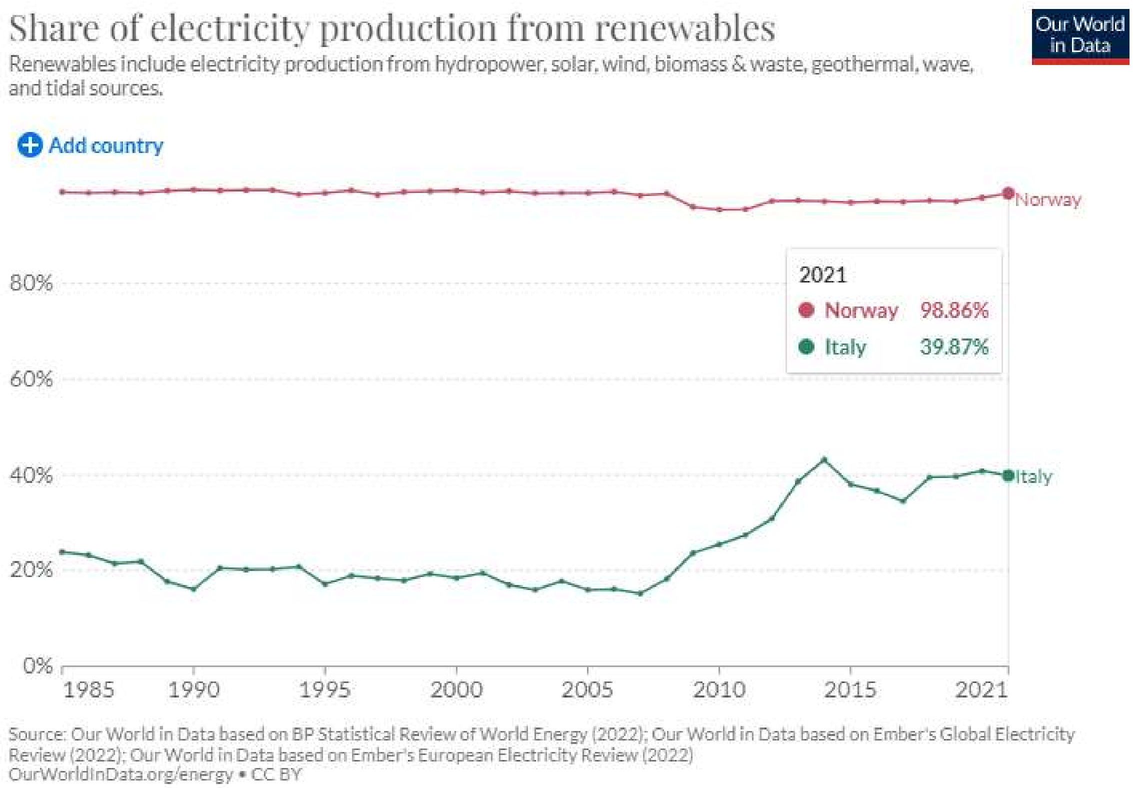

Figure 4 % of renewable electricity.

2.1.4 Verification Confidence Levels (VCLs)

The Verification Confidence Level (VCL) metric represents the confidence that carbon removal and storage durability outcomes can be accurately quantified using the best scientific understanding, measurement, and modelling approaches available today.

2.1.4.1 LIMENET - DAC uncertainties:

LIMENET-DAC is a new innovative method to make negative emission, and because it involves a complex chemistry, it is reasonable to have different uncertainties that must be considered to calculate the GHG emission avoidance during the lifetime project.

2.1.4.1.1 Mineral dissolution:

Environmental conditions and alkalinity addition dynamics (e.g. rate of point source additions) result in different fractions of carbonate (CO_3^{-2}) versus bicarbonate (HCO_3^{-}) in process seawater. This is important to characterize the stability of calcium bicarbonate as alkalinity in sea water. In LIMENET is estimated to be 100% on a mol-to-mol basis due to experimental data on LIMENET TRL6 prototype.

2.1.4.1.2 Abiotic precipitation:

Secondary precipitation of calcium carbonate ($CaCO_3$) into seawater may occur abiotically in the plume at the discharge point if the rate of alkalinity addition compared to diffusion and water movement is such that the saturation state is too high. In LIMENET abiotic precipitation is reduced to zero because is ensured a quick dilution of the process alkaline water into sea water.

2.1.4.1.3 Biotic calcification response:

Since calcification releases CO_2 as a by-product, any changes to the rate of biotic calcification in response to alkalinity additions on the ocean must be considered[7],[8]. Shifts in biotic calcification rates could occur in both coastal and open ocean waters and could be tracked by measuring changes in total alkalinity over time and by sampling the water column to study changes in calcified populations. In practice, quantifying the biotic calcification response to alkalinity addition may pose significant spatial and temporal challenges also because it will be overlapped to the ongoing ocean acidification that is depressing the calcification rate of the calcifying organisms. In any case, any effect in biotic calcification response could be an issue only at a very large deployment scale of the LIMENET technology when the alkaline discharged water could alter the pH and the Ω_{ar} of the ocean at local or global scale and thus, eventually, the biological precipitation of calcium carbonate.

- At local scale, the alkalinization of the sea depends on the specific location of the plants, on the marine currents, on the discharge depth, on the coast configuration, etc.[9] that make impossible to find a common criterion to assess a biotic calcification response.
- At global scale, until when the LIMENET-DAC combined effect of CO_2 removal from the atmosphere and of alkalinity addition to the ocean will be of a comparable effect of the ongoing acidification due to the CO_2 entering the ocean from the atmosphere (i.e. G_{ton} scale) we will not consider any decreasing in carbon storage efficiency due to increased biological calcification activity.

For large deployments of OAE technologies, the biotic calcification response should be assessed by the scientific community both at local and ta global scale: the results of these studies will determine the loss in efficiency in storing CO_2 into seawater in form of alkalinity.

These studies are exceeding the scope and the knowledge of the LIMENET S.R.L. BENEFIT team that will consider any given results the scientific community will agree upon.

2.1.4.1.4 Secondary precipitation of $CaCO_3$:

The very supersaturated ionic solution formed after the injection of the $Ca(OH)_2$ for buffering the CO_2 should be thoroughly mixed with the surrounding seawater, lowering the overall saturation state of calcite/aragonite (i.e. to Ω_{ar} = 5) and avoiding the risk of $CaCO_3$ precipitation. Bicarbonate stability is well known from literature. However, recent studies on the stability of bicarbonates in seawater were analysed by different research groups in the world. Of particular interest is the

[7] Renforth and Henderson (2017): assessing ocean alkalinity for carbon sequestration, doi:10.1002/2016RG000533
[8] A Research Strategy for Ocean-based Carbon Dioxide Removal and Sequestration (2022), DOI 10.17226/26278
[9] Kirchenr et al.: Carbon capture via accelerated weathering of limestone: Modeling local impacts on the carbonate chemistry of the southern North Sea, doi.org/10.1016/j.ijggc.2019.102855

study of the university of Kiel conducted by Ulf Riebesell[10] and the study conducted by Charly A. Moras in the article: "Avoiding runaway $CaCO_3$ precipitation during quick and hydrated lime dissolution"[11]. Similar tests were carried out on our LIMENET pilot plant at La Spezia CSSN[12] to evaluate the different stability of calcium bicarbonate varying the concentration of seawater total alkalinity: the preliminary results confirm the ones of Moras et al. and Riebesell et al.

2.1.4.2 LIMENET - DAC VCL

The conclusion of the uncertainties study is that for LIMENET a VCL of 3-4 can be considered, for the DAC, a VCL of 4 -5 can be considered. As described in the formula of calculating the absolute emission avoidance, LIMENET S.R.L. BENEFIT will discount all the uncertainties from the gross negative emission.

2.1.5 Calculation of absolute GHG emission avoidance for LIMENET-DAC projects plus uncertainties

Giving that all LIMENET-DAC uncertainties have been reported and that the concept of storage of CO_2 as alkalinity into the ocean as DIC has a lifetime well-established theory and is accepted within the community to lie somewhere between 10,000 and 100,000 years[13], it is possible to calculate the absolute GHG emission of the DAC - LIMENET system.

Table 5 GHG emission avoidance calculator

GHG emission avoidance	=	Reference scenario emissions	-	Project scenario emissions

$$\Delta \mathrm{GHG}_{\mathrm{abs,LIMENET-DAC}} = \sum_{y=1}^{n} Ref_{release,y} - \sum_{y=1}^{n} (\mathrm{Proj}_{\mathrm{LCA,y}} + \mathrm{Proj}_{\mathrm{uncertantier,y}})$$

- $\Delta GHG_{abs,LIMENET - DAC}$ = Absolute GHG emissions avoided by the FOAK project, in tonnes CO_{2e}.
- $Ref_{release,y}$ = Amount of CO_2 that would be available in the atmosphere in the absence of the project activity.
- $Proj_{LCA,y}$ = Complete LCA of the specific LIMENET - DAC plant.
- $Proj_{uncertanties,y}$ = $Proj_{mineral\ dissolution,y}$ + $Proj_{abiotical\ precipitation,y}$ + $Proj_{biotic\ calcification\ response,y}$ + $Proj_{secondary\ precipitation\ of\ CaCO3,y}$

  y = year of operation

  n = 10th year following the start of operation

[10] https://www.geomar.de/en/news/article/using-rock-minerals-to-combat-climate-change

[11] Moras et al. (2021) Ocean Alkalinity Enhancement - Avoiding runaway CaCO3 precipitation during quick and hydrated lime dissolution - https://doi.org/10.5194/bg-2021-330

[12] https://www.difesa.it/Protocollo/AOO_Difesa/Marina/Pagine/MCSSNSP.aspx

[13] https://carbonplan.org/research/cdr-verification/ocean-alkalinity-enhancement-mineral

2.2 MRV, Overview of the Monitoring Reporting and Verification

2.2.1 Legislation Overview

LIMENET S.R.L. BENEFIT monitoring, reporting and verification plan consisting of a detailed, complete, and transparent documentation of the monitoring procedure, parameters used in calculations and data sources. LIMENET S.R.L. BENEFIT plan is to make monitoring procedure in line with the Commission Implementing Regulation (EU) 2018/2066 of 19 December 2018 on the monitoring and reporting of greenhouse gas emissions pursuant to Directive 2003/87/EC of the European Parliament and of the Council as it has been amended by Regulation 2020/2085.

2.2.2 Monitoring available methodologies

Under the MRV Regulation (Articles 21 and 22) LIMENET S.R.L. BENEFIT is using the following methodologies for monitoring the GHG emissions:

- Calculation based approaches:
    - Standard methodology (distinguishing all the process emissions);
    - Mass balance with the process efficiency;
- Measurement based approaches.

In order to be as fair as possible LIMENET S.R.L. BENEFIT has decided to implement in the preliminary stage a combination of both methodologies in order to see if the calculation-based approach is confirmed by the measurement-based approach.

With more details:

2.2.2.1 Calculation based approach:

As described by article 21 of Regulation (EU) 2018/2066, the calculation-based methodology consists in determining CO_{2e} emissions from source streams based on activity data obtained by means of measurement inline systems with additional parameters from laboratory analyses. LIMENET S.R.L. BENEFIT calculation-based methodology is implemented according to the standard methodology set out in Article 24 and the mass-balance methodology set out in Article 25. In fact, the emissions of the total process covered by the mass balance is the sum of the CO_2 quantities corresponding to all source streams covered by the mass balance.

2.2.2.2 Measurement based approach:

Because LIMENET S.R.L. BENEFIT is implementing a specific MRV for LIMENET, it wants to be as much precise as possible reducing any uncertainties. For that reason, LIMENET R&D team is developing a measurement-based methodology that follows the CO_2 in the process and see its reactions with inline flow samples. This implies a continuous sampling method.

Because monitoring is crucial to be sure about emissions and storage, LIMENET S.R.L. BENEFIT is developing with Politecnico of Milano a specific procedure, according to article 33 and 34 of Regulation (EU) 2018/2066 a sampling plan with the use of laboratories to verify inline flow.

Even though Regulation (EU) 2018/2066 requires a sampling procedure of at least 4 times a year (See article ANNEX VII Minimum frequency of analyses (Article 35)) LIMENET S.R.L. BENEFIT is considering a more frequency sampling time due to changing of LIMENET efficiency due to environmental condition (i.e. Temperature).

2.2.2.3 Classification of installations

Under the MRV Regulation (EU) 2018/2066 (Article 19(2)), installations included in Annex I of the EU ETS Directive are classified into three categories based on their average annual emissions:

- Category A: ≤ 50 000 tonnes of CO_{2e}.
- Category B: > 50 000 tonnes of CO_{2e}, and ≤ 500 000 tonnes of CO_{2e}.
- Category C: > 500 000 tonnes of CO_{2e}.

LIMENET S.R.L. BENEFIT, until its TRL 8 will be in category A with an annual production of less than 50000 tonnes of CO_{2e}.

2.2.2.4 Classification of source streams

LIMENET S.R.L. BENEFIT would classifies all source streams in which the calculation-based approach is done according to Article 19(3). However, because LIMENET S.R.L. BENEFIT is not using any fossil fuel in the process because it uses just electricity and renewable energy and because all fossil fuel utilization is just for suppliers' material (counted in the LCA), no stream sources has been considered.

2.2.2.5 The Tier System

Each parameter needed for the determination of emissions can be determined by different "data quality levels". These "data quality levels" are called "tiers". It can be said that tiers with lower numbers represent methods with lower requirements and being less accurate than higher tiers.
LIMENET S.R.L. BENEFIT LIMENET - DAC industrial plant has the final objective to reach the highest tier possible (Tier 4). This is needed to decrease the uncertainties in the process. Till now, LIMENET S.R.L. BENEFIT LIMENET industrial TRL6 it can be considered Tier 2 for the specific category of "Production of lime and calcination of dolomite and magnesite" described in ANNEX II table 1, (See Table 6).

Table 6 Tiers for activity data (maximum permissible uncertainty for each tier).

Activity/source stream type	Parameter to which the uncertainty is applied	Tier 1	Tier 2	Tier 3	Tier 4
Production of lime and calcination of dolomite and magnesite					
Carbonates and other process materials (Method A)	Each relevant kiln input [t]	± 7,5 %	± 5 %	± 2,5 %	
Alkali earth oxide (Method B)	Lime produced [t]	± 5 %	± 2,5 %		
Kiln dust (Method B)	Kiln dust [t]	n.a. (**)	± 7,5 %		

2.2.3 Reporting LIMENET and DAC

LIMENET-DAC specific reporting includes:

- Process diagrams for "LIMENET project" and "reference" scenarios, with all the sub-processes, inputs, and products.
- The decision of the reference scenario.
- A list quantifying all the material and energy flows between the LIMENET processes and reference scenarios.
- Description of the "principal product(s)" of LIMENET respect to the project scenario (if there are, i.e. Carbon free slaked lime, PCC, negative emissions).
- A list of the emissions intensities taken from the literature and the sources of the data (from LCA).
- A documented calculation of the absolute and relative emission avoidance from the project.
- Hourly profiles for use and feed-in from grid electricity (depending of suppliers capability).

2.2.4 Verification of LIMENET - DAC

According to REGULATION (EU) 2015/757 of 29 April 2015, LIMENET S.R.L. BENEFIT will make the verification of the monitoring and reporting system with a third party that must assess the conformity of the documents transmitted by LIMENET S.R.L. BENEFIT with the requirements of REGULATION (EU) 2015/757. The verifier has not been yet decided by LIMENET S.R.L. BENEFIT, but it must be a legal entity carrying out verification activities which is accredited by a national accreditation body pursuant to Regulation (EC) No 765/2008.
Verification by accredited verifiers should ensure that monitoring plans and emissions reports are correct and in compliance with the requirements set out in REGULATION (EU) 2015/757. As an important element to simplify verification, LIMENET S.R.L. BENEFIT delegates the third company

(verifier) to check data credibility, reported data with estimated data based on ship tracking data and characteristics.

2.3 Blockchain tracking system

As described in the introduction, LIMENET S.R.L. BENEFIT is evaluating a specific platform for confirmation and validation of data, based on a blockchain tracking system that will be implemented to support MRV validator for ensuring traceability, transparency, and integrity of production data. All data coming from the monitoring sensors will be processed and collected by a specific smart contract that will validate permanently the information. This will be done on an Ethereum second layer, and it will make it possible to establish an open access database for everyone to control at any time sensible process data about the generation of net negative emissions. The blockchain carbon footprint will be evaluated in the LCA.

2.3.1 The reason

Blockchain is a new innovative tool that can be defined as a distributed immutable registry. With the birth of the Ethereum blockchain with smart contracts, it is possible to write on this registry not only a transfer of an amount of money, but anything else. We can imagine the blockchain as a digital notary. When one or more people use a smart contract and they register something, it will remain forever on the chain, it will be immutable and linked to its owner, who is not expressed as a natural person but as an account (also known as a wallet).

We think that in LIMENET + DAC transparency is fundamental; it is important that anyone can see everything we do, the electricity we consume, what sources and raw materials we use and every detail of the whole process accessible almost in real time. In fact, because it is immutable, anyone can read whatever is written on the blockchain and this denies us, as negative emission provider, the ability to hide anything. Therefore, we have decided to evaluate the utilization of this type of technology which is, to date, the thing that best meets these requirements.

2.3.2 Traceability

Traceability is something that must be on a continuous improvement to be as much reliable as possible. This phase begin with the receipt of a batch of raw material, calcium carbonate: here a smart contract will be launched on the blockchain that will immediately record the data relating to the LCA analysis of the supplier and of the carrier in order to immediately record how much CO_{2eq} that carbonate cost. This contract will also have fields relating to process parameters.

When the batch starts to be processed in LIMENET calciner, the local LIMENET computer monitoring system (based on calculation and measurement approach), will start communicating with a central computer and write on the smart contract. It will pass-on all the necessary data such as the amount of energy used, where it comes from, the amount of calcium hydroxide produced and used, the amount of bicarbonate discharged into the sea and in what place. All these data will be recorded on the smart contract launched at the beginning and, due to the memory of the blockchain, it will also be possible to see at what time they were recorded and look the batch history processing moments.

At the end of the process, only if all the fields of the contract are filled in it will automatically calculate the CO_2 debt of the calcium hydroxide produced, and the code will follow the batch in the next phase

After that the batch will be used to remove CO_2 in the DAC facility, the smart contract will automatically calculate the final net CO_2. At this point the contract will be closed, it will no longer be possible to write anything on it. Hence, the closed contracts will be used to store the credit of CO_2 produced. This smart contract with inside a credit of negative emission will be counted in LIMENET S.R.L. BENEFIT digital wallet.

In the first phase there will be one or more operators who will manage some parts of the tracking but over time we aim to develop a fully automatic system that will completely remove the possibility of human error.

2.3.3 Buyers' agreement

To buy negative emission of CO_2 from the LIMENET + DAC facility, the buyer must enter in a specific web page in which it is request buyers' information and the quantity of purchase. There, LIMENET S.R.L. BENEFIT internal software will see if the amount of net negative CO_2 emission is present in LIMENET S.R.L. BENEFIT digital wallet and, if this is affirmative, it will mint a "NFT" and decrease the quantity of total net CO_2 present in the LIMENET S.R.L. BENEFIT digital wallet.

Minting the smart contract will insert in the NFT the amount of net CO_2 for which the customer has paid, the data he has entered, the address of the smart contract.

2.3.4 Verification

Although this technology is quite new and not a lot of firms are implementing it, we recognize a big potential on this new method to help verificatory on their job. Once the first LIMENET + DAC first prototype will be fully working, LIMENET S.R.L. BENEFIT hopes to make a new accepted protocol to be implemented in the verification procedure.

2.3.5 Energy consumption and stereotypes

To develop this project, we use Polygon blockchain, which uses the infrastructure and security systems of Ethereum, the most used and reliable blockchain, but with reduced costs. In fact, for everything that is written on a block of the chain, a fee must be paid for people who validate transaction.

Since September 2022 Ethereum and Polygon change their validation system from the so called classic "proof of work" chain such as bitcoin to the innovative "proof of stake" that allows the use of much less energy-intensive machinery. So far, energy consumption drastically dropped making Ethereum one of the most promising blockchain in line with our business principles.

On the following Figure 5, it is possible to see the annual energy consumption of proof of work (80-90 TWh/Year) and proof of stake system (0.01 TWh/Year) from September 2022.

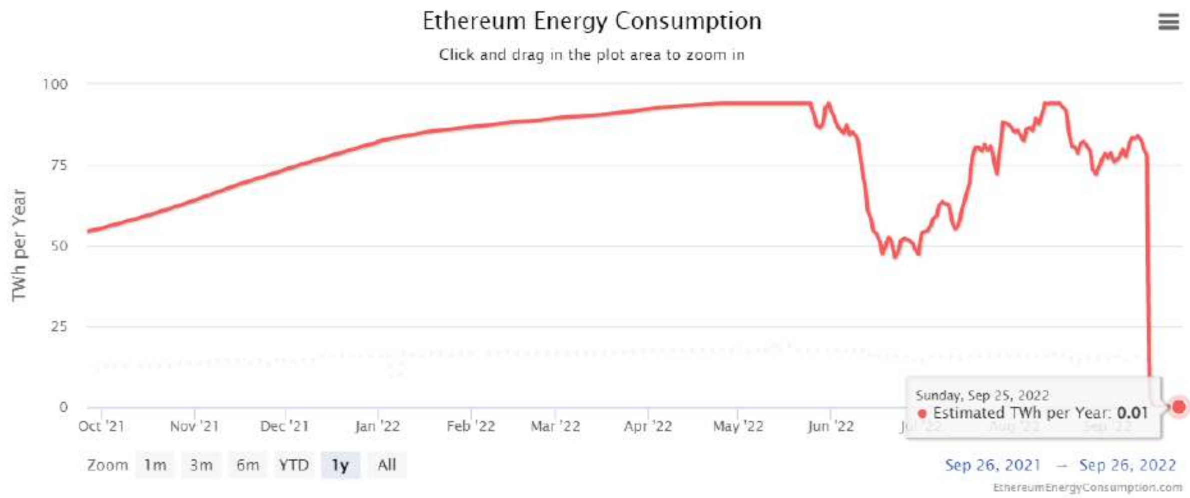

Figure 5 Ethereum prof of work and proof of stake energy comparison[14].

In any case, the environmental impact of the chain, even if minimal, will be counted in the LCA.

[14] https://digiconomist.net/ethereum-energy-consumption/

3 Reference information

This document is based on the following directives:

- Regulation (EU) 2015/757
- Commission Implementing Regulation (EU) 2018/2066
- Commission Implementing Regulation (EU) 2021/447
- Commission Implementing Regulation (EU) 2020/2085
- Annex A: Methodology for calculation of GHG emission avoidance
- LIFE CYCLE ASSESSMENT: PRINCIPLES AND PRACTICE, EPA/600/R-06/060 May 2006