HANZŌ
LAMARCK Group

METHODOLOGY FOR THE ASSESSMENT OF THE CARBON FOOTPRINT OF BLOCKCHAIN-BASED FINANCIAL INSTRUMENTS

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Prepared for

FORGE
SOCIETE GENERALE GROUP

With the support of

MigaLabs Blockchain Ecosystem Observatory
CCRI
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1. Executive summary

1.1. Introduction to the research topic

Global warming and its main cause, greenhouse gas emissions related to human activities, are an important concern for states, population and corporates. Being able to measure the level of emission for any specific activity is now required for many reasons from being able to assess its contribution to global warming to answering to regulatory requirements and reporting.

Like any human activity, information technology has its own growing carbon footprint as usage and equipment are spreading across all populations. In 2020, Information and Communication Technology (ICT) accounted for around 1.8% to 3.9%[1] of human global emissions of greenhouse gas.

This study is initiated by SG-Forge.
SG-Forge believes that blockchain technology has the potential to play an important role in addressing climate change by creating a more transparent way to store and manage ESG KPIs linked to financial instruments and improve the funding of the transition to a sustainable economy.
SG-Forge also believes that blockchain-based market infrastructures can have a lower carbon footprint than current infrastructures.

From this perspective, SG-Forge's goal is typically to provide a comprehensive and accurate assessment of the carbon footprint of its Security Token activity.

1.2. Objectives of the study

The main objectives of this study are:

- To propose a generic framework and methodology for the measurement of the carbon footprint of a financial product tokenization project on Ethereum,
- To provide a calculation of the carbon footprint of a complete tokenization project (from development phase to bond issuance, management and redemption),
- To identify most significative improvements in Greenhouse Gas (GHG) emissions linked to the usage of a blockchain network.

1.3. Key findings and recommendations

- GHG emissions related to the usage of the Ethereum network remain low compared to generic cloud infrastructures, making Ethereum the right tool for IT sobriety,
- Methodologies for blockchain carbon footprint assessment can still be improved, while cloud service providers can improve the availability of accurate and reliable data,
- All stakeholders in the value chain (issuers, investors, custodians, central securities depositaries, exchanges) have the tools to conduct similar studies and share results to enhance carbon footprint transparency and provide more accurate data.

[1] Charlotte Freitag et al. - "*The real climate and transformative impact of ICT: A critique of estimates, trends, and regulations*" (August 2022)

1.4. Illustration of the study

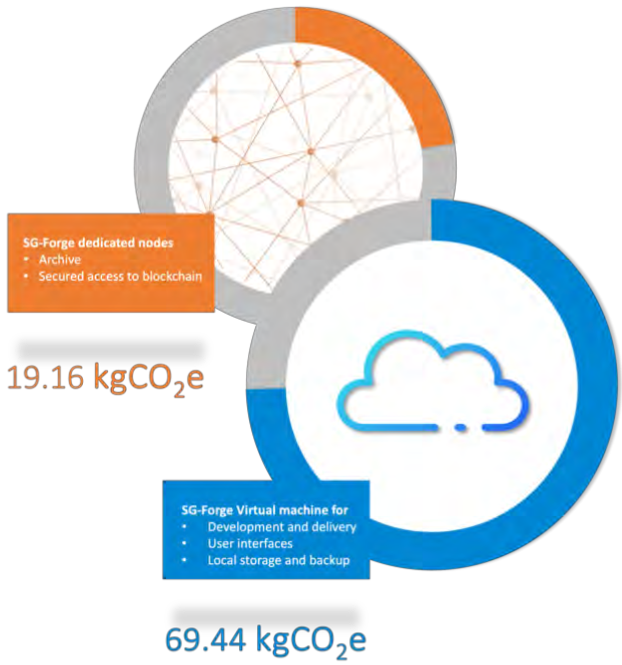
Figure 1 Visualizing the annualized carbon footprint estimation of a SG-Forge's tokenized bond project

Calculated for **one bond issuance** and encompassing the entire life of the financial product on blockchain.

TOTAL
0.82 $kgCO_2e$
Equivalent to*:

3.8
km by car

General use of SG-Forge: Fixed values independent of the number of issuances.



TOTAL
88.6 $kgCO_2e$
market-based approach
Equivalent to*:

0,4
Years of electric heating

or

407
km by car

or

385
km by plane and passenger**

As a point of reference, the yearly carbon emissions of an average French citizen are roughly equivalent to **9.9 tCO2e** in 2019 ***.

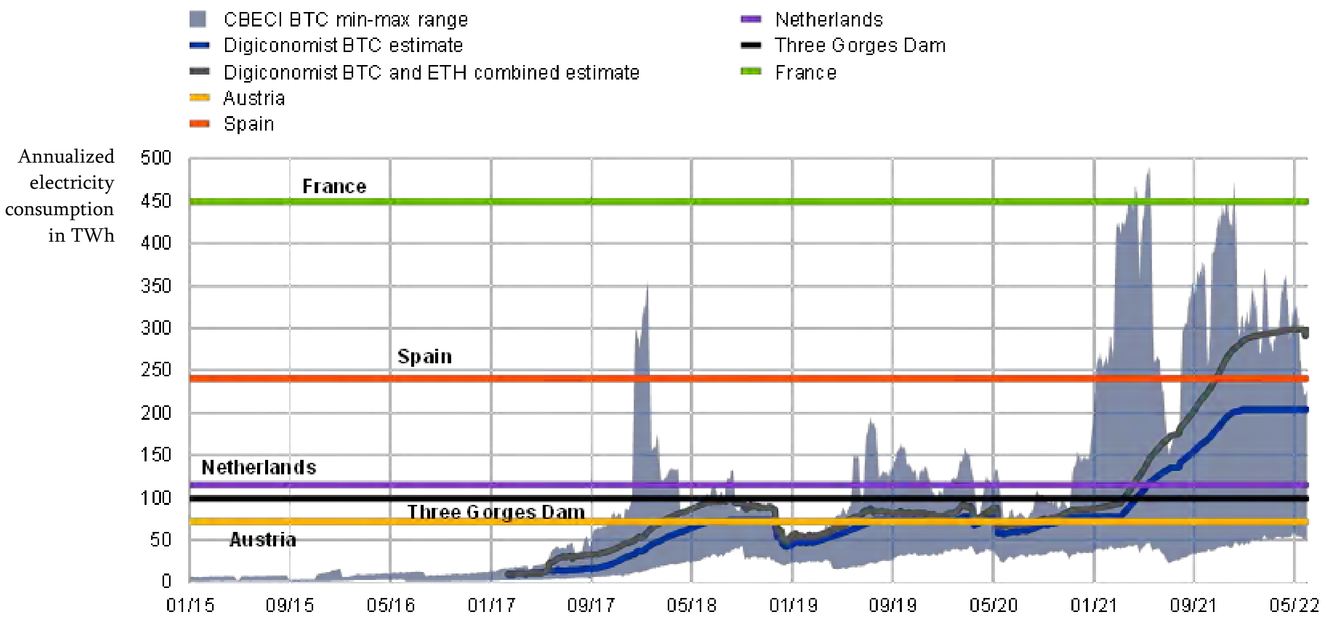
*The comparisons are made using the values provided by https://impactco2.fr supported by the Ecological Transition Accelerator, the internal incubator of ADEME (French Environment and Energy Management Agency).
** The carbon emissions from both airplanes and cars are comparable due to the calculation method factoring in 220 seats for airplanes, as opposed to one seat for cars.
*** Data sourced from Carbon4, which integrates information from the French government while also benefiting from an enhanced calculation methodology. https://www.carbone4.com/myco2-empreinte-moyenne-evolution-methodo

2. Introduction

2.1. Significance of studying of Carbon Emissions

Like any technology or human activity, **blockchain has its own climate impact**. Many studies and communications have been created about the impact of Bitcoin, comparing its carbon footprint to those of many countries as shown in the following figure.

Figure 2 Estimated annualized electricity consumption of global bitcoin (BTC) and ether (ETH) compared with that of selected countries[2]



In this context, evident concerns have been raised about the environmental impact of cryptocurrencies and the associated blockchains' impact and it has become clear that we require specific assessments for blockchain carbon footprint as its usage is spreading to develop new applications or to bring automation and efficiency to existing ones.

While general ICT carbon footprint methodologies are now commonly accepted and used to estimate corporate carbon footprints, blockchain technology is still relatively new, in perpetual evolution, and has a large diversity in its inner components and hardware requirements. Even within the same blockchain, some improvements can bring critical changes, the most known example being the change from a Proof of Work protocol to a Proof a Stake protocol for Ethereum, known as "The Merge".[3] The Merge reduced the energy consumption of the Ethereum network by a factor 99,998[4].

[2] Sources: Cambridge Bitcoin Electricity Consumption Index (CBECI), Digiconomist, Cambridge Centre for Alternative Finance, International Energy Agency, Morgan Stanley and ECB calculations

[3] Every blockchain is secured through a consensus protocol allowing to collect, validate and store new transactions without any trusted third party. The proof of work is the original consensus used by Bitcoin and Ethereum and requires heavy computer calculation and power. Ethereum switched to a more energy efficient consensus with « The Merge » update in September 2022.

[4] Implications on the Environmental Sustainability of Ethereum - CCRI Industry Report (September 2022)

2.2. Purpose and organization of this document

The purpose of this document is to present and explain the development of a general methodology allowing us to **measure the global carbon footprint of the tokenization process of a security issuance and management**, i.e. the representation on a public blockchain of a security and its management, from its issuance to its redemption including all security and cash settlements.

Based on previous work and deliverables (available as appendices) we present how to track the carbon footprint of SG-Forge tokenization activity.

We begin by describing the internal SG-Forge tokenization process. Next, we provide a detailed explanation of the methodology used to calculate carbon footprints, followed by a clear definition of the scope of our analysis. We also address data collection and the assumptions made, emphasizing the importance of reliable sources. Carbon emission scenarios are a key section where we assess different contexts and their potential impacts.

Furthermore, we project future emissions using available data. The study explains some limitations in our work, explaining some limits in our work due to specific choices or to a lack of data or model, while highlighting the benefits and perspectives associated with emission reduction and presenting some propositions to improve our methodology for future projects and issuances.

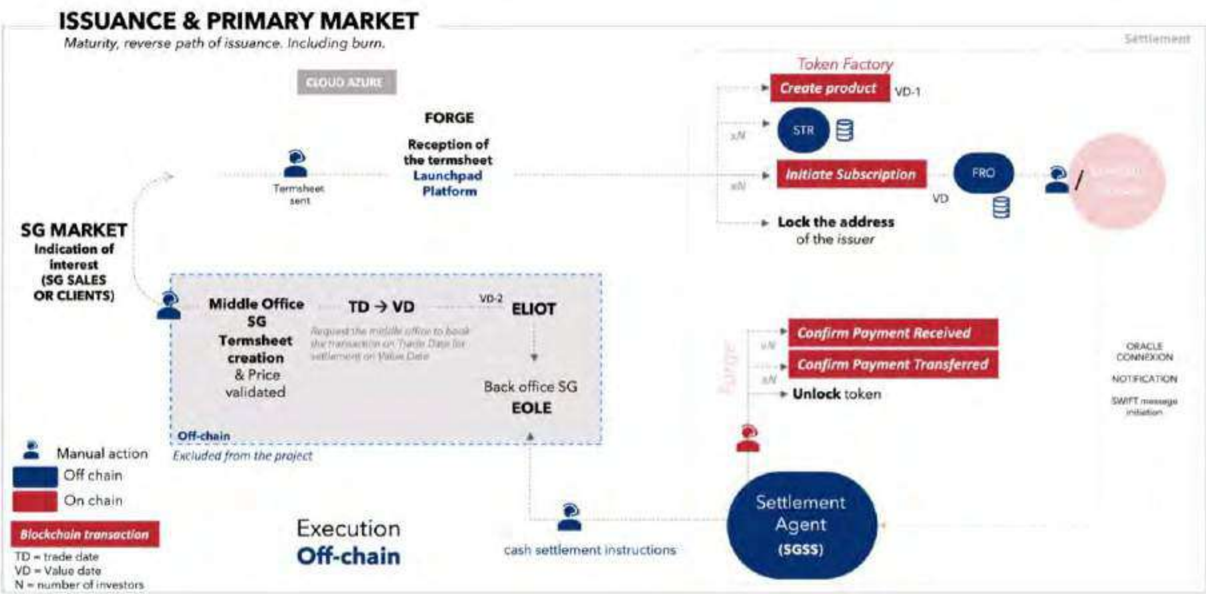
Finally, we conclude our report by summarizing the key findings and providing the necessary references and annexes for a better understanding.

3. Presentation of SG-Forge tokenization process

3.1. Identification of SG-Forge tokenization process

SG-Forge security token is designed after the **CAST framework**,[5] which is composed of market standards designed for digital blockchain-based securities. The CAST Framework enables the creation of an integrated financial ecosystem across blockchain-native and legacy systems. It is intended to give issuers, investors, financial institutions and other service providers an easy, trustworthy and seamless access to the developing market of tokenized securities.

Figure 3 Schematic representation of the issuance and primary market of SG-Forge's tokenization process



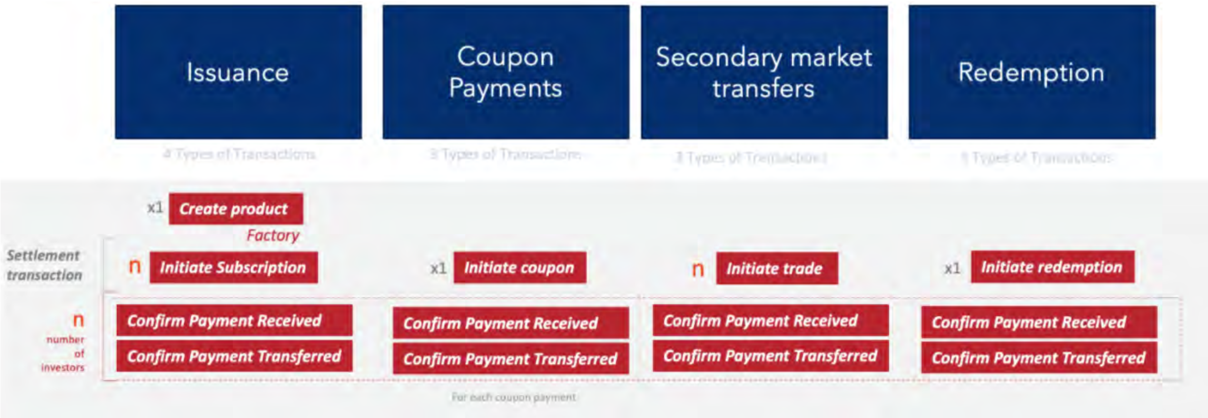
Please note:

- **Registrar** refers to the Agent of the security Issuer mandated to **provide the record-keeping of the security** on behalf of the Issuer (i.e. development of the Smart Contracts creating the Digital Assets and the recording of the Digital Assets on the relevant DLT and of the settlement transactions) as well as to provide registry management services to the Issuer (e.g. to put in place a business continuity plan which would notably consist of keeping at least one full node of the Digital Asset's DLT in order to be able to rebuilt off-chain the registry of the Digital Asset holders).

- **Settlement Agent** refers to the Agent of the security Issuer mandated to **handle cash settlement instructions management** in respect of the issuance of the Digital Assets, their sale on the secondary market and/or any payment of interest or principal related to the Digital Assets. The Settlement Agent is a role that can be carried out by the Registrar.

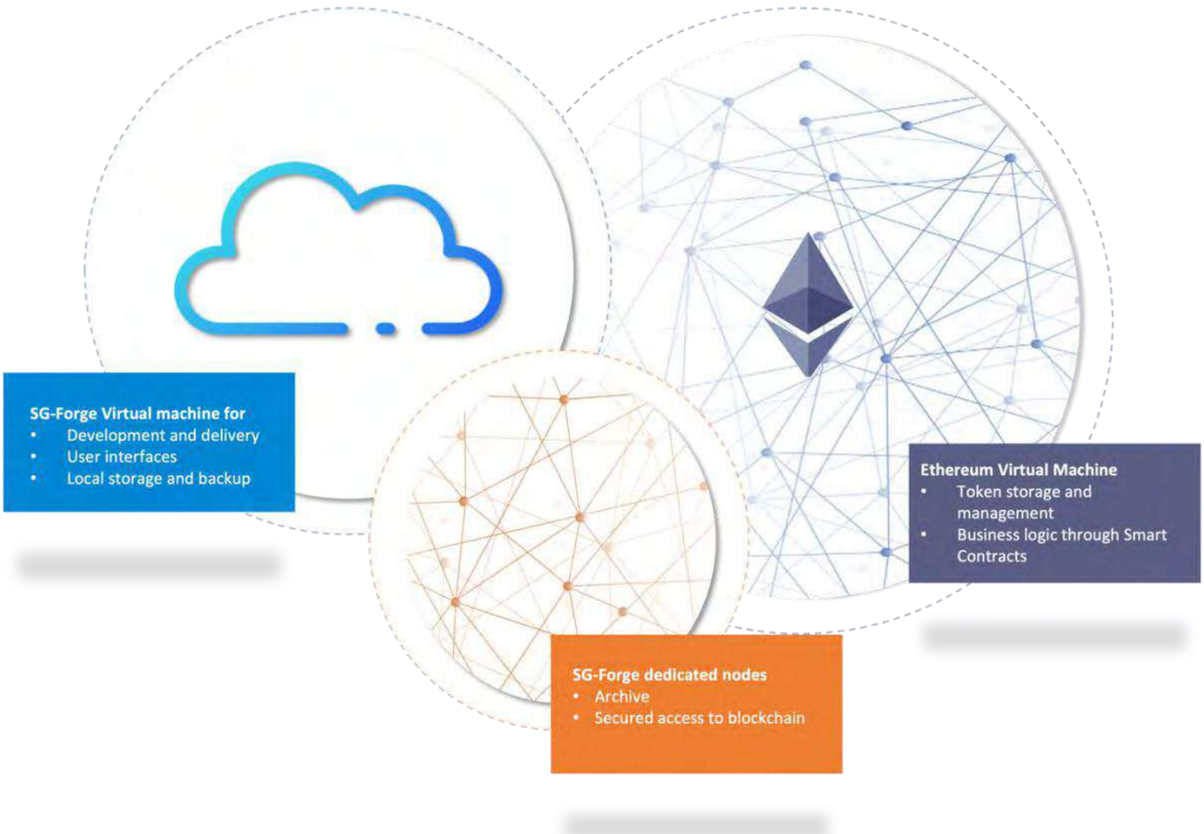
[5] Cast Framework information (2023) ELIOT and EOLE are in-house middle/back trade management software – https://www.cast-framework.com

Figure 4 Steps of the tokenization process and corresponding operations on blockchain



3.2. SG-Forge Architecture

Figure 5 SG-Forge tokenization environments



4. Carbon footprint methodology

4.1. Overview of existing standards for CO_2 emissions calculations

a. GHG Protocol

Launched in 1998, the GHG Protocol seeks to develop internationally accepted Greenhouse Gas (GHG)[6] accounting and reporting standards and tools to promote their adoption worldwide. To date, the GHG Protocol has released four standards that address how GHG emissions inventories should be prepared at the corporate, project, and product levels.

In accordance with the GHG Protocol, GHG emissions are categorized into three groups:

- **Scope 1**: Direct emissions - Emissions from stationary and mobile combustion, as well as process and fugitive emissions. For instance: emissions related to gas heating or oil generator.
- **Scope 2**: Indirect emissions - Emissions from the consumption of electricity, heat, or steam. These emissions are directly related to the energy source type. For electricity production, there are huge gaps between a production based on coal power plant or a nuclear or solar power plant.
- **Scope 3**: Other indirect emissions - Emissions associated with activities up and down the company's value chain.

Upstream phases:

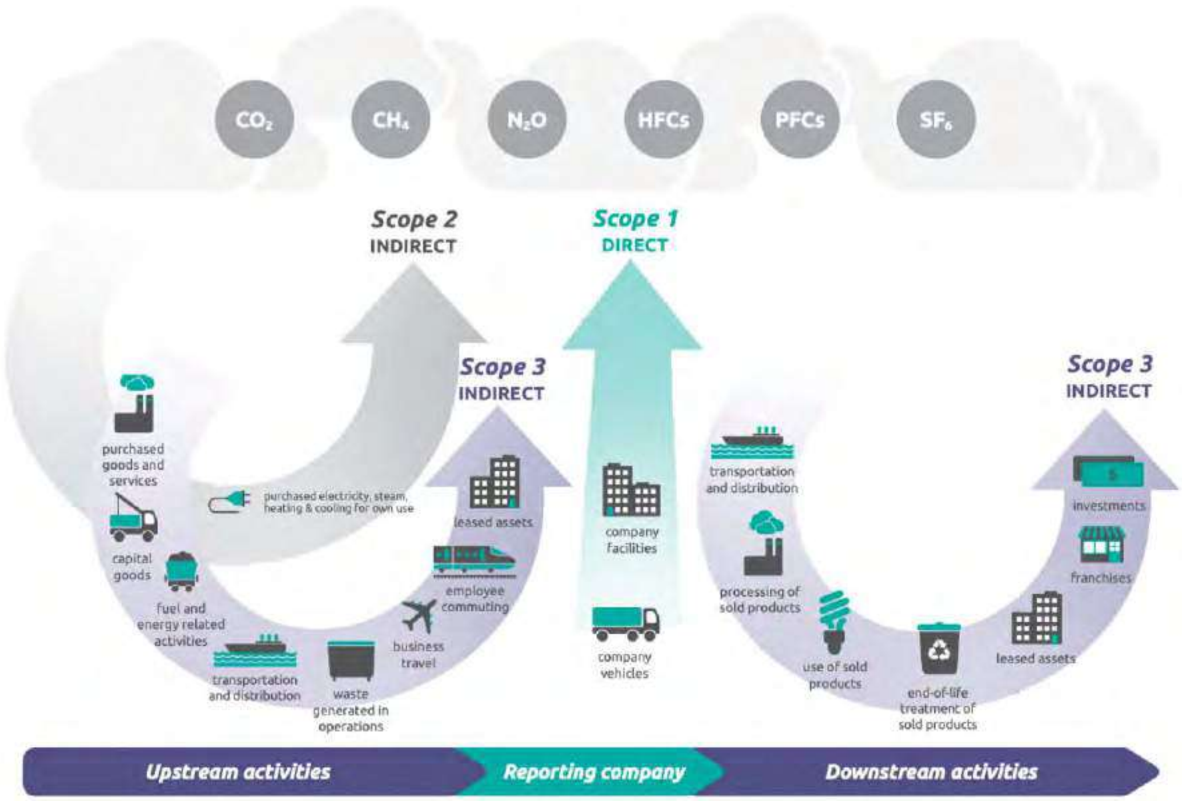
- Purchased goods and services,
- Capital goods,
- Fuel & energy-related activities,
- Upstream transportation and distribution,
- Waste generated in operations,
- Business travel,
- Employee commuting,
- Upstream leased assets.

Downstream phases:

- Downstream transportation and distribution,
- Processing of sold products,
- Use of sold products,
- End-of-life treatment of sold Products,
- Downstream leased assets,
- Franchises,
- Investments.

[6] About **GHG Vs. CO_2**: Carbon emissions refer specifically to carbon dioxide (CO_2), a byproduct of burning fossil fuels. On the other hand, greenhouse gas (GHG) emissions is a broader term that includes other gases like methane (CH_4), nitrous oxide (N_2O), and fluorinated gases, which can have a much higher global warming potential than CO_2. To standardize measurement of all these gases' global warming impact, we often use the term "CO_2 equivalent" or "CO_2e". This converts the emissions of different gases into an equivalent amount of CO_2, based on their global warming potential. So, while all carbon emissions are greenhouse gas emissions, not all greenhouse gas emissions are carbon emissions, and CO_2e provides a comprehensive measure of their collective impact.

Figure 6 Overview of GHG Protocol scopes and emissions across the value chain[7]



An important thing to understand carbon footprint assessments is the **notion of product life cycle**. GHG emission can be assessed at a company level but also at the product or service level. From a user point of view, product or service doesn't only emit greenhouse gas while it's being used. The product or service requires many materials and transformation of these materials to come into life. Extractions of base materials also requires energy and emits GHG during the process. Manufacturing also requires employees work force and we need to consider their commute, their food, their tools as well as additional factors.

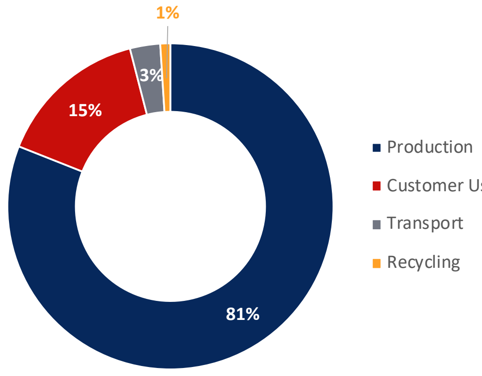
And after the normal life of the product or service, we still have emission related to its end-of-life processes, mainly recycling phase. So, we still have scope 1, 2 and 3 emissions from the producer point of view but it's very important to consider another kind of view, mainly between GHG emissions related to production and use.

And this is exactly what we want to assess here: the GHG emission related to the use of specific IT services supported by IT infrastructures.

[7] Greenhouse Gas Protocol - Corporate Value Chain (Scope 3) Accounting and Reporting Standard - Supplement to the GHG Protocol Corporate Accounting and Reporting Standard (2011)
https://ghgprotocol.org/sites/default/files/standards/Corporate-Value-Chain-Accounting-Reporing-Standard_041613_2.pdf

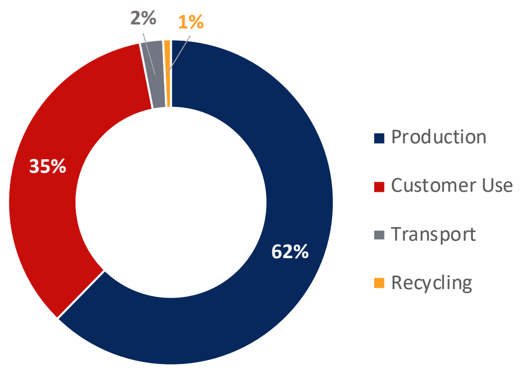
Based on the usage time of the product, the ratio of carbon footprint between production and use can be very different. For instance, we have the following repartition for a specific model of smartphone.

Figure 7 iPhone 14 Pro carbon footprint repartition – 2 years usage[8]



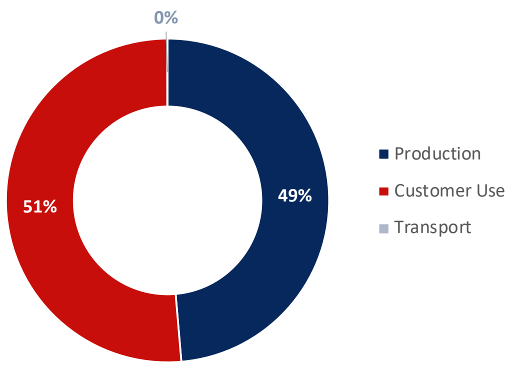
The GHG emissions ratio between the customer use and the production is strongly related to the duration of use. The numbers here are given for a customer changing his smartphone every two years. For a goal of six years with the same smartphone, we have the same amount of emissions for production, recycling and transport but emissions related to customer's use are tripled.

Figure 8 iPhone 14 Pro carbon footprint repartition – 6 years usage



For usage intensive hardware, like production servers in a data center, customer's use contributes the most to the GHG emissions of the product.

Figure 9 DellPowerEdge 740 carbon footprint repartition – EU energy mix[9]

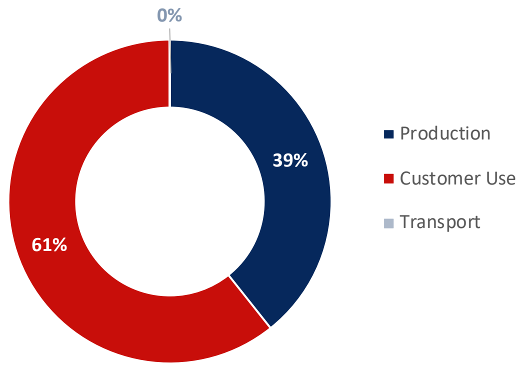


[8] Apple Product Environmental Report- iPhone 14 Pro (September 2022) https://www.apple.com/environment/pdf/products/iphone/iPhone_14_Pro_PER_Sept2022.pdf

[9] DELL – Report product – Life Cycle Assessment of Dell PowerEdge R740 (June 2019) https://corporate.delltechnologies.com/content/dam/digitalassets/active/en/unauth/data-sheets/products/servers/lca_poweredge_r740.pdf

In this case, we remark that the energy mix considered for the customer use has a huge impact on the carbon footprint (it is also strongly relevant for manufacture, but contrary to usage which can be anywhere in the world, production of a specific device is generally located in a specific place).

Figure 10 DellPowerEdge 740 carbon footprint repartition – US energy mix[10]



US energy mix being on average more carbon intensive than EU energy mix, using this hardware in the US emits more GHG than in EU.

b. International standards

- **ISO 14067 standard** builds largely on other existing ISO standards for Life Cycle Assessment and was published in 2018. It can be considered the international reference standard for conducting a product's carbon footprint.
- **National standard PAS 2050**, which was developed by the British Standards Institute (BSI), came into effect in October 2008 and was revised in 2011. PAS 2050 is widely used and is considered the first carbon footprint standard used internationally.
- **The GHG Protocol Product Standard** was created by the WRI/WBCSD and published in October 2011. It was developed to be consistent with the first version of PAS 2050, with the difference that the GHG Protocol Product Standard includes requirements for public reporting. The GHG Protocol also provides additional standards for corporate assessments and project-related emission calculations.

4.2. A presentation of Ethereum blockchain operation

a. What is Ethereum? [11]

"In the Ethereum universe, there is a single, canonical computer (called the Ethereum Virtual Machine, or EVM) whose state everyone on the Ethereum network agrees on. **Everyone who participates in the Ethereum network** (every Ethereum node) **keeps a copy of the state of this computer**. Additionally, any participant can broadcast a request for this computer to perform arbitrary computation. Whenever such a request is broadcast, other participants on the network verify, validate, and carry out ("execute") the computation. This execution causes a state change in the EVM, which is committed and propagated throughout the entire network.

Requests for computation are called transaction requests; the record of all transactions and the EVM's present state gets stored on the blockchain, which in turn is stored and agreed upon by all nodes.

[10] DELL – Report product – Life Cycle Assessment of Dell PowerEdge R740 (June 2019) https://corporate.delltechnologies.com/content/dam/digitalassets/active/en/unauth/data-sheets/products/servers/lca_poweredge_r740.pdf
[11] Ethereum Foundation: Ethereum.org – https://ethereum.org/kk/developers/docs/intro-to-ethereum/

Cryptographic mechanisms ensure that once transactions are verified as valid and added to the blockchain, they can't be tampered with later. The same mechanisms also ensure that all transactions are signed and executed with appropriate "permissions" (no one should be able to send digital assets from Alice's account, except for Alice herself)."

b. What is a client?[12]

"An Ethereum node requires two software clients: an execution client and a consensus client.

The **Execution Client** listens and executes transactions and maintains the latest state and database of all Ethereum data, while the Consensus Client provides consensus (using PoS algorithm) from validated data from the Execution Client. These two clients work together to sync the Ethereum state.

A validator is an optional add-on to a consensus client that enables the node to participate in proof-of-stake consensus. This means creating and proposing blocks when selected and attesting to blocks they hear about on the network. To run a validator, the node operator must deposit 32 ETH into the deposit contract."

c. What is gas?[13]

"Gas refers to the unit that measures the amount of computational effort required to execute specific operations on the Ethereum network.

Since each Ethereum transaction requires computational resources to execute, each transaction requires a fee. Gas refers to the fee required to execute a transaction on Ethereum, regardless of transaction success or failure."

d. What was the Merge and its environmental impact?[14]

"The Merge was the joining of the original execution layer of Ethereum with its new proof-of-stake consensus layer, the Beacon Chain. It eliminated the need for energy-intensive mining and instead enabled the network to be secured using staked ETH."

The Merge marked the end of proof-of-work for Ethereum and start the era of a more sustainable, eco-friendly Ethereum. Ethereum's energy consumption dropped by an estimated 99,98%[15], making Ethereum a low carbon blockchain.[16]

	Ethereum PoW	Ethereum PoS	Reduction factor
Electricity consumption [MWh/year]	22,900,320	6,570	0.99971
CO_2e emissions [t/year]	11,016,000	2,200	0.99980

4.3. Identified methodologies for carbon emissions calculation on blockchain networks

We identify papers, including university papers, written or updated after the transition of Ethereum to a proof a stake consensus. This transition, called "The Merge", occurred in September 2022.

[12] Ethereum Foundation - https://ethereum.org/en/developers/docs/nodes-and-clients/node-architecture/
[13] Ethereum Foundation - https://ethereum.org/en/developers/docs/gas/#what-is-gas
[14] Ethereum Foundation- https://ethereum.org/en/roadmap/merge/
[15] Using CCRI methodology
[16] Ethereum Foundation - https://ethereum.org/en/energy-consumption/

Moreover, it is important to select methodologies that were recognized and used by the main blockchain foundations and actors. We also add less well-known methodologies, study their originality and use them to benchmark the references.

We collected information from Ethereum Foundation and Consensys and completed our study with sources provided by SG-Forge, search on Google, and Google Scholar using key words such as: "energy consumption"; "carbon emission"; "carbon footprint" "proof of stake"; "electricity consumption"; etc. with a selection on post "Merge" studies.

- **Methodology 1**: Juan Ignacio Ibanez, Francisco Rua, Universidad Catolica de Cordoba[17]
- **Methodology 2**: Electricity Consumption of a Distributed, Consensus Algorithm - Wilhelm Wanecek – Lund University [18]
- **Methodology 3**: CCRI methodology [19]
- **Methodology 4**: Cambridge Blockchain Network Sustainability Index (CBNSI)[20]
- **Methodology 5**: PwC for Tezos Blockchain [21]

Among the five methodologies studied in a previous document[22] provided to SG-Forge, we considered the one that appears to be the most reliable to date. This chosen methodology is the one developed by CCRI, adopted by the University of Cambridge, and recognized by the Ethereum Foundation. To confirm this choice, we conduct a thorough analysis, considering various criteria such as data source quality, parameter accuracy, and consistency of results. By opting for this methodology, we aim to ensure the rigor and credibility of our calculations regarding on-chain carbon emissions.

4.4. Methodology selected for the on-chain calculation

a. About

1) CCRI

The Crypto Carbon Rating Institute is an interdisciplinary team working for more than 7 years on the climate impact of crypto currencies and blockchain networks. It produces methodologies and measures on carbon emissions for blockchains and related activities.

2) Cambridge Centre for Alternative Finance

The Cambridge Centre for Alternative Finance (CCAF) is a research center at the University of Cambridge Judge Business School. They have established the Cambridge Blockchain Network Sustainability Index (CBNSI) and the Cambridge Bitcoin Electricity Consumption Index (CBECI). These tools examine the electricity consumption of blockchain networks as Ethereum and more specifically Bitcoin, providing daily estimates and comparisons. The CCAF's aim is to enhance understanding and inform decision-making regarding the sustainability and environmental impacts of these blockchain networks.

3) MigaLabs

MigaLabs is a research group specialized in next-generation Blockchain technology. The team works on in-depth studies and solutions for Blockchain Scalability, Security and Sustainability.

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[17] J. I. Ibañez and F. Rua, Centre for Blockchain Technologies, University College London, London, UK2DLT Science Foundation Facultad de Ciencia Politica y Relaciones Internacionales, Universidad Catolica de Cordoba "*The energy consumption of Proof-of-Stake systems:Replication and expansion*"
[18] W. Wanecek, Department of Electrical and Information TechnologyLund University "*Electricity Consumption of a Distributed Consensus Algorithm*"
[19] CCRI, "*Determining the electricity consumption and carbon footprint of Proof-of-Stake networks*" (Dec. 2022), CCRI "The Merge - Implications on the Electricity Consumption and Carbon Footprint of the Ethereum Network" (Sept. 2022)
[20] Cambridge Centre for Alternative Finance, University of Cambridge - Cambridge Blockchain Network Sustainability Index (2023)
[21] Study prepared for Nomadic Labs by PricewaterhouseCoopers Advisory "Study of the environmental impact of the Tezos blockchain Life Cycle Assessment of the Tezos blockchain protocol" (Dec.2021)
[22] *Carbon Footprint Calculation - Summary of methodologies & best practices* document (annex 13.3)

It develops state of the art software providing insights about blockchain networks and configuration of its constitutive nodes.

b. Steps of the CCRI methodology [23]

- "In the **first step**, we analyze the different client solutions and **their minimum hardware requirements**. The hardware requirements are an indicator of the hardware composition of the network. We use this information and additional hardware data from PassMark to select and obtain hardware that we use to measure a single node's electricity consumption.

- In the **second step**, we estimate the **electricity usage of a single node** participating in the network that runs a specific combination of one consensus and one execution client.
    - For this, we first determine the **electricity usage of the hardware** devices while idling.
    - Secondly, we measure the e**xecution of different consensus and execution clients on their own on the hardware** devices selected. We provide upper and lower bounds as well as a best guess metric for each client software considered.
    - Thirdly, we subtract the **idle electricity usage from the results obtained for each client**, allowing us to calculate the power consumption for arbitrary combinations of consensus with execution clients. Taking the idle power consumption into account, these values allow us to produce reasonable upper and lower bounds and a best guess for running a full node applying different client software combinations, as our hardware is selected accordingly. We also measure other data points, such as CPU utilization and processed blocks, to be able to evaluate additional metrics.

- In the **third step**, we estimate the electricity consumption of the complete network.
    - Firstly, we collect information about the **size of the network**, as the node count significantly influences the amount of electricity consumed. Thereby, we consider the client diversity within the Ethereum network since the various combinations differ in terms of electricity usage. We thus weight the electricity consumption of client combinations according to their frequency of occurrence in the network.
    - Secondly, we develop a weighting between the single hardware devices.
    - Lastly, we multiply the electricity consumption, adjusted for the client diversity, of the weighted nodes by the number of accounts in the network.

- In the **fourth step**, we estimate the **CO2 emissions** arising from the operation of the Ethereum PoS network. For this, we use our weighted data on electricity consumption calculated and multiply it with a carbon intensity factor adjusted to the regional distribution of the nodes in the network. We provide a best guess as well as an upper and a lower bound for the carbon footprint of the Ethereum PoS network."

4.5. Cloud Provider's Carbon Emission Calculation

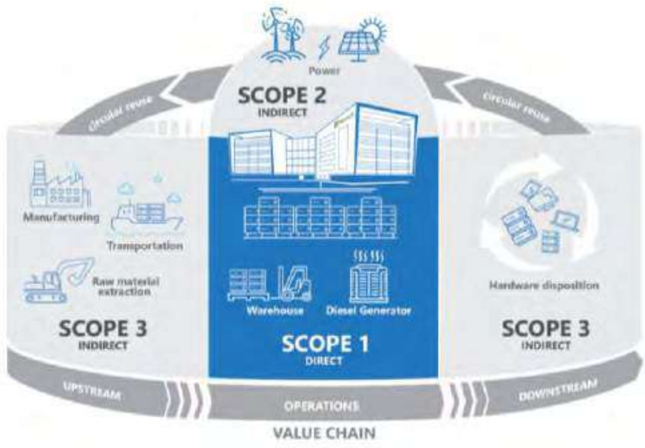
For its off-chain activities, SG-Forge uses cloud services for which its cloud provider produces its own life cycle assessments. It is therefore essential to understand the specific methodology used to measure these emissions.

For instance, the documentation provided by Microsoft for Azure clearly outlines the principles and practices they have adopted to evaluate and reduce greenhouse gas emissions, especially the use of GHG Protocol and the alignment with international standards.

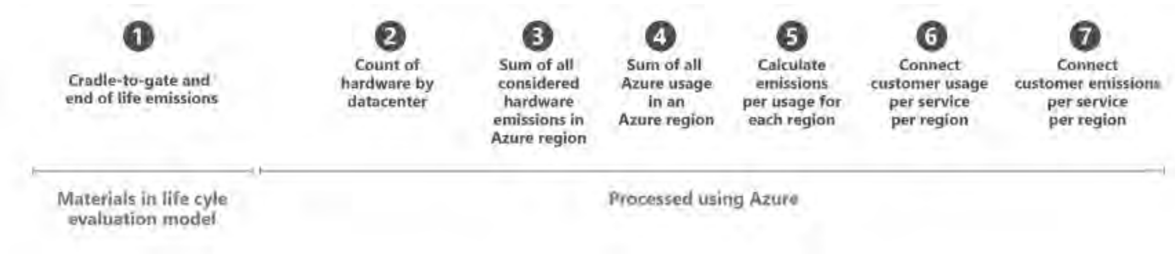
[23] CCRI "The Merge - Implications on the Electricity Consumption and Carbon Footprint of the Ethereum Network" (Sept. 2022)

In our study, we will consider the actual emissions provided by SG-Forge cloud provider. Even though most cloud providers implement and communicate on measures to offset a portion of their emissions with the goal to achieve carbon neutrality, it is crucial to focus on the actual emissions generated using the cloud services.

Figure 11 Calculation basis for the emission types in the value chain of Microsoft Cloud based on the different scopes (1, 2, and 3). [24;25]



Microsoft's emissions calculation methodology consists of 7 steps, which are identified below [26]:



Following this methodology, SG-Forge cloud provider quantifies carbon emissions in its cloud services based on aggregated IT hardware emissions and allocates them equitably to customers based on their actual usage.

It offers its clients an emission impact dashboard that allows their clients to access a wide range of data on the company's energy consumption.

The table below[27] identifies the **different scopes based on various stakeholders**. From a "cloud customer's" point of view, we only have Scope 3 emissions. However, it is important to identify the emissions related to cloud operations that appears as Scope 1 and 2 from the cloud provider point of view. These are the emissions related to the energy consumption for the use of the cloud services by customers.

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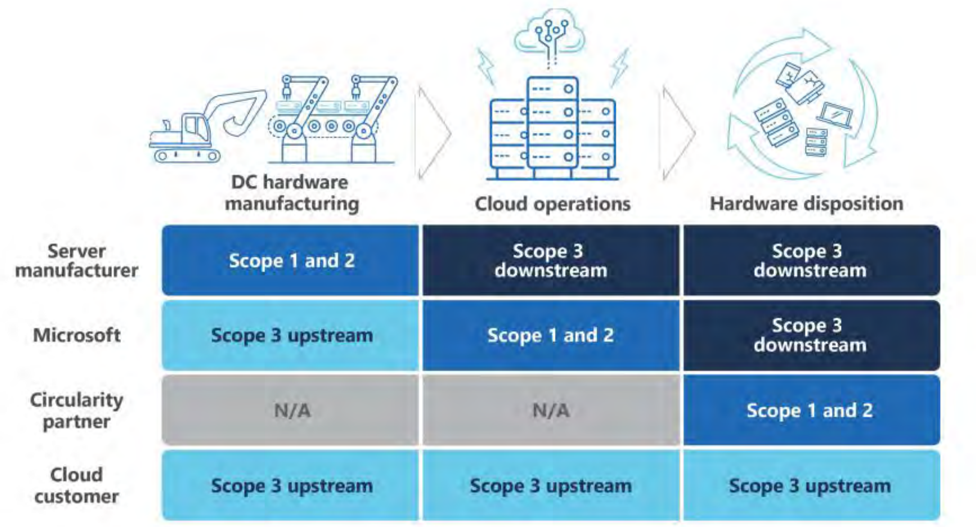
[24] Microsoft's Emission Impact Dashboard - Calculation methodology – Microsoft's cloud-carbon accounting practices
[25] You will also find in the appendix (annex 13.3) the key parameters identified by Microsoft for the calculation of its carbon emissions.
[26] Microsoft publication - *A new approach for Scope 3 emissions transparency* (2021)
[27] Microsoft publication - *A new approach for Scope 3 emissions transparency* (2021)

Figure 12 Emission scopes given from different stakeholders' point of view



We decide to focus on cloud operations and to exclude the "DC hardware manufacturing" and "Hardware disposition" from our calculation methodology. However, we consider that a full lifecycle assessment may be possible soon with more data and better data quality.

4.6. SG-Forge nodes managed by node service provider

Due to SG-Forge's ownership of its nodes hosted by its node service provider, we need to incorporate the carbon footprint of these nodes separately into our methodology to have a complete and accurate picture of the whole project carbon footprint.

To date, SG-Forge's node service provider was not able to provide us any methodology or data to collect this information. We will use some elements of our selected blockchain carbon footprint methodology to estimate the carbon footprint of the SG-Forge managed nodes.

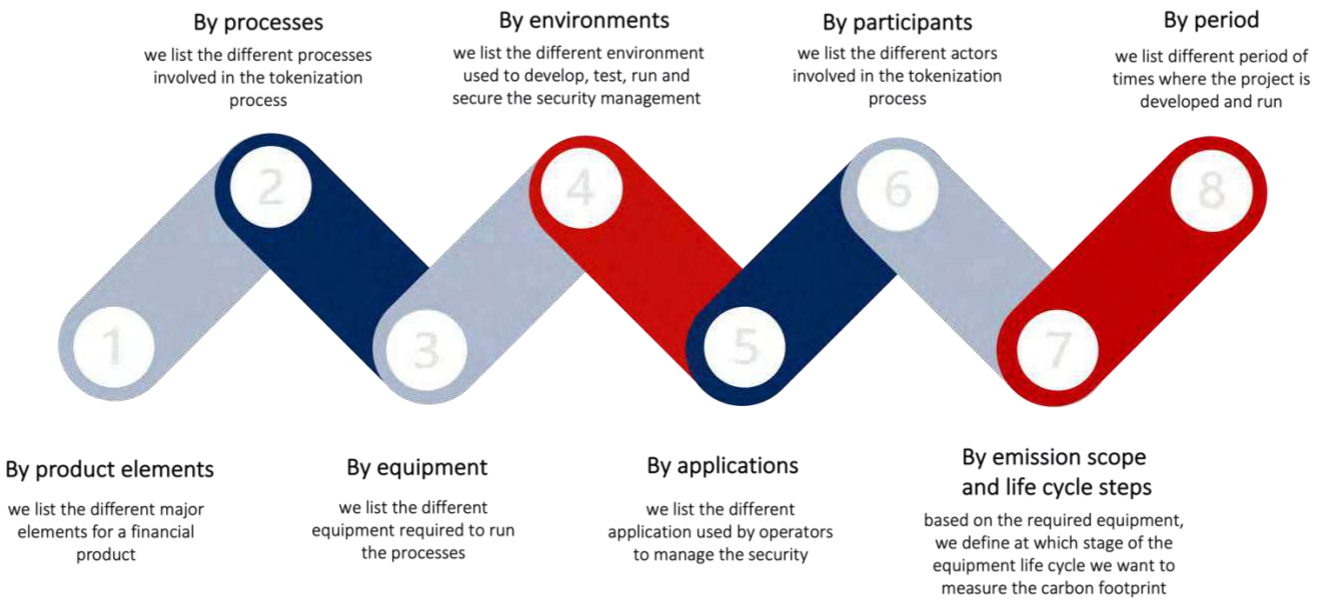
5. Selected perimeter for analysis

5.1. General approach

When delimiting the carbon footprint of an IT project, there are several elements to consider, and a variety of possible approaches that can be taken.

We can list the following:

Figure 13 Different approaches to define the selected perimeters for the study



Our general methodology is based on these different approaches and selects the most relevant elements required for our study.

When some elements are discarded, an explanation is presented.

5.2. Details for each approach

a. Elements of the financial product

When talking about a financial product, we can distinguish three major elements which have impact on its carbon footprint:

- Its supporting IT infrastructure, defining how it is stored and managed,
- The usage of the funding, or use of proceed if it is clearly defined,
- The underlying asset in the case of a structured product.

In the specific case of this study, we explicitly focus our work on the GHG emissions related to the IT infrastructure.
However, it must be noted that funded emissions related to the use of the funding for economic activities are generally a lot higher than those related to IT infrastructure. According to CDP (Carbon Disclosure Project), finance sector's funded emissions are more than 700x greater than its own[28].

[28] https://www.cdp.net/en/articles/media/finance-sectors-funded-emissions-over-700-times-greater-than-its-own

As for underlying assets, they generally exist outside of the related financial product and should not be considered. However, in the case of a sustainability related product, strong incentives are given by the objective of the financial product to achieve a positive impact, socially or environmentally speaking.

In scope	Out of scope
• Supporting IT infrastructure	• Usage of funds • Underlying assets

b. Processes

Even the most common financial products require many processes between the indication of interest of a customer for a specific product and its end of life or maturity.
Most basic financial product processes are:

- Issuance
- Initial placement on primary market
- Trading on secondary market
- Corporate event management
- Redemption

In scope	Out of scope
• Structuration • Placement • Issuance processing • Order management and execution • Initial placement on primary market • Trading on secondary market • Corporate action management • Redemption • Settlement • Safekeeping / Custody • Register management	• Origination • IOI & quotes management • Market making • Marketing and sales • Clearing • Collateral management • Reconciliation • Risk management • Accounting • Pricing/Valuation

c. Equipment

Different kinds of equipment can be used for the development, maintenance and running of an information system.

The main elements are:

- Servers
- Storage
- Network and security equipment (Hub, Switch, Firewall, HSM…)
- Desktops and laptops
- Screens
- Miscellaneous peripherical (mouse, keyboard, printers…)

Even though most of the servers are now configured in Cloud configuration allowing the presentation to the users of virtual machines (VM), the cloud farms allowing to create and manage these VMs are still based on common server hardware with specific configuration (CPU, GPU, RAM, internal storage).

In scope	Out of scope
• SG-Forge dedicated environment hosted by cloud provider • SG-Forge dedicated nodes hosted by a specialized node service provider • Ethereum network • Dedicated security equipment (HSM)	• Shared SG offices and associated services • Shared SG Servers • Shared SG Network and security equipment (Hub, Switch, Firewall) • SG-Forge desktops and laptops • SG-Forge miscellaneous peripherical (screen, mouse, keyboard, printer…)

Hardware security modules should be used for the management of private keys, especially private keys required for Blockchain identification. However, at this stage of the project, no production HSM configuration has been configured yet. Private keys are still managed using dedicated off-line hardware with virtually no energy consumption.

d. Environments

Developing, maintaining, and running securely an information system requires several environments, generally:

- **Development:** this is where developers code, compile, deploy and test the last features for an application. The activity is linked to the development phase and the type of test. Many different software versions of the same application can be installed and running at the same time or on demand by automated software.
- **Test/acceptance:** this environment is used for acceptance tests. Software should be close to the production version with new features, versions, or bug fixes. Final users will test and validate (accept) the changes done on the application.
- **Preproduction/homologation:** this environment should be a replication of the production environment (hardware and software) where the deployment phases can be validated.
- **Production:** this is where the software runs for final users to use it on a daily basis.
- **Backup/DR:** this is supposed to be a close copy of the production environment which can replace the production environment in case of severe failure on critical applications. With cloud infrastructure, this environment can be partially managed through specific service level.

As we want to cover the complete project, we need to get the entire carbon impact of the use of all environments.

In scope	Out of scope
• Development • Test/acceptance • Preproduction/homologation • Production • Backup/DR	

Development, test and homologation environments can be grouped together to estimate the corresponding energy consumption. However, it's difficult to attribute a development phase to a specific token issuance as this is shared amongst all consecutive issuances. Moreover, we do not have the same monitoring tools on Ethereum testnets and mainnet[29]. For instance, there is no historical chart on testnests on Etherscan[30] which is our main reference for collecting the gas units used for a specific issuance.

e. Applications

Most financial systems require several different applications to manage all the processes related to financial product management. Booking, risk, accounting, settlement are some of these many processes which can involve many different applications.

In scope	Out of scope
• SG-Forge	• All other applications, including booking systems, middle, back office, and risk

At this stage, we include the sole application identified for the management of the tokenization process. This is in relation with SG-Forge dedicated environment running the application services and databases.

f. Participants & roles

Issuers, dealers, agents, investors are the most common participants of a financial product management. The chosen scope focuses on roles played by SG-Forge services.

In scope	Out of scope
• Registrar • Wallet provider • Settlement Agent • Infrastructure provider	• Investor • Broker/Dealer • Market maker • Issuer • Facility Operator • Other service provider

g. Periods

As we want to analyze the tokenization project, it is important to assess the carbon impact of the different phases before the tokenization process itself and mainly the development phase if we have enough data to estimate it.

In scope	Out of scope
• Development phase • Idle phase • Financial product life cycle	

Idle time is all the time where there is no activity on the equipment but still energy consumption. Between the issuance of the product and its tokenization on blockchain and the redemption or trade events, some parts of the system are idle. Idle time represents an important part of the product life cycle, even for development phase.

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[29] The mainnet is the principal production network while testnets are dedicated for test and homologation and do not support production applications. Well known Ethereum testnets are Sepolia and Goerli.
[30] Etherscan – https://etherscan.io/

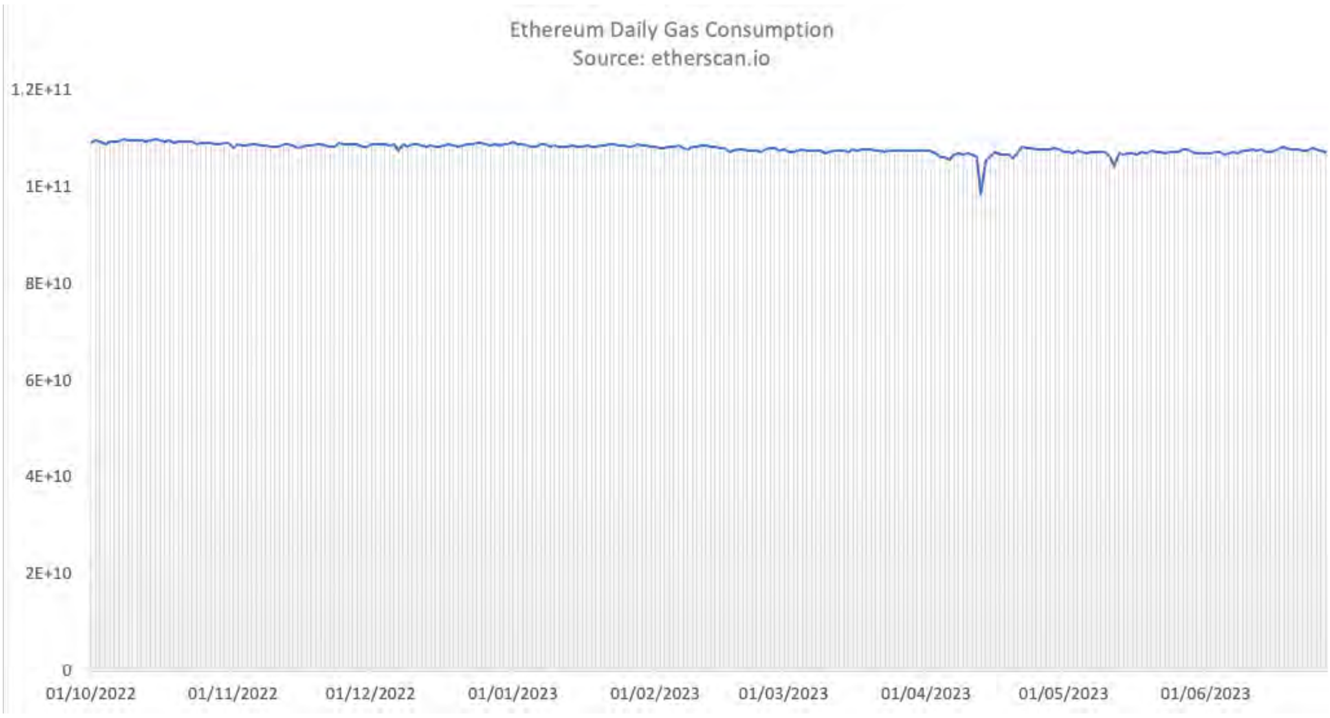
For instance, Dell 740 Server LCA[31] uses the following load profile:

- 100% load mode: 10% of the time
- 50% load mode: 35% of the time
- 10% load mode: 30% of the time
- Idle mode: 25% of the time

As SG-Forge environments are solely dedicated to the tokenization process, we consider that their whole energy consumption, even during idle phase, must be taken into account for the carbon footprint.

However, with the Ethereum blockchain being highly mutualized, we cannot say there is any idle phase. This is demonstrated in the fact that the gas consumption is stable in time and shows no relevant peak activity over long period of time (a notable drop is visible mid-April 2023 and is related to Shapella Ethereum update which occurred April 12th 2023). Even within short time period, at the block creation level (every 12 seconds), we do not observe any idle period, every block showing a minimum number of transactions.[32]

Figure 14 Ethereum Daily Gas Consumption[33]



This explains why we must separate Ethereum carbon footprint related to the tokenized financial product management (highly variable with the number of issuances and market activity) from SG-Forge cloud service carbon footprint.

h. Carbon emission scope

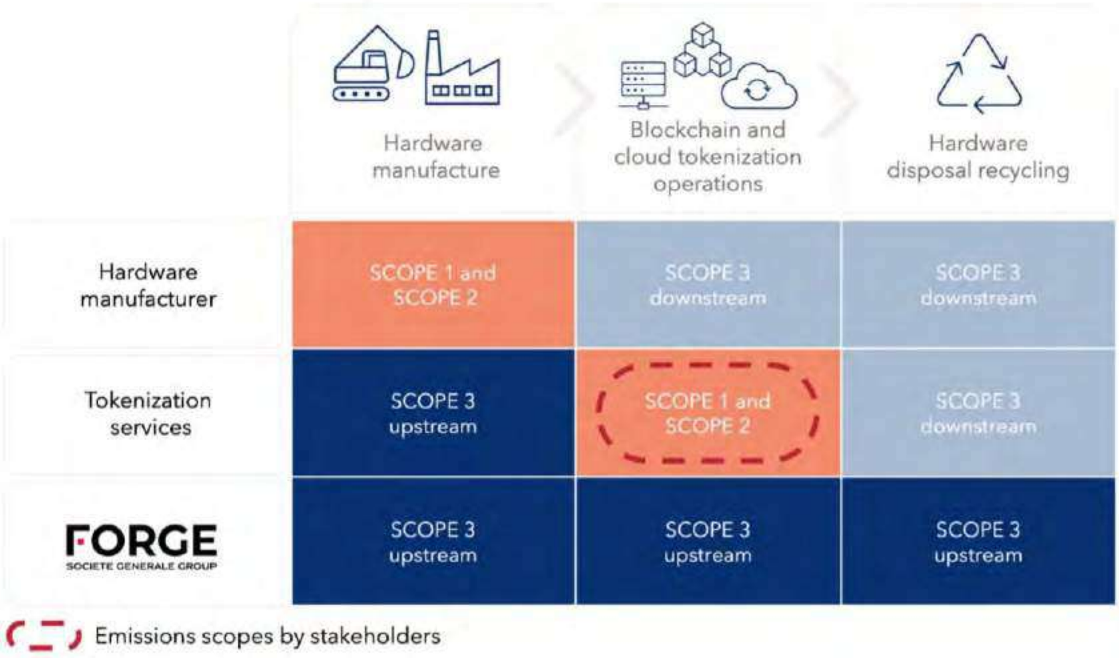
First, we define from which point of view we consider GHG emission scope.
For this we don't consider carbon emissions from SG-Forge point of view as most emissions would be included in scope 3 (cloud and blockchain services alike).

[31] DELL - Life cycle assessment of Dell R740 – 2019 – https://www.delltechnologies.com/asset/en-us/products/servers/technical-support/Full_LCA_Dell_R740.pdf
[32] https://etherscan.io/blocks
[33] Etherscan.io – https://etherscan.io/

Rather we consider all services and infrastructures involved in the tokenization process and management as a unique service provider entity and defines the scopes for this entity (as performed by Microsoft Azure):

- Scope 1: direct emissions related to operations,
- Scope 2: Indirect emissions related to energy consumption,
- Scope 3: other indirect emissions (upstream and downstream).

Contrary to an entire infrastructure assessment, we limit the study to one single application running on its infrastructures.



For a tokenization application project, we consider the use of an existing public and shared infrastructure (the blockchain network) that is **not dedicated to the project.** This infrastructure relies on very **heterogeneous hardware** which makes it difficult to estimate the real hardware. Reviewed methodologies to estimate the carbon footprint of the Blockchain make **some assumption on the required hardware** and corresponding power, and derive the **energy consumption at use** and related carbon footprint (corresponding in this view as **scope 2**) from this element (along with the number of active nodes running the network).

At this stage, it is **very difficult to estimate scope 3** as it was done on PwC methodology for Tezos[34]. As said previously, **the exact nature of hardware is not known for Ethereum nodes** (hardware configuration, manufacturer, age, previous usage…) which would make a **scope 3 calculation hazardous**. However, as many nodes are now running on cloud hosted infrastructure, it may be possible to get **information from the cloud providers** themselves which could be an interesting **update of this methodology in the future**, provided that the information of these cloud providers is reliable (for more information, see 9.7)

In this context, a whole life cycle analysis of the infrastructure is not justified yet, and the carbon footprint assessment is limited to the energy consumption required for the project to run.

[34] Study prepared for Nomadic Labs by PricewaterhouseCoopers Advisory "Study of the environmental impact of the Tezos blockchain Life Cycle Assessment of the Tezos blockchain protocol" (Dec.2021)

In scope	Out of scope
• Scope 1 (limited to backup generator for energy production) • Scope 2	• Scope 1 (other emissions) • Scope 3

5.3. Synthesis

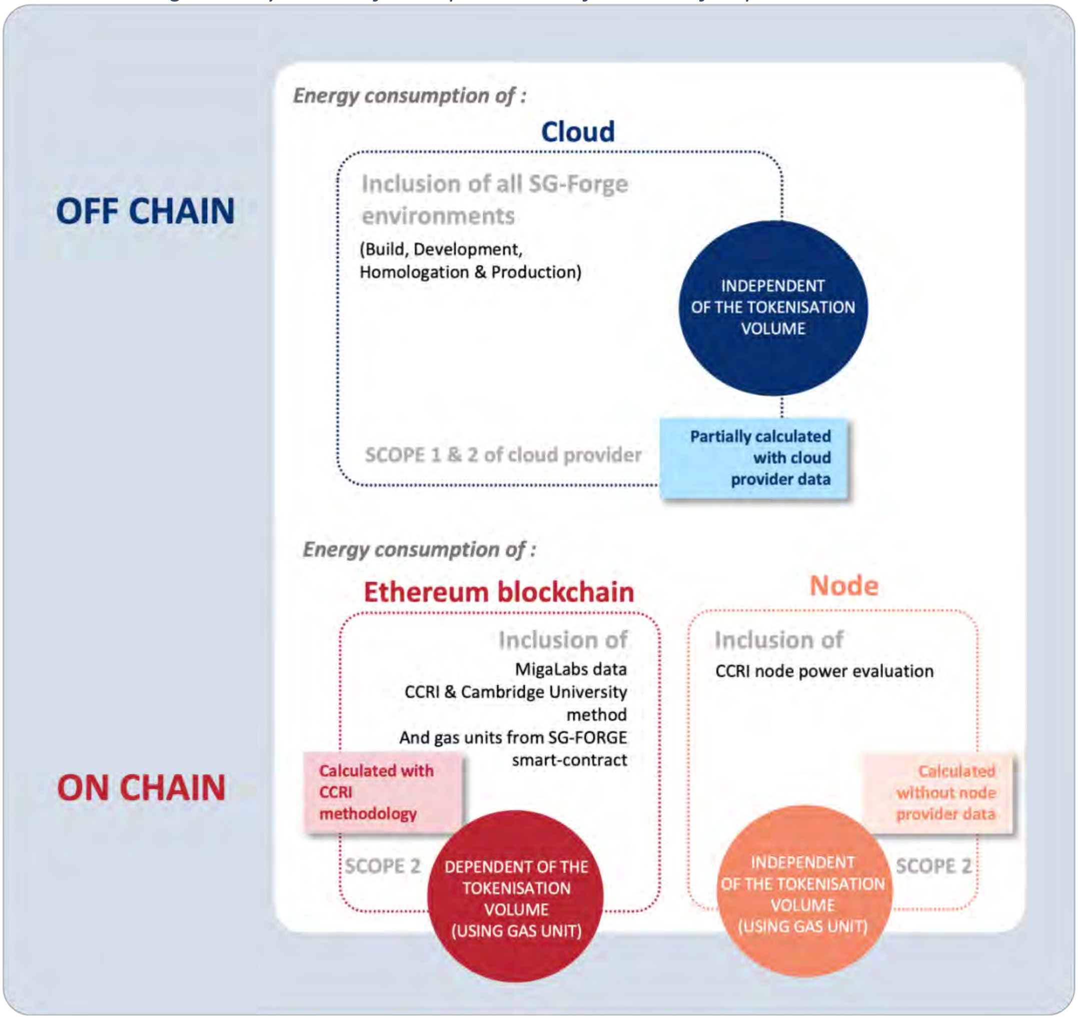
We think this methodology with different approaches allows us to have an exhaustive view of the project. The rejected elements, out of scope for this study, can be part of further studies by SG-Forge and other stakeholders and help complete the global carbon footprint for the management of financial products.

It is important to note that:

- the energy consumption and carbon footprint related to the on-chain management of the tokenized financial product depends on the number of issuances and on the market activity.
- the energy consumption and carbon footprint related to the use of mutualized SG-Forge cloud services and dedicated node services are calculated based on the study of one tokenization project and the support of one bond issuance. This part of the carbon footprint should be shared and mutualized between SG-Forge future issuances so the carbon footprint per issuance for this part should diminish with every new issuance.

We summarize the in-scope elements in the following figure:

Figure 15 Synthesis of in scope elements for carbon footprint assessment



6. Data collection and assumptions description

6.1. Selected GHG emission scopes

To resume, for each identified part, we only consider the following GHG emission scopes covering the energy consumption in use:

	SCOPE 1	SCOPE 2	SCOPE 3
ON CHAIN ETHEREUM		X	
ON CHAIN NODE PROVIDER		X	
OFF CHAIN CLOUD PROVIDER	X	X	

We include **Scope 1** of SG-Forge's cloud provider because it is related to energy production by generators for securing the energy supply of its infrastructure, which is not a concern for decentralized blockchain-type infrastructures.

The calculation excludes **Scope 3** which refers to indirect greenhouse gas emissions resulting from an organization's value chain, encompassing activities beyond its operational control, (also called "life cycle," emissions). It is challenging to determine the Scope 3 emissions for the on-chain part due to the lack of information regarding the true nature of the equipment. Factors such as whether the equipment is second-hand, recycled, or amortized can significantly impact carbon accounting. As a result, the Scope 3 emissions of SG-Forge's cloud provider are also excluded to align with our overall calculation. To address the lack of information, a questionnaire targeting node owners has been developed in order to build a better knowledge of the blockchain infrastructure.

6.2. Cloud provider

Sum of Carbon emissions (MTCO2e)	Scope 1				Total Scope1	Scope 2				Total Scope2	Scope 3				Total Scope3
Assumption environment	**2020**	**2021**	**2022**	**2023 JAN - APR**		**2020**	**2021**	**2022**	**2023 JAN - APR**		**2020**	**2021**	**2022**	**2023 JAN - APR**	
build environment	0.0000	0.0133	0.0133	0.0016	0.0282	-	-	-	-	-	0.0000	0.1410	0.1601	0.0505	0.3517
developpment/test environment	0.0011	0.0113	0.0160	0.0023	0.0307	-	-	-	-	-	0.1895	0.2650	0.2535	0.0833	0.7913
homologation envirnoment	0.0000	0.0090	0.0126	0.0015	0.0231	-	-	-	-	-	0.0000	0.0948	0.1519	0.0481	0.2948
homologation environment			0.0001	0.0001	0.0002			-	-	-			0.0262	0.0223	0.0485
SUBTOTAL BUILD / TEST / HOMOLOGATION ENVIRONMENT	**0.0011**	**0.0336**	**0.0420**	**0.0055**	**0.0823**	**-**	**-**	**-**	**-**	**-**	**0.1896**	**0.5008**	**0.5917**	**0.2043**	**1.4864**
production environment		0.0024	0.0261	0.0015	0.0300		-	-	-	-		0.0877	0.3103	0.0478	0.4458
production environment				0.0007	0.0007				-	-				0.0240	0.0240
production environment		0.0165	0.0246	0.0030	0.0440		-	-	-	-		0.1748	0.2931	0.0973	0.5652
production environment			0.0011	0.0007	0.0017			-	-	-			0.2557	0.1336	0.3893
production environment	0.0001	0.0113	0.0095	0.0016	0.0224	-	-	-	-	-	0.0109	0.1218	0.1137	0.0505	0.2969
SUBTOTAL PORDUCTION ENVIRONMENT	**0.0001**	**0.0301**	**0.0613**	**0.0075**	**0.0989**	**-**	**-**	**-**	**-**	**-**	**0.0109**	**0.3843**	**0.9728**	**0.3532**	**1.7213**
TOTAL	0.0011	0.0638	0.1033	0.0130	0.1812	-	-	-	-	-	0.2005	0.8852	1.5644	0.5575	3.2077

We consider the calculation of SG-Forge cloud provider's **Scope 1** emissions (mainly related to backup generators owned by the cloud provider) in the calculation of SG-Forge's off-chain emissions. For this, we take an annualized average of the values from 2022 and 2023.

For the scenario document, we consider all the environments. However, once we have more specific information about the production environments, we will only take those into account for the final calculation.

	Carbon emissions annualized (kgCO_2e) *taking into account 2022 and 2023:*
SCOPE 1	87.2
SCOPE 3	1591.5

As of now, we don't have the specific carbon emissions data for **Scope 2**. However, based on other data provided by SG-Forge's cloud provider[35], we estimate that Scope 2 emissions are approximately **38% of the combined emissions from Scope 1 and Scope 3**. This estimation is in line with another study conducted by DELL[36], which also reported a similar percentage of 50% for Scope 2 emissions compared to the combined emissions of Scope 1 and Scope 3.

Concerning the **market-based** approach, it would account for approximately 4.5% of the previously calculated 38% for the **location-based** approach based on data provided by SG-Forge's cloud provider.

According to GHG protocol guidance, a **location-based** method reflects the average emissions intensity of grids or regions on which energy consumption occurs (using mostly grid-average emission factor data). For instance, the French energy mix is around an average of carbon intensity 85 gCO_2/kWh.

A **market-based** method reflects emissions from electricity that companies have purposefully chosen (or their lack of choice). It derives emission factors from contractual instruments, which include any type of contract between two parties for the sale and purchase of energy bundled with attributes about the energy generation, or for unbundled attribute claims. For instance, SG-Forge's cloud provider gets a specific renewable energy contract to supply data centers and uses the renewable energy mix instead of the regional energy mix, even if it is connected to the same energy grid.

Therefore, a company can claim that it uses electricity from a green energy source, such as solar or wind power. The CO_2 emissions associated with that consumption would a lot lower compared with a medium carbon intensive mix.

Even if it's clearly not recommended by GHG accounting experts, this still can be accounted for in the calculation of CO_2 emissions, allowing the company to reduce its total emissions. That is why we decided to present both methods/approaches in the following grid.

SCOPE 2 ESTIMATION

Carbon emissions SCOPE 2 ($kgCO_2e$) "**Location Based**"Estimation: 38% of the scope 1 + scope 3	637.89
Carbon emissions SCOPE 2 ($kgCO_2e$) "**Market Based**" Estimation: 4,5% of the 38% of the scope 1 + scope 3	28.71

SG-Forge's cloud provider adopts the market-based approach, which leads us to estimate Scope 2 emissions at **28.71** $kgCO_2e$**.**

Finally, we further categorize carbon emissions into different environments (namely production and other environments).

[35] Microsoft Environment Report 2022
[36] DELL Life Cycle Assessment of Dell R740 (June 2019) https://www.delltechnologies.com/asset/en-us/products/servers/technical-support/Full_LCA_Dell_R740.pdf

	SCOPE 1 ($kgCO_2e$)	SCOPE 2 ($kgCO_2e$)		SCOPE 3 ($kgCO_2e$)
		Location based	Market based	
BUILD / TEST / HOMOLOGATION ENVIRONMENT	36	240	11	597
PRODUCTION ENVIRONMENT	52	398	18	995
TOTAL ENVIRONMENTS	**87**	**638**	**29**	**1 591**

6.3. Node service provider

In the absence of data from the company to date, we make the following assumption:

	Value	Source reference
Number of hosted nodes	1	SG-Forge’s node provider
Node power (W)	62.44	Best guess CCRI
Average annualized consumption (kWh)	547.35	
Energy Grid Carbon Intensity (gCO_2e/kWh)	35	Low French Energetic Mix (Green energy)
Annual emissions ($kgCO_2$)	19.16	

Please note:

In this study, we are considering a low French "green" energy mix for the calculation of the nodes hosted by SG-Forge's provider, given their geolocation in Normandy and their operation by EDF.

This assumption is very conservative as the average consumption of a node on the provider’s infrastructure is likely to be a lot lower. Indeed, CCRI best guess node hardware is an average self-hosted computer while the provider’s infrastructure is composed of recycled servers with optimized services.

6.4. On chain – Ethereum

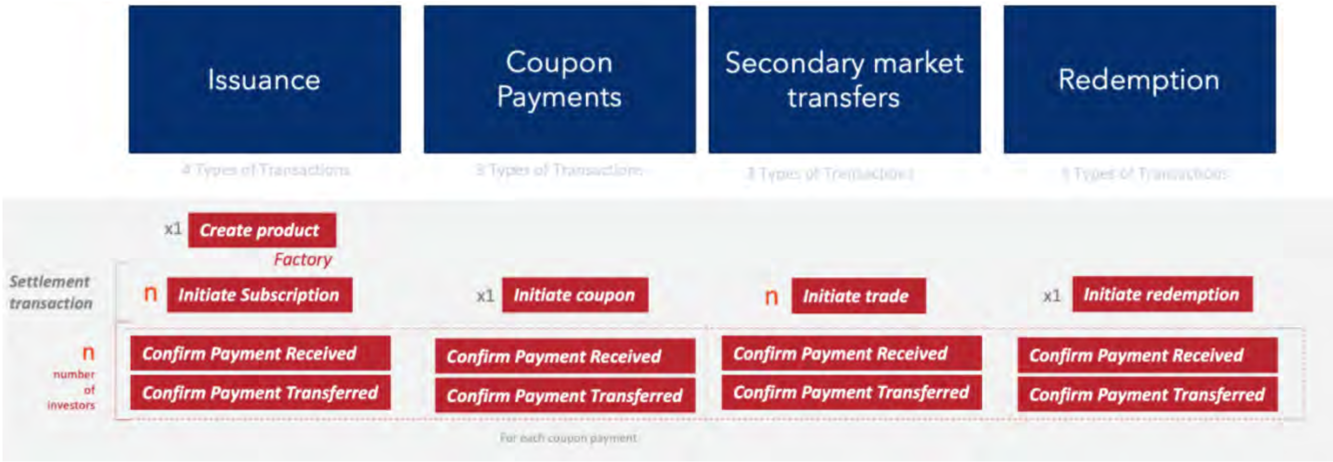
a. Mainnet

1) SG-Forge Tokenization process

As of today, the tokenization activity has been limited in terms of number issuances by financial institutions, corporates and supranationals.

Taking into account past emissions and corresponding gas usage from Etherscan, we implement the identified processes and extract the corresponding gas units for each step of the product lifecycle.

Figure 16 Tracking transactions in the smart contract [37]



Function	*Token factory*	*Create product + contract creation*	*Initiate subscription*	*Payment Received*	*Payment Transferred*	*Initiate coupon*	*Initiate trade*	*Initiate redemption (included burn)*
Average Gas per function Based on previous bonds issuances	**6,080,662**	**5,273,861**	**275,217**	**109,909**	**59,027**	**3,619,282**	**279,293**	**3,640,333**

Please note:

To extract the average of these gas units, we only refer to the first EIB digital bond issuance, as it is the only one which redeemed. This bond was issued before the transition of Ethereum Network to proof-of-stake and its carbon footprint on a proof-of-work blockchain was a lot higher. However, the change in the consensus protocol has no impact on the gas consumption and the use of this data to simulate further issuances.

2) Gas unit & nodes

It is important to note that gas-related data represents average values. They are **specific to a particular version of a smart contract.** The gas unit values assigned to each operation take into account the **historical issuances**.

These values provide a general indication of the amount of gas used in executing different identified transactions associated **with a specific smart contract.** However, it should be emphasized that gas consumption may vary depending on the specific conditions of each transaction.

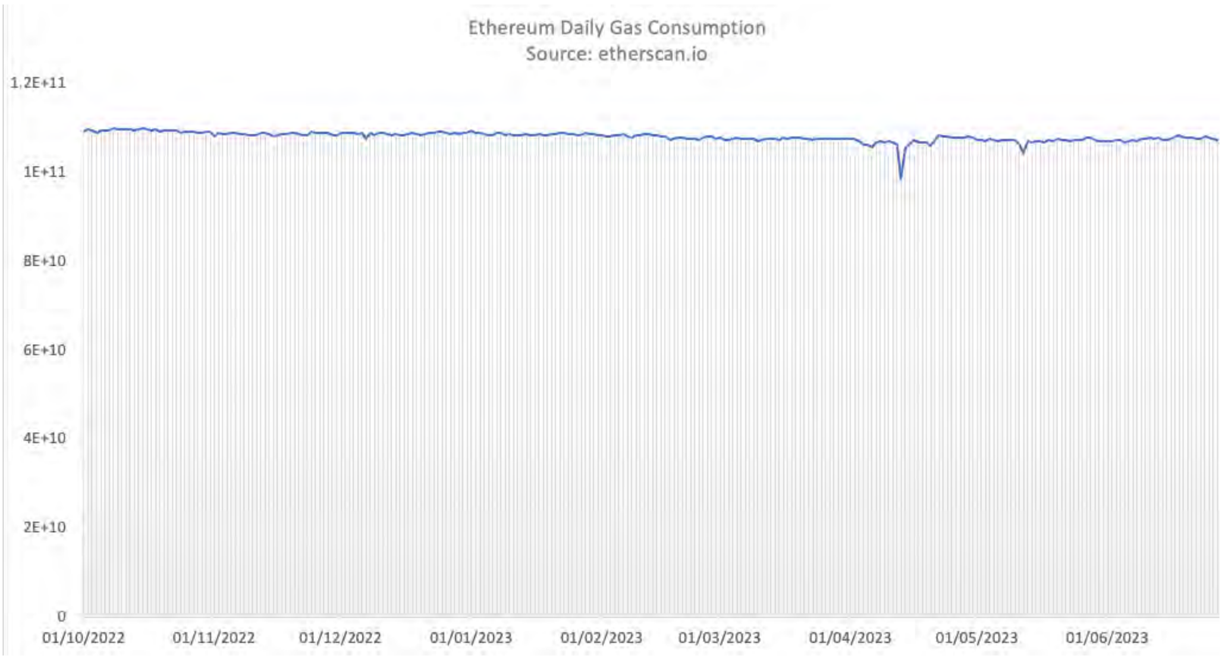
In considering the gas units for calculating energy consumption, we make the following assumption: on **an observation period**, the average daily **gas consumption and average daily number of nodes remain constant**. Indeed, linking the gas unit consumption to energy is done directly through the energy consumption of the nodes supporting the consumption of these gas units.

On an observation period of 9 months (post Ethereum merge), we observe a **very limited volatility of the daily gas consumption.** It's important to note that the huge change in the discovered number of

[37] SG-Forge Process document (annex 13.2)

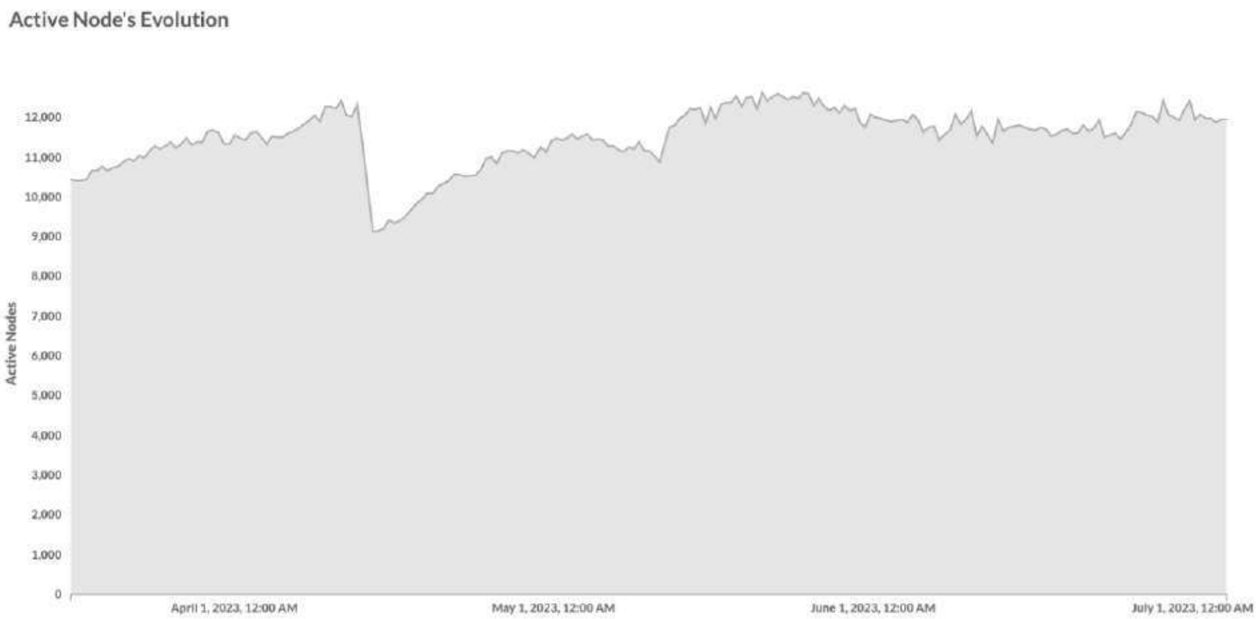
active beacon nodes[38] that we observe at the beginning of March is related to technical amelioration of the crawler program developed by MigaLabs.

Figure 17 Ethereum Daily Gas Consumption [39]



We assume that, apart from this software update, the number of **beacon nodes remains globally constant** over the same 9-month period, considering the observed limited volatility. We didn't display earlier node count because of the main update in MigaLabs node discovery software in March 2023.

Figure 18 Number of active beacon chain nodes [40]



[38] *Beacon nodes are computer nodes that are part of the Ethereum 2.0 network and interact with the beacon chain by participating in the Proof of Stake consensus mechanism, validating blocks, and facilitating the security and coordination of the network.* https://ethereum.org/en/roadmap/beacon-chain

[39] Source : Etherscan.io – http://www.etherscan.io/

[40] Source: MigaLabs – https://monitoreth.io/nodes

By **considering all nodes in the Ethereum blockchain**, a conservative and comprehensive approach is adopted, taking into account the ecosystem as a whole. This approach ensures a thorough evaluation of the carbon footprint by considering all energy resources used by the network, including all beacon nodes (also known as consensus clients and execution clients). We aim to minimize the risks of underestimating carbon emissions, particularly for nodes with higher energy consumption due to hardware, geographical location, or specific configurations. This approach aligns with both CCRI and Cambridge University methodologies.

However, discrepancies are observed regarding the number of nodes identified on the Ethereum blockchain. For example, as of May 17th, Etherscan identifies 10,977 nodes while **MigaLabs** identifies **12,323 nodes**. We have considered the count provided by the source that has identified the highest number of nodes and is recognized as the most sophisticated and up to date identification method[41]. By doing so, we adhere to a conservative methodology and we ensure that the evaluation considers the maximum potential environmental impact.

Identified gas unit per function:

Function	Average Gas per function *Based on first EIB digital bond issuance*
Token factory *	6,080,662
Create product + contract creation	5,273,861
Initiate subscription	275,217
Payment received	109,909
Payment transferred	59,027
Initiate coupon**	3,619,282
Initiate trade	279,293
Initiate redemption (included Burn) ***	3,640,333

Please note:

*We incorporate the "**token factory**" operation into our calculations as a one-time factor, as its evolution is solely dependent on code updates and not tied to new emissions.

The gas unit used for the **coupon payment part is provided for reference only. At this stage, we have no data on this operation, so we assume it to be **similar to the redemption part**, according to our discussion with SG-Forge. Gas unit for coupon payment may evolve based on future developments and initiatives of SG-Forge.

We also take into account the gas unit relative to the **burn** process even if it will not appear in future emissions (as it is integrated in the redemption part).

When updates or improvements are made to a contract, it is possible to optimize its operation to reduce gas consumption. Therefore, current data can differ significantly from future versions with optimized smart contracts.

It is therefore important to consider the relative and historical nature of gas consumption data. However, within the proposed scenario, we assume a very high level of gas consumption for the coupon payment component, similar to that of the initiation phase. Therefore, we adopt a very conservative position.

3) Network

- **Inclusion of the CCRI methodology for hardware assumptions**

CCRI & Cambridge university methodologies consider the range of energy consumption based on the specific hardware configurations employed for running a node.

[41] By both CCRI and Cambridge Center For Alternative Finance

	Upper bound		Medium		Lower bound	
Average power of a node (W)	150.00	Upper Bound of CCRI methodology	62.44	Best guess of CCRI methodology	20.00	Lower Bound of CCRI methodology
Internet node traffic annual consumption (GWh)	0.82	Electricity Intensity of Internet Data Transmission Untangling the Estimates[42]	0.82		0.82	

- **Inclusion of data traffic over the internet**

We consider the impact of data traffic over the Internet, which is not considered in several methodologies.

Estimates suggest that traffic (upload and download) can reach several GB per day and per node. However, it's important to note that this figure should be halved for the network as a whole, as the download from one node is part of the upload of other nodes. According to a study titled "Electricity Intensity of Internet Data Transmission: Untangling the Estimates"[43] the electricity required per GB has decreased from 0.06 kWh/GB in 2015 to approximately 0.00375 kWh/GB in 2023.

Regarding data traffic, even with high traffic per node (100 GB/day), we observe that the additional consumption remains low compared to the overall network consumption:
with an average traffic per node of 100 GB/day i.e. 3 TB/month and a total of 12 000 nodes, we arrive at an energy consumption of 0.82125 GWh/year using the formula: 0.00375 kWh/GB * 100 GB * 365 days * 12 000 nodes / 2. This estimate provides us with a more accurate picture of the energy footprint related to internet traffic of blockchain infrastructures.

Please note:

These figures are based on a small number of declarative estimates from some node managers. To date, there is no advanced study on the average traffic of a validator node depending on its configuration and connectivity that may differ depending on installed clients and setup.

4) Energy Mix

One of the variables that we include in our stress test scenario is the **energy mix**. This refers to the distribution of energy production among different energy sources in a country or region. Different energy sources are taken into account to determine the energy mix of a country or a region (coal, natural gas, oil, wind, solar, hydro, biomass, nuclear...) and we match this data with node location.

[42] *Joshua Aslan , Kieren Mayers , Jonathan G. Koomey, and Chris France – "Electricity Intensity of Internet Data Transmission Untangling the Estimates – Journal of Industrial Ecology"* (2017)
[43] Joshua Aslan, Kieren Mayers, Jonathan G. Koomey, and Chris France "*Electricity Intensity of Internet Data Transmission: Untangling the Estimates*" Journal of industrial technology (August 2018)

Figure 19 MigaLabs nodes repartition (as of 13/06/23) [44]

Country	Number of nodes	%
USA	4520	38.74%
Germany	1997	17.12%
Finland	551	4.72%
UK	520	4.46%
Singapore	409	3.51%
France	390	3.34%
Netherlands	379	3.25%
Canada	362	3.10%
Japan	286	2.45%
Australia	252	2.16%
South Korea	230	1.97%
Switzerland	210	1.80%
Ireland	166	1.42%
Russia	111	0.95%

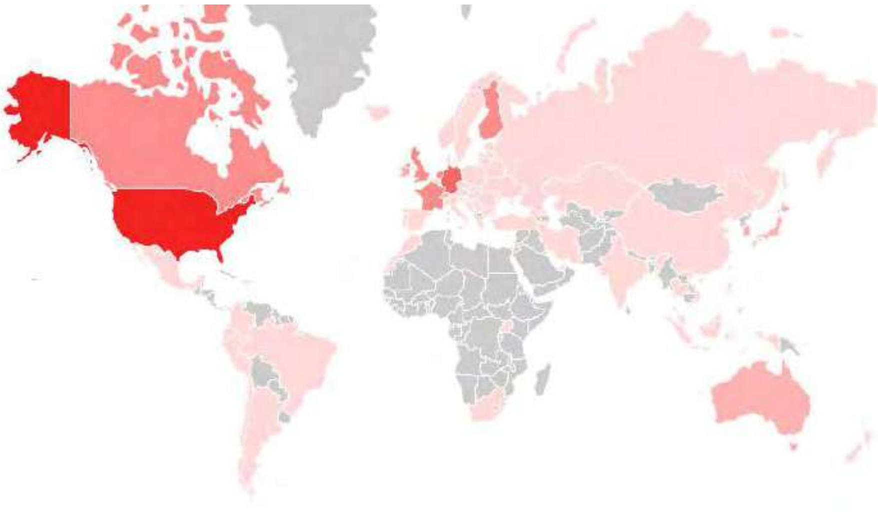
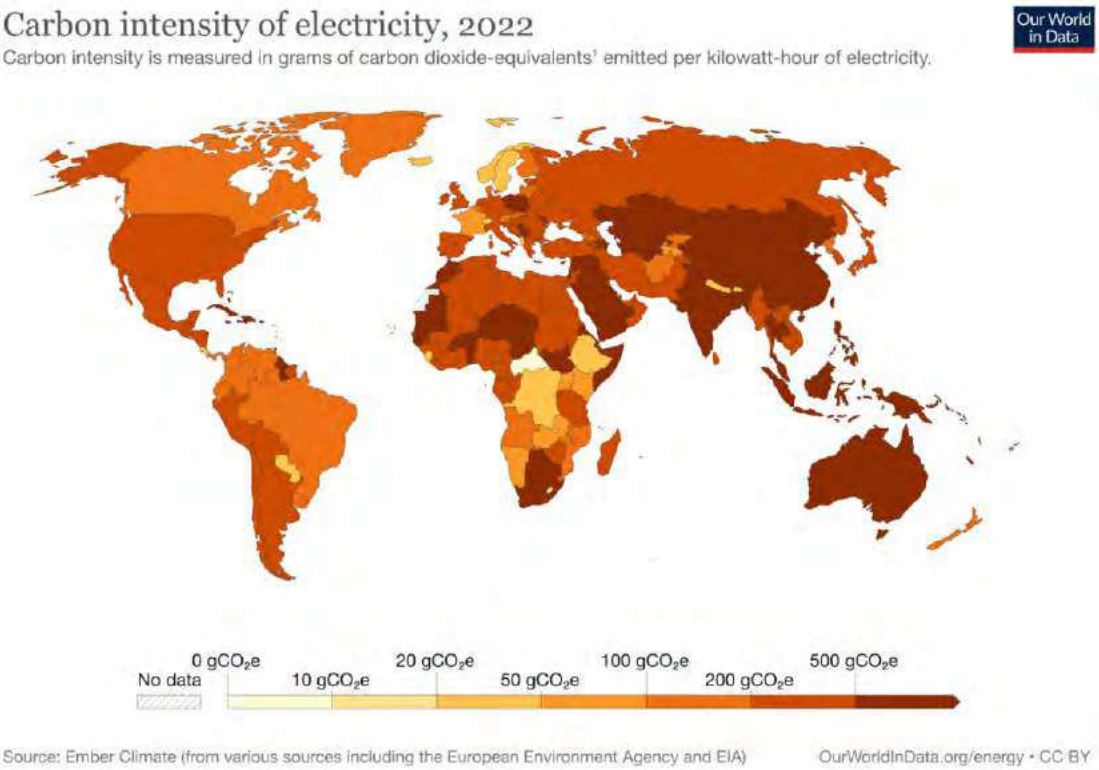


Figure 20 Carbon intensity from Our World in Data Website [45]



[44] MigaLabs: https://monitoreth.io/nodes
[45] Our world in data: https://ourworldindata.org/grapher/carbon-intensity-electricity

Figure 21 Energy mix evolution 2018-2022 for principal node locations[46]

Country	Carbon intensity of electricity (gCO_2/kWh) (*Ember Climate / OurWorldInData.org*)					Carbon intensity of electricity (gCO_2/kWh) 2021 OR 2022	Nodes % (MigaLabs)
	2018	2019	2020	2021	2022		
United States	412	393	369	379	367	367	38.74%
Germany	412	362	333	366	386	386	17.12%
Finland	200	180	142	146	132	132	4.72%
United Kingdom	283	266	246	268		268	4.46%
Singapore	492	491	490	489		489	3.51%
France	67	69	67	67	85	85	3.34%
Netherlands	497	455	395	389	361	361	3.25%
Canada	133	131	120	128		128	3.10%
Japan	508	492	494	479		479	2.45%
Australia	618	582	554	531		531	2.16%
South Korea	508	488	457	458		458	1.97%
Switzerland	59	57	58	47		47	1.80%
Ireland	379	335	312	364	342	342	1.42%
Russia	376	373	349	360		360	0.95%
World	459	448	437	441		441	11.01%

By considering the geographical distribution of Ethereum nodes and factoring in the energy mix of countries, specifically focusing on the top 14 countries with the largest node count and using a global energy mix for the remaining countries, we obtain an energy mix value of **352 gCO_2e/kWh**.

Please note that this value, selected for the "lower bound" scenario, slightly exceeds the estimate of **335 gCO_2e/kWh** used by the CCRI for the energy mix (334.42 gCO2/kWh rounded up at 335)[47].

Therefore, even if we were to consider scenario where the energy mix becomes even more carbon intensive, with a greater share of high-carbon-intensity energy sources, the variation in terms of carbon emissions would likely be minimal (Lower bound scenario: 352 gCO_2/kWh ; medium scenario : 441 gCO_2/kWh ; Upper bound scenario 500 gCO_2/kWh). Indeed, since the energy mix is already unfavorable in our base methodology, moving to a more carbon intensive mix would only marginally increase emissions.

For this reason, although the energy mix is an important variable in our stress test scenario, we do not expect variations in this variable to lead to significant short-term changes in our results.

Furthermore**, a global trend towards improving the energy mix of countries** is emerging year by year due to decarbonization policies and engagement to reach GHG neutrality by 2050 according to the Paris Agreement. Indeed, as countries recognize the importance of combating climate change and reducing carbon emissions, many governments are committed to diversifying their energy mix by incorporating a larger share of renewable energy. Thus, the situation is gradually improving thanks to a global

[46] Our world in data: https://ourworldindata.org/grapher/carbon-intensity-electricity using www.ember-climate.org data (methodology: https://ember-climate.org/app/uploads/2022/07/Ember-Electricity-Data-Methodology.pdf)

[47] CCRI uses emission factors from the Environmental Protection Agency for U.S. states, from the Environmental Energy Agency for European countries and from Climate Transparency for all other G20 countries. For the remaining countries, they calculate emission factors based on the electricity generation per source provided by the IEA. Also, they used the node locations at the time of the merge.

commitment to cleaner energy, and it seems that in the future the energy mix used for the methodology will improve and be less carbon intensive.

b. Testnet

In the context of calculating carbon emissions, it is crucial to take the test environment into account as a contributing factor. The inclusion of the test environment in the assessment is strongly recommended to ensure a comprehensive calculation of carbon emissions.

Due to the unavailability of gas unit information on Etherscan for the testnet over the course of a year, we are compelled to assume that the value of a gas unit correlates with the corresponding energy consumption on the mainnet.

Moreover, considering the limited information available about the operations made by SG-Forge on the testnet (currently having the "token Factory" available today on the testnet), we formulate the following hypothesis: the energy consumption on the testnet is assumed to be comparable to that of the mainnet, and we further presume that the gas units used for the identified operations are identical on the testnet as those used on the mainnet.

To calculate carbon emissions of the testnet, we used the parameters provided in the table on the right (our best guess) and computed based on the average gas units extracted from the EIB bond smart contract.

	Parameter	Value used	Source used
Blockchain	**Average consumption of a node (W)**	62.44	Best Guest CCRI
Blockchain	**Number of Ethereum nodes**	12 000	MigaLabs / Cambridge University / CCRI
Blockchain	**Usage energy consumption (GWh)**	6.57	Calculated *(using "number of nodes" and "average consumption of a node values")*
Blockchain	**Usage Carbon Footprint (tCO2e)**	2312.00	Calculated *(using "usage energy consumption" and "energy mix node location weighted values")*
Blockchain	**Annualized gas consumption**	3.79451E+13	Etherscan
Blockchain	**Energy per gas unit (Wh)**	1.73E-04	Calculated *(using "usage energy consumption" and "annualized consumption values")*
Blockchain	**Carbon Footprint per gas unit (gCO2e)**	6.09E-05	Calculated *(using "usage carbon footprint" and "annualized gas consumption")*
Node Data Traffic	**Internet Data energy consumption (kWh/GB)**	0.00375	Electricity Intensity of Internet Data Transmission Untangling the Estimates
Node Data Traffic	**Daily node traffic (GB)**	100	High average selected
Node Data Traffic	**Internet node traffic annual consumption (GWh)**	0.82125	Calculated *(using "number of nodes", internet data energy consumption" and Daily node traffic")*
Energy Mix	**Energy Mix Node location weighted (gCO2e/kWh)**	352	Calculated *(Total gas usage calculated by considering the top 14 countries with the most nodes and incorporating their respective energy mixes, while using the global energy mix for the remaining nodes)* For comparison purposes : CCRI use 335 gCO2e/kWh

Operation		Gas	Energy (Wh)
Issuance	Create product	5 273 861	913
Issuance	Initiate subscription	275 217	48
Issuance	Payment Received	109 909	19
Issuance	Payment Transferred	59 027	10
Coupon payment	Initiate coupon	3 619 282	626
Coupon payment	Payment Received	109 909	19
Coupon payment	Payment Transferred	59 027	10
Secondary market transactions	Initiate trade	279 293	48
Secondary market transactions	Payment Received	109 909	19
Secondary market transactions	Payment Transferred	59 027	10
Redemption	Initiate redemption (included burn)	3 640 333	630
Redemption	Payment Received	109 909	19
Redemption	Payment Transferred	59 027	10
	Total	**13 763 730**	**2382**

Operation	Gas	Energy (Wh)
Token Factory	**6 080 662**	**1 053**

We assume that each operation is tested at least twice before a new issuance.

	Total TOKENIZATION PROCESS ON THE TESTNET	Total TOKEN FACTORY (TESTNET)
Gas	13,763,730	6,080,662
Energy (kWh)	2.38	1.05
Carbon emission (kgCO2e)	0.84	0.37
X2 TESTS PER OPERATION	**1.68**	**0.74**

	For two tests per operation
Energy (kWh)	**6.87**
Carbon emission ($kgCO_2e$) *(Using as energy mix: 352)*	**2.42**

7. Scenario and Results

7.1. Considered assumptions in the 4 scenarios

Tokenized financial products are assumed to be **plain vanilla bonds** and **structured products.** The market for these products is nascent, hence we propose various scenarios in terms of issuances depending on adoption of the technology by issuers and investors of these financial products.

These products are mostly **bought to be held to maturity with only a few trades on the secondary market**. Structured products are usually tailormade for a single investor while bonds are subscribed by several investors. If coupons are paid, they are usually delivered annually.

Structured products usually have maturities between 1 to 5 years, while plain vanilla bonds have maturities between 2 to 10 years.

These are **non-listed OTC (over the counter) products**. Hence the securities to be traded in a distributed ledger technology (DLT) multilateral trading facility (MTF) of the **EU Pilot Regime**[48], which started in March 2023**, are not included.**

	Parameter	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Token emission and life	Nb Issuances	1	10	30	100
	Nb Investors	10	3	3	3
	Nb Trades	20	10	10	10
	Coupons frequency per year	2	1	1	1
	Product maturity in year	5	5	5	5

For each scenario we use an upper bound, medium value and lower bound based on energy consumption of a node and energy mix.

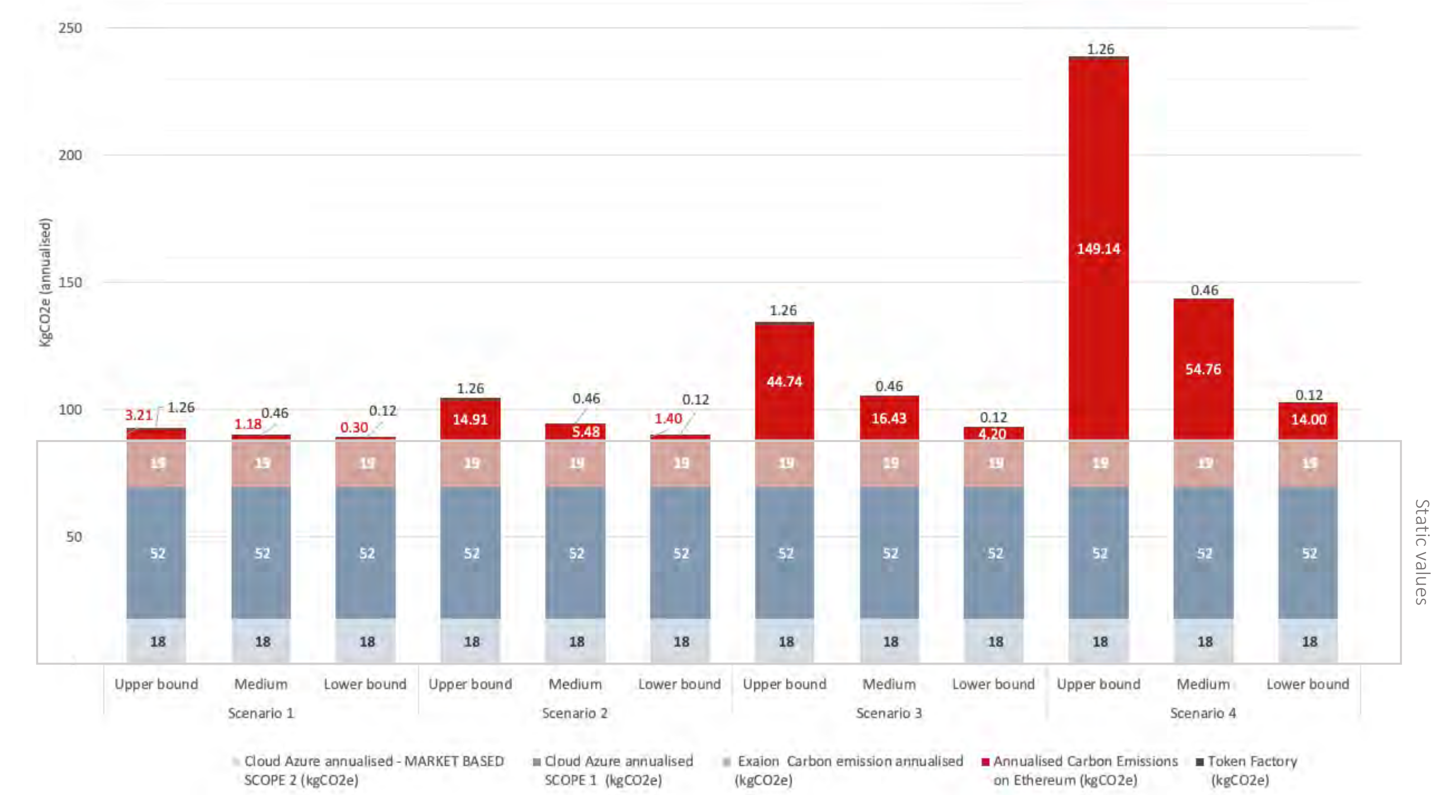
	Upper bound		Medium		Lower bound	
Average power of a node (W)	150.00	Upper Bound of CCRI methodology	62.44	Best guess of CCRI methodology	20.00	Lower Bound of CCRI methodology
Energy Mix Node location weighted (gCO_2e/kWh)	500	boosted world mix	441	World mix	352	Energy mix based on node location
Number of nodes*	12,000	MigaLabs	12,000		12,000	
Internet node traffic annual consumption (GWh)	0.82	Electricity Intensity of Internet Data Transmission Untangling the Estimates	0.82		0.82	

48 https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32022R0858&qid=1693819423640

7.2. Results

Figure 22 Annualized carbon emissions of the tokenization process by scenario

		On-Chain					Off-chain			
		SG-Forge Tokenisation process on Ethereum				Carbon emissions of nodes managed by Exaion	Microsoft Azure carbon emissions Scope 1 & 2(for production environments only)			
		Energy (kWh)	Total Carbon emission (kgCO2e) per emission	Annualised Carbon Emissions on Ethereum (kgCO2e)	Token Factory (kgCO2e)	Exaion Carbon emission annualised (kgCO2e)	Cloud Azure annualised SCOPE 1 (kgCO2e)	Cloud Azure annualised LOCATION BASED SCOPE 2 (kgCO2e)	Cloud Azure annualised MARKET BASED SCOPE 2 (kgCO2e)	Total (kgCO2e)
Scenario 1	Upper bound	32	16.03	3.2	1.26	19	52	398	18	**93**
	Medium	13.35	5.89	1.2	0.46	19	52	398	18	**90**
	Lower bound	4.27	1.50	0.3	0.12	19	52	398	18	**89**
Scenario 2	Upper bound	149.14	74.57	14.9	1.26	19	52	398	18	**105**
	Medium	62.08	27.38	5.5	0.46	19	52	398	18	**95**
	Lower bound	19.89	7.00	1.4	0.12	19	52	398	18	**90**
Scenario 3	Upper bound	447.43	223.72	44.7	1.26	19	52	398	18	**135**
	Medium	186.25	82.14	16.4	0.46	19	52	398	18	**105**
	Lower bound	59.66	21.00	4.2	0.12	19	52	398	18	**93**
Scenario 4	Upper bound	1 491.43	745.72	149.1	1.26	19	52	398	18	**239**
	Medium	620.83	273.79	54.8	0.46	19	52	398	18	**144**
	Lower bound	198.86	70.00	14.0	0.12	19	52	398	18	**103**



Please note:

- Although we consider the **Factory** operation as a one-time factor in our calculations (indicated by it being grayed out in the table), we still include it in the graph for each scenario to provide a clear perspective on its relative value compared to other factors.
- Since the calculations are also based on gas units, the values fluctuate depending on the chosen energy mix and the energy consumption per node (decided for the upper,medium and lower bound).

- For the off-chain calculation of carbon emission, we only consider **production environments**.
- Values identified in blue and pink (cloud provider & node service provider) are **static values based on global energy consumption of the considered environments and** are not dependant on tokenization activity. Values per issuance should decrease proportionally with the actual number of issuances.
- For **Microsoft Azure Scope 2**, we adopt the market-based method as our reference, (as it is the Microsoft Azure approach). The value for location-based method would be much higher at 637.89 $kgCO_2e$ for, representing nearly the entire value identified of the global carbon footprint of a 5 year maturity token from SG-Forge.
- Due to our already high and **conservative energy mix selected**, there is limited fluctuation in

7.3. Node count evolution

As we observe between September 2022 and March 2023, evolution of the node discovery programs caused a doubling of the number of nodes. Indeed, accurate observation of the number of nodes on a peer-to-peer infrastructure remains a complex operation and there will always be nodes that refuse unauthorized connections and that aren't discovered.

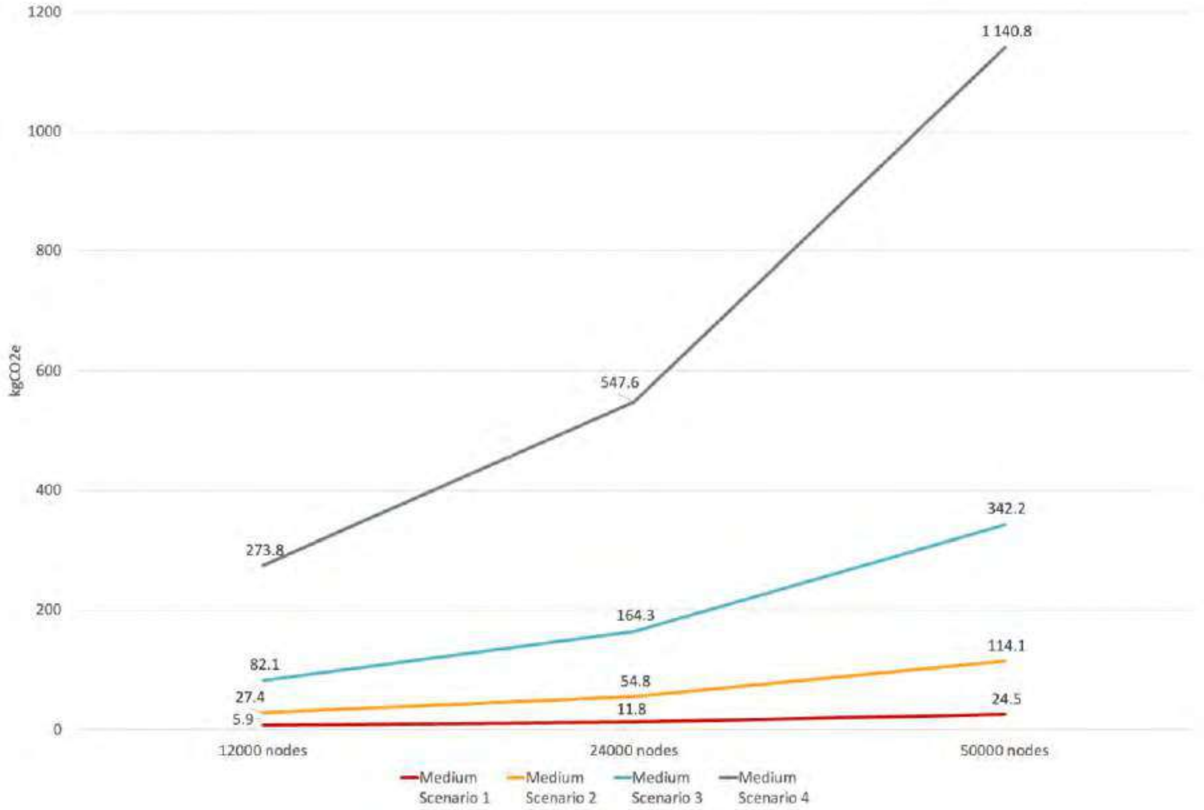
However, with its latest improvement, MigaLabs observes remarkable similarities between its nodes' client identification and another methodology used in BlockPrint tool created by Sigma Prime, developer of Lighthouse consensus client. These similarities allow MigaLabs to have a high confidence in the reliability of its results.

As for the possible evolution of the actual number of nodes due to new incentives for node owners, we currently lack studies providing insights on the main reasons to build and run a node. The financial incentive related to staking could be proposed. However, we observe that, of 275 000 Ethereum accounts with at least 32 ETH, enough able to run a validator and stake their Ethers, only 6 000[49] nodes have open channels for the validating and staking process. This leaves a path for new nodes creation, even if staking is mainly managed for Ether owners by exchanges such as Kraken, Coinbase and Binance and liquidity pools such as Lido.

For this reason, we propose to incorporate variations of node count within all 4 scenarios.

[49] https://monitoreth.io/validators

Figure 23 Tokenization carbon footprint evolution with node count



	Scenario 1			Scenario 2			Scenario 3			Scenario 4		
	Upper bound	Medium	Lower bound	Upper bound	Medium	Lower bound	Upper bound	Medium	Lower bound	Upper bound	Medium	Lower bound
12000 nodes	16.03	5.89	1.50	74.57	27.38	7.00	223.72	82.14	21.00	745.72	273.79	70.00
24000 nodes	32.06	11.77	3.01	149.14	54.76	14.00	447.43	164.27	42.00	1 491.43	547.58	140.01
50000 nodes	66.79	24.52	6.27	310.72	114.08	29.17	932.15	342.23	87.50	3 107.15	1 140.78	291.68

7.4. Comparisons and insights

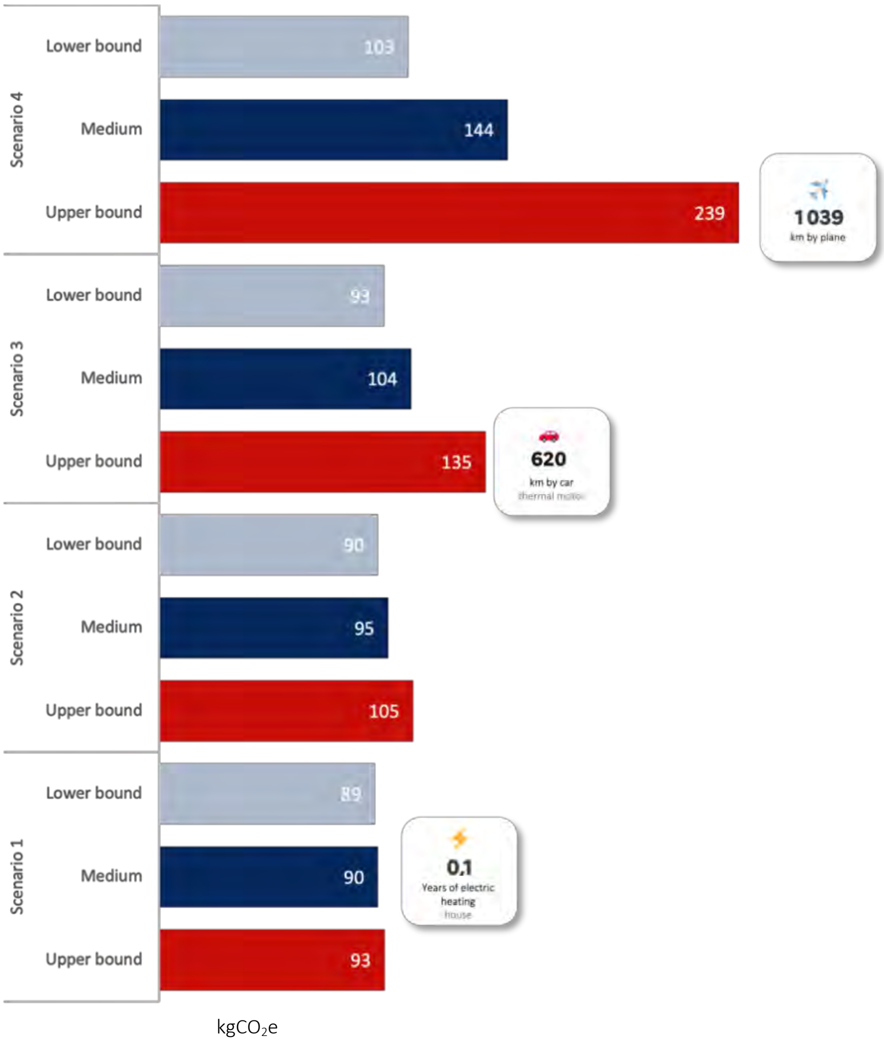
Figure 24 Annualized carbon emissions of the tokenization process with comparison of usual carbon emissions[50]

Parameter	Scenario 4
Number of issuances	100
Number of investors per issuance	3
Number of secondary market trades per issuance	10
Coupons frequency per year	1
Product maturity in year	5

Parameter	Scenario 3
Number of issuances	30
Number of investors per issuance	3
Number of secondary market trades per issuance	10
Coupons frequency per year	1
Product maturity in year	5

Parameter	Scenario 2
Number of issuances	10
Number of investors per issuance	3
Number of secondary market trades per issuance	10
Coupons frequency per year	1
Product maturity in year	5

Parameter	Scenario 1
Number of issuances	1
Number of investors per issuance	10
Number of secondary market trades per issuance	20
Coupons frequency per year	2
Product maturity in year	5



These scenarios and associated results show that, on a limited number of tokenizations, the main part of the energy consumption is located in SG-Forge dedicated infrastructure, mainly cloud services and node services.

Only in scenarios where the number of tokenizations gets significantly higher and with "upper bound" average node power can we get a situation where the Ethereum on-chain processes consumes more than the static and dedicated environment. Moreover, this is done with the hypothesis that these dedicated cloud services can manage the greater volume of transactions with the same energy consumption.

[50] The comparisons are made using the values provided by https://impactco2.fr supported by the Ecological Transition Accelerator, the internal incubator of ADEME (French Environment and Energy Management Agency).

Nevertheless, in the context of an annualized medium scenario, the on-chain emissions on Ethereum range from 1.2 kgCO_2e to 161.4 kgCO_2e for the most extreme scenario, which is equivalent to driving 6 km by car (or 19 hours of video streaming) in the former case and driving 742 km by car in the most extreme case. [51]

On a highly mutualized and shared platform like a blockchain network, with little or no idle period, there is no surprise that the energy consumption per operation will be lower than the one on a dedicated and private infrastructure where idle periods represent majority.

However, we still have in mind the huge energy consumption of the Bitcoin and other Proof-of-Work blockchains. Fortunately, this is not true anymore with the Proof-of-Stake and the results presented here are a good proof of it.

This shows the important efficiency of the Ethereum blockchain for the support of financial products, especially for simple products as bonds and loans where the code to manage the products and the data to describe them remains simple and light.

However, it must be recognized that, for the time being, it is not possible to rely solely on a blockchain infrastructure for the tokenization of a financial product. Core elements of the registrar and the settlement agents must remain on private and secured infrastructure, at least for regulatory purposes.

More generally, the possibility to monitor and simulate the carbon footprint of a financial product management information system allows us to identify the areas where optimization is possible:

- in the code of a dedicated function,
- in the stored data format and size,
- in the choice of a cloud provider or the set-up of its services,
- in the location of the dedicated infrastructure (given that we shouldn't rely on the market-based approach for GHG accounting),
- etc.

[51] The comparisons are made using the values provided by https://impactco2.fr supported by the Ecological Transition Accelerator, the internal incubator of ADEME (French Environment and Energy Management Agency).

8. Next issuance – Our best guess

This section describes how to assess the carbon footprint of a future bond's issuance.

8.1. Input data

a. Ethereum mainnet

	Parameter	Value used	Source used
Blockchain	**Average consumption of a node (W)**	62.44	Best guess CCRI
Blockchain	**Number of Ethereum nodes**	12,000	MigaLabs / Cambridge University / CCRI
Blockchain	**Usage energy consumption (GWh)**	6.57	Calculated *(using "number of nodes" and "average consumption of a node values")*
Blockchain	**Usage carbon footprint (tCO_2e)**	2312	Calculated *(using "usage energy consumption" and "energy mix node location weighted values")*
Blockchain	**Annualized gas consumption**	3.79451E+13	Etherscan
Blockchain	**Energy per gas unit (Wh)**	1.73E-04	Calculated *(using "usage energy consumption" and "annualized consumption values")*
Blockchain	**Carbon footprint per gas unit (gCO_2e)**	6.09E-05	Calculated *(using "usage carbon footprint" and "annualized gas consumption")*
Node data traffic	**Internet data energy consumption (kWh/GB)**	0.00375	Electricity Intensity of Internet Data Transmission Untangling the Estimates
Node data traffic	**Daily node traffic (GB)**	100	High average selected
Node data traffic	**Internet node traffic annual consumption (GWh)**	0.82125	Calculated *(using "number of nodes", "internet data energy consumption" and "Daily node traffic")*
Energy mix	**Energy Mix Node location weighted (gCO_2e/kWh)**	352	Calculated *(Total gas usage calculated by considering the top 14 countries with the most nodes and incorporating their respective energy mixes, while using the global energy mix for the remaining nodes)* For comparison purposes: CCRI use 335 gCO_2e/kWh

	Hypotheses	
Token issuance and life	Number of **issuances**	1
Token issuance and life	Number of **investors** per issuance	5
Token issuance and life	Number of secondary market **trades** per issuance	5
Token issuance and life	**Coupon** frequency per year	1
Token issuance and life	Product **maturity** (in year)	5

Annualized value for the tokenization process on Ethereum	Energy (kWh)	1.27
	Carbon emission (kgCO_2e)	0.45

b. Ethereum testnet [52]

	For two tests per operation
Energy (kWh)	6.87
Carbon emission (kgCO_2e) *(Using as energy mix: 352)*	2.42

c. Dedicated nodes hosted by node provider

In the absence of data from the company to date, we make the following assumption:

	Parameter	Value	Source reference
Node provider Hypotheses	**Number of hosted beacon chain nodes**	1	SG-Forge's node provider information
	Node power (W)	62.44	Best guess CCRI
	Average annualized consumption (kWh)	**547.35**	**Calculated** (using *"Node power")*
	Energy mix (gCO_2e/kWh)	35.00	Conservative value of French green energy mix
	Annual emissions (kgCO_2/kWh)	**19.16**	**Calculated** (using number of hosted nodes*"; "average annualized consumption" and "energy mix")*

d. Cloud provider

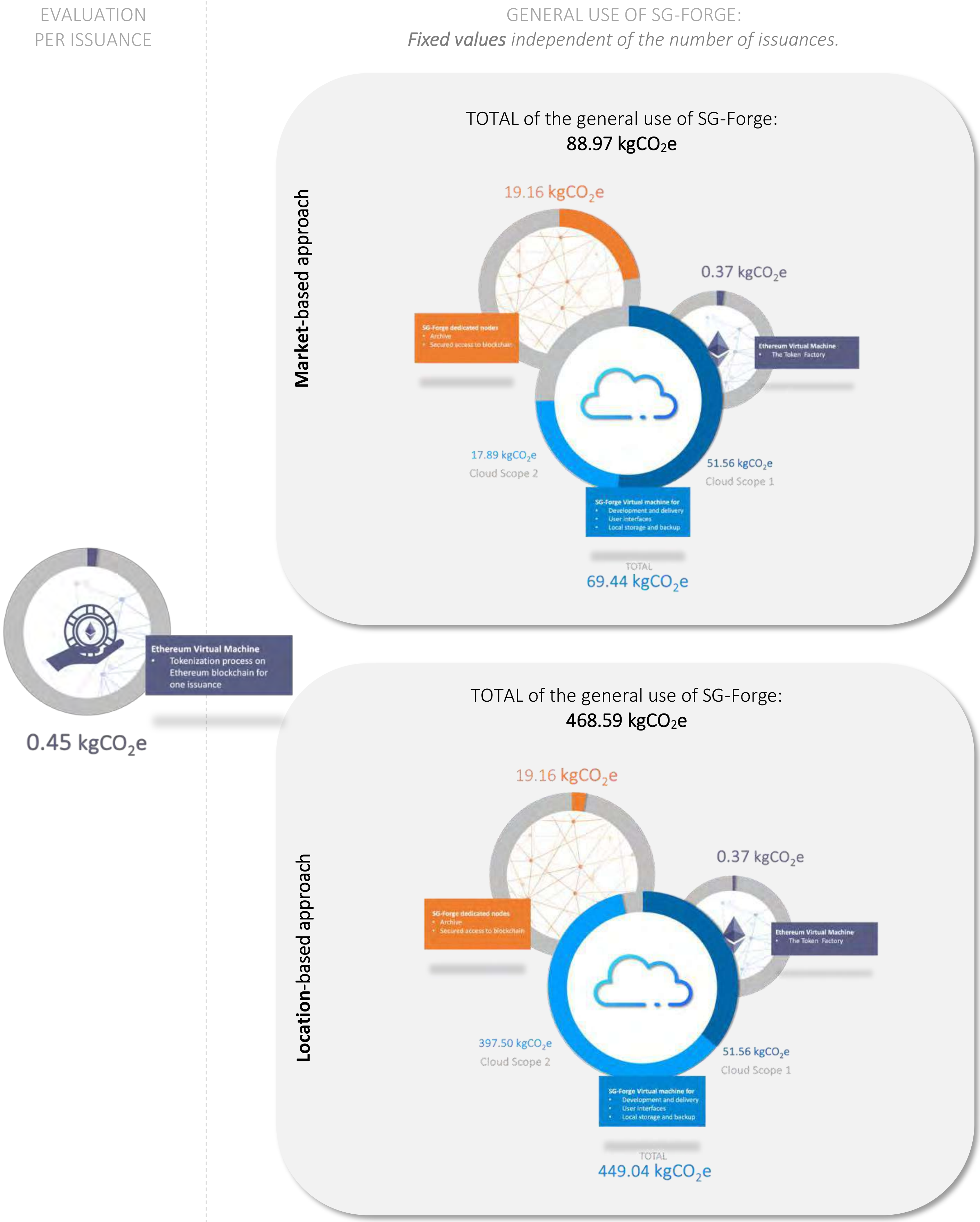
Figure 25 SG-Forge's cloud provider carbon emissions data

Annualized value	SCOPE 1 (kgCO_2e)	SCOPE 2 (kgCO_2e)		SCOPE 3 (kgCO_2e)
		Location-based	Market-based	
BUILD / TEST / HOMOLOGATION ENVIRONMENT	35.64	240.39	10.82	596.96
PRODUCTION ENVIRONMENT	**51.56**	397.50	**17.89**	994.51
TOTAL ENVIRONMENTS	87.20	637.89	28.71	1,591.46

[52] using the following hypothesis: following hypothesis: the energy consumption on the testnet is assumed to be comparable to that of the mainnet, and we further presume that the gas units used for the identified operations are identical on the testnet as those used on the mainnet.)

8.2. results

Figure 26 Assessing the Annualized Carbon Footprint of Token Issuance and Lifecycle

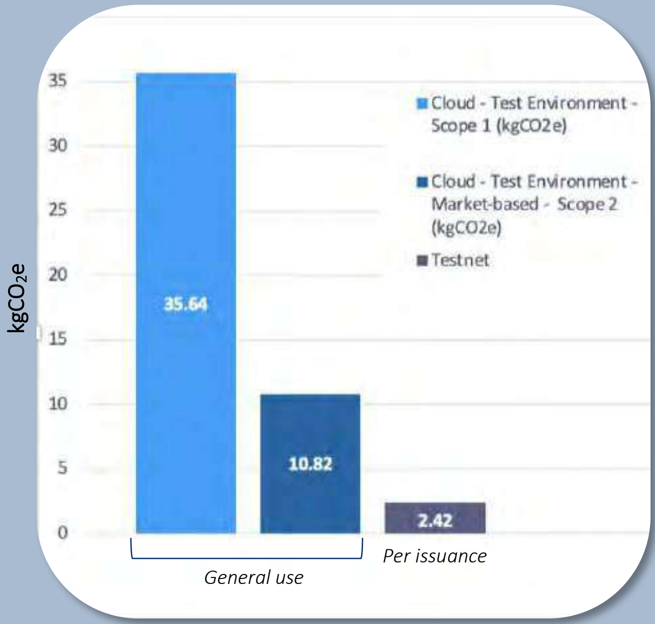


We present two graphical representations of the projected carbon emissions for a future bond issuance to account for both the market-based method and the location-based method. This approach allows us to provide a comprehensive and informative view of different perspectives related to greenhouse gas emissions.

The first graphical representation uses the market-based method, following the communication of SG-Forge's cloud provider. It shows the estimated emissions based on the energy source listed in the contracts with the cloud provider's energy suppliers (mainly renewable energy sources). This perspective helps understand the environmental impact as it is commonly reported by cloud providers.

The second graphical representation is based on the location-based method, considering the actual geographical location of energy consumption. This approach takes into account regional-specific energy mixes and provides a more accurate view of the real emissions associated with energy usage.

By creating these two graphical representations, we recognize the increasing importance of the location-based method, in line with the recommendations of the ISSB[53] and evolving standards in emission reporting. This enables us to present a comprehensive and balanced analysis, reflecting our commitment to adopting the best sustainability practices and providing transparent information about our future carbon footprint.



For informational purpose:

Assessing the **Annualized** Carbon Footprint of Token implementation **prior to launch**

[53]IFRS - ISSB announces guidance and reliefs to support Scope 3 GHG emission disclosures https://www.ifrs.org/news-and-events/news/2022/12/issb-announces-guidance-and-reliefs-to-support-scope-3-ghg-emiss/

9. Limitations and challenges

9.1. Lack of accurate and reliable data

a. Blockchain

Based on the selected methodology, we understand that blockchain energy consumption depends on two specific data:

- the number of nodes
- the average power of a node

While there has been major improvement in the data collection for the number of active nodes, we still use a theoretical proxy hardware as our best guess for node power and energy consumption.

b. Cloud

In relation to the cloud services carbon footprint, our study shows how difficult it is to obtain accurate and complete data about energy consumption. Cloud providers do not directly provide this kind of data and prefer to disclose carbon emission using a market-based approach. This can lead these companies to purely nullify Scope 2 carbon footprint related to hardware usage. We also remark that cloud providers use misleading terms such as carbon neutrality at the company level and zero carbon electricity. These misconceptions threaten the necessary reporting of energy consumption and related energy reduction efforts.

If we were to expand our study to all three scopes, it would be even more difficult to estimate the carbon footprint on theoretical hardware required for nodes. Indeed, a product lifecycle assessment is already a complex thing on a precise and well-known piece of hardware. On a custom and unknown machine, it becomes hardly possible while many nodes may be run on recycled equipment on which scope 3 have already been attributed for a previous use or customer.

9.2. Energy mix

a. Discrepancies in emissions factors

As we analyze different sources of emissions data (International Energy Agency, US Environmental Protection Agency and other data sources), we observe variations in the reported carbon intensities of electricity. These variations can be attributed to a range of factors, including differences in methodologies, data collection practices, and calculation approaches employed by each organization.

In our study, we decided to rely on data from "Our World in Data," which uses information provided by Ember-climate[54] that combine:

- EIA: U.S Energy Information Administration
- ENTSO-E: European Network of Transmission Systems Operators for Electricity
- GEM: Global Energy Monitor
- IEA: International Energy Agency
- IRENA: International Renewable Energy Agency
- WRI: World Resources Institute

We have considered these sources as the most reliable for our study.

[54] www.ember-climate.org - You can find more about Ember's methodology in this document: https://ember-climate.org/app/uploads/2022/07/Ember-Electricity-Data-Methodology.pdf

b. Evolution and variation of the energy mix

A global trend towards decarbonizing the energy mix of countries is emerging year by year due to climate policy and technological innovation. Indeed, as countries recognize the importance of combating climate change and reducing carbon emissions, many governments become increasingly committed to reducing their energy mix carbon intensity by incorporating a larger share of renewable or low carbon electricity generation resources. Thus, the situation is gradually improving thanks to a global commitment to cleaner energy, and it seems that in the future the energy mix used for the methodology will be better and less carbon intensive.

However, there are certain situations where this will not be true. The war in Ukraine has shown that countries are sometimes forced to rely on more carbon intensive production units, like coal power factories in Germany to replace gas power factories.

c. Production mix vs. consumption mix

In our study, we use the production-based energy mix of countries due to data availability. However, it is important to acknowledge that this approach has certain limitations. It does not account for energy exchanges between countries or losses that occur during transmission and distribution. Despite these limitations, the production-based energy mix remains a commonly used measure to assess the composition of energy sources used in electricity generation.

It would be opportune to include the consumed-based energy mix in our future calculations, rather than solely relying on the production-based energy mix. Obtaining consolidated data on the consumed-based energy mix would provide a better understanding of how countries actually use energy across all aspects of their economy. This would give us a more accurate picture of the global environmental impact, taking into account a country's utilization of energy sources beyond what it produced locally. For instance, during peak cold periods, a country may need to rely on a neighboring country for additional energy. By including the consumed-based energy mix, we would be able to consider such interactions between countries and more precisely evaluate overall sustainability and energy efficiency.

9.3. Hardware evolution

We have seen in the various methodologies we studied, the specific nature of the **required hardware** largely depends on the **individual requirements of consensus & execution clients**[55], which makes general forecasting difficult.

Furthermore, we are aware that the computing power required by the machines is likely to increase, particularly due to the **expansion of the Ethereum blockchain** and the range of its applications. However, this does not necessarily suggest a proportional increase in energy consumption. Indeed, **technological evolution in the field of computer hardware** generally tends to improve energy efficiency. Consequently, an increase in computing power does not necessarily lead to a corresponding increase in carbon emissions related to energy consumption.

As for all three scopes, we remark that some manufacturers are improving the carbon footprint of their product generation by generation with better processes, better use of recycled materials and better energy mix for manufacture.

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[55] *When Ethereum was using proof-of-work, an execution client was enough to run a full Ethereum node. However, since implementing proof-of-stake, the execution client needs to be used alongside another piece of software called a "consensus client". The* ***execution client*** *listens to new transactions broadcasted on the network, executes them in the EVM, and maintains the latest database and state of all current Ethereum data. The* ***consensus client*** *implements the proof-of-stake consensus algorithm, which enables the network to reach agreement based on validated data from the execution client.* Source : Ethereum.org https://ethereum.org/en/developers/docs/nodes-and-clients

Finally, it should be noted that the progress of computer hardware is extremely rapid and going in different ways (raise in the number of transistors vs. energy consumption optimization for instance). Making predictions based on the current state of technology could lead us to make inaccurate projections. For this reason, we have chosen to focus our attention on variables whose evolution is more predictable and more directly related to our operations.

Moreover, **SG-Forge use of its infrastructure is not currently optimized**, mainly because the security tokens issuance is still in an early stage. As the number of issuances increases, it will proportionally reduce the fixed emission attributed to the off-chain part (SG-Forge's cloud services) and the on-chain portion relative to SG-Forge dedicated nodes.

9.4. Cloud infrastructure

In the various proposed scenarios, we assume no evolution of the Azure cloud infrastructure despite a growing number of issuances. As we do not have specific information about the current capacity of the cloud infrastructure, it is possible that an increase in carbon emissions could occur if the cloud infrastructure were to undergo significant expansion after reaching a certain threshold of issuances.
Being able to monitor cloud services load during tokenization processes would be necessary to accurately assess the required amount of energy.

9.5. Blockchain network improvements

In regard to the blockchain part itself, there has been significant progress in the last few months at both the methodology and data collection level, mainly in the node discovery process performed by MigaLabs.

The overall annualized consumption of a proof of stake blockchain network compared to proof of work blockchain and even to cloud computing usage is now very limited but the study shows that there is still some space for critical improvement.

Indeed, the gas consumption of functions is directly related to the energy consumption (assuming a stable gas usage) and the code optimization is necessary to reduce gas usage and related fees, which is a big driver of energy efficiency in the process.

Moreover, the optimization of nodes location to places with lower carbon intensity energy sources could lead to a factor 10 reduction of blockchain carbon footprint (mean carbon intensity is 335gCO_2e/kWh while countries like Island and Sweden have an energy mix around 30gCO_2kWh). This optimization should still take into consideration the required decentralization of the network. Still, this decentralization is already an issue due to the usage of cloud hosted nodes (62% of the total according to some sources).

Finally, future upgrade of the network could have huge impact on the energy consumption of the network as "The Merge" did in September 2022 (perhaps not on the same scale though). Use of Layer 2, rollups and danksharding[56] may change the overall energy consumption while improving the scalability of the network, i.e. its ability to support a heavier load. It will also add some complexity to the calculation of the carbon footprint.

The use of a **Layer 2 scaling solution** in the context of the Ethereum blockchain will require a revision of the methodology to account for this new dimension. Layer 2 solutions provide scalability mechanisms

[56] DFG Official – *"Ethereum After Shapella: A Rollup-centric Era To Shine"* https://dfg-official.medium.com/ethereum-after-shapella-a-rollup-centric-era-to-shine-edcbce6b274a and https://ethereum.org/en/roadmap/danksharding/

that enable processing a larger number of transactions outside the main layer of the blockchain, thereby reducing the load on the main network. This will have an impact on carbon emissions for the beacon chain.

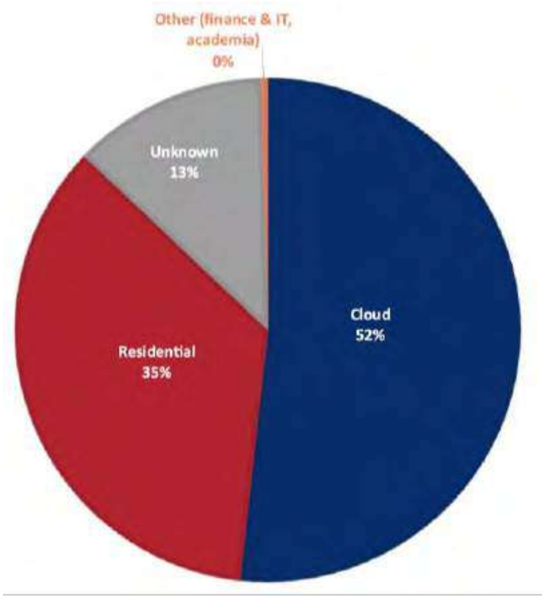
However, when assessing the carbon footprint, it becomes imperative to **consider transactions occurring on both the main layer and the Layer 2.** Consequently, the development of an appropriate methodology becomes essential to accurately and comprehensively estimate the environmental consequences associated with the adoption of Layer 2 scaling solutions.

9.6. Nodes count

As described in Scenario 5, even if we observe a stable number of beacon chain node over time, there could be some important variation in the number of nodes depending on Ethereum users and Ether (ETH) owners and potential incentives of maintaining their own nodes.
As of today, half the active nodes are also validator nodes (used for staking) but this number could be a lot higher as more than 125k Ethereum accounts own the minimum 32 ETH to run their own validator node. Currently, however, ETH owners are still delegating the staking through pools maintained by exchanges (Binance, Coinhouse, Kraken…) or Liquid Staking protocols such as Lido.

9.7. Nodes consumption and relation to hosting type

Figure 27 Node hosting distribution[57]



CCRI and Cambridge methodologies compute the average energy consumption of the Ethereum network from the average power of a hardware unit running a beacon chain node.
This hardware represents a self-hosted node which is certainly, as CCRI recognized, a conservative approach as some of the nodes are running on cloud infrastructure.

Thanks to updated node crawlers and IP addresses of discovered nodes, MigaLabs is able to classify the type of hosting used by node owners, many cloud provider hosting (52%) and residential hosting (35%).

[57] MigaLabs : https://migalabs.io/

We can consider that residential hosting corresponds to self-hosted nodes as described in CCRI methodology.

We can adapt the CCRI and Cambridge carbon footprint by using a different energy consumption and GHG emissions for Cloud hosted nodes. According to a study by Microsoft[58], "Microsoft Cloud is between 22 and 93 per cent more energy efficient than traditional enterprise datacenters" and "when taking into account renewable energy purchases, between 72 and 98 per cent more carbon efficient".

Of course, we need to get more precise data and study the Microsoft's assumptions used to get these results. We need to:

- Separate the different scopes,
- Get GHG emission numbers with both location-based and market-based methods for scope 2

We should also consider a recent Carbon 4 study[59], which gives a serious criticism of the use of the market-based method for GHG accounting of scope 2 and on the cloud infrastructure energy efficiency because of added redundancy and rebound effect.
Finally, Carbon 4 concludes with this: "Amazon's, Microsoft's, and Google's purchases of labeled renewable energy and energy efficiency efforts will not be enough to reduce emissions from their operations. To be aligned with the Paris Agreement, these companies should be leaders in creating a new business model that does not encourage overconsumption of resources."

This conclusion highlights the need for cloud providers such as Microsoft, Amazon and Google to provide more accurate and transparent data and methodology to assess the reduction ratios from self-hosted to cloud-hosted.

9.8. Internet traffic

As the blockchain grows, we must also pay attention the growing data traffic. This part seems to be less studied as internet traffic looks even more decentralized and difficult to monitor in comparison to a blockchain network. We still lack updated and recognized studies about the energy consumption of data transfer over Internet.

9.9. Location-based vs market-based method

As stated in part 8 '*Next issuance - Our best estimate*', and as per the GHG Protocol's recommendation of "dual reporting," which involves using both approaches, we have decided to illustrate both the location-based and market-based methods for considering carbon emissions from Azure cloud. However, based on the ISSB's recommendations[60], it is potentially expected that we may only need to consider the location-based method for calculating emissions.

9.10. Hybrid methodology (Hybrid between transaction-based and holding-based methodology)

In our study, we have taken a conservative approach by evaluating the annual energy consumption of the Ethereum blockchain, focusing exclusively on transactions. Based on this approach, we allocate the electricity consumption according to the execution of operations performed on the blockchain. However, at this stage, we do not segregate the portion related to holdings (holding-based methodology), which considers the electricity consumed by token holders when they retain their assets without conducting transactions.

[58] A study on the Microsoft Cloud in partnership with WSP – "*The carbon benefits of cloud computing*" (2020)
[59] Carbon4 : https://carbone4.com/en/analysis-carbon-footprint-cloud
[60]Reference: https://www.ifrs.org/news-and-events/news/2022/12/issb-announces-guidance-and-reliefs-to-support-scope-3-ghg-emiss/

This refers to the hybrid approach proposed by the CCRI and South Pole[61], which distinguishes between transactions and holdings, and offers a potential avenue for improvement in future developments. However, in the scope of our current study, we choose to remain conservative by attributing the whole blockchain network consumption to transactions (identified in gas units). This approach allows us to provide a robust initial estimate while acknowledging the possibility of exploring more complex approaches in the future.

[61] CCRI "Accounting for carbon emissions caused by cryptocurrency and token systems" Version 3 (March 2023)

10. Benefits and perspectives

10.1. Benefits of public blockchain use

This study demonstrates the interest of working on decentralized public infrastructure such as the Ethereum network. Even with hardware and service optimization facilitated through cloud infrastructures, the **mutualization of resources** remains low compared to the blockchain infrastructure. The Ethereum network can be seen as a shared world computer with thousands of users and services. As of today, there are more than 3,000 dApps (decentralized Applications) running on Ethereum. The blockchain, with its multitude of users and services, is never idle while a virtual environment or a cloud needs to maintain essentials services even if there is no client activity.

As told in the '*Result*' part, many other factors explain why the public blockchain should be better than a cloud infrastructure, on cost, security and optimization:

- Nodes are operated by people and organization sharing interests in the development of the blockchain, main motivations being:
  - Earning token by staking
  - Keeping a full archive of the blockchain
  - Securing access to the network
  - Adding decentralization to the network
- There is no client/provider relationship on blockchain infrastructure and no motivation to sell computer and storage capacities that don't reflect users' needs,
- There is no rebound effect related to cheap or seen as cheap (with delayed and global billing) capacities. Elastic or on-demand computer and storage capacities can lead to consume more than necessary and reduce effort to sobriety,
- Gas fees computation method and smart contract transparency are strong incentives to optimize code and data quality, efficiency and size,
- With its decentralization, blockchain is resistant to failure and censorship,
- Blockchain represents a shared infrastructure for financial actors and allows them to work on identical and unduplicated data facilitating reconciliation processes and preventing disputes.

However, Blockchain cannot and will not replace classic IT infrastructure, especially when big data and heavy computation is required. Also, all private and confidential data should remain on financial institutions own infrastructure.

We must notice here that all the explanations above only refer to public blockchain infrastructures. Indeed, on private infrastructures:

- There are no gas fees, owners of the chain are financially involved by running nodes,
- Decentralization is poor,
- Accesses are permissioned and transparency is limited.

10.2. Comparison

To contextualize Ethereum's energy consumption, Ethereum foundation has compared annualized estimates for some other industries.

Figure 28 Comparison of Ethereum energy consumption - May 2023[62]

	Annualized energy consumption (TWh)	Comparison to PoS Ethereum	Source
Global data centers	200	77,000x	*Iea.org*
Gold mining	131	50,000x	*ccaf.io*
Bitcoin	131	50,000x	*ccaf.io*
PoW Ethereum	78	30,000x	*digiconomist.net*
Youtube (direct only)	12	4,600x	*gstatic.com*
Gaming in USA	34	13,000x	*researchgate.net*
Netflix	0.451	173x	*assets.ctfassets.net*
PayPal	0.26	100x	*app.impaakt.com*
AirBnB	0.02	8x	*Airbnb ESG Factsheet*
PoS Ethereum	0.0026	1x	*carbon-ratings.com*

To make a comparison between the annualized emissions of a financial product on the blockchain with some modes of transportation such as airplane and car, as well as the heating emissions from a home using gas or electricity, please refer to the section Scenario - 7.2 Results.

[62] Ethereum.org – http://ethereum.org/

11. Conclusion

This study provides a comprehensive view of the management of a financial product on a hybrid classic IT/blockchain infrastructure and how to measure its carbon footprint.

Study on the assessment of the energy consumption of specific IT services in Cloud and Blockchain is still new and original. Therefore, numerous items still should be improved in order to get a better view of the carbon footprint analysis.

We hope this first work will open a way for other contributors to complete the scope of the study we intentionally limited to SG-Forge processes and roles in the financial product life cycle.

As for the blockchain infrastructure, we show how its usage can lead to better sobriety in IT project thanks to the fact that any operation is monitored and priced instantly. Moreover, there is a strong will in the developer community to limit as much as possible the size of the blockchain even as it grows constantly with new transactions. As monitoring tools are improving, we will also improve the methodology to assess the energy consumption of specific functions on the blockchain and see how it will evolve with more users and applications (relation between gas usage, gas limit, block size and number of nodes is open field for study).

There is also an opportunity to develop a field of study in the relationship between the blockchain use, its underlying cryptocurrency, gas fees computation and gas consumption and its number of nodes (which essentially drives the global footprint of the chain).

Moreover, with the development of danksharding, layer 2 and rollup solutions, we will have to extend the carbon footprint assessment to these new infrastructures and processes.

Apart from the methodology to assess the carbon footprint of a financial product IT management and related energy consumption, the blockchain shows it has a real interest for this type of use case:

- Low energy consumption
- Security
- Resistance to failure and censorship
- Transparency, especially important for indicators used in the management of sustainability linked bonds and loans
- Shared and centralized data for multiple entities management
- Sobriety of code and data

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Figures and illustrations presented:

13. ANNEXES

13.1. Glossary

- CAST "COMPLIANT ARCHITECTURE FOR SECURITY TOKENS"

The CAST framework is an open-source initiative designed to foster adoption of digital assets, by providing legal, operational and technical frameworks, to ease at lower cost and secure the on-boarding of potential market participants and their service providers.

- REGISTRAR

Registrar refers to the Agent of the Digital Assets' Issuer mandated to **provide the record-keeping of the Digital Assets** on behalf of the Issuer (i.e. development of the Smart Contracts creating the Digital Assets and the recording of the Digital Assets on the relevant DLT and of the settlement transactions) as well as to provide registry management services to the Issuer (e.g. to put in place a business continuity plan which would consist notably in keeping at least one full node of the Digital Asset's DLT in order to be able to reconstitute the registry of the Digital Asset holders off-chain).

- SETTLEMENT AGENT

Settlement Agent refers to the Agent of the Digital Assets' Issuer mandated to **handle cash settlement instructions management** in respect of the issuance of the Digital Assets, their sale on the secondary market and/or any payment of interest or principal related to the Digital Assets. The Settlement Agent is a role that can be carried out by the Registrar.

- CONSENSUS MECHANISM

The term consensus mechanism refers to the entire stack of protocols, incentives and ideas that allow a network of nodes to agree on the state of a blockchain.

- PROOF OF WORK

Proof of work is a consensus mechanism used in blockchain networks where participants, known as miners, must solve computationally difficult puzzles to validate and add new blocks to the blockchain. This process requires a significant amount of computational power, providing security and preventing malicious activities such as double-spending.

- PROOF OF STAKE

Proof of stake is a consensus mechanism used in blockchain networks where participants, known as validators, are chosen to validate new blocks based on the amount of cryptocurrency they hold and "stake" in the network. Validators are selected to create blocks and validate transactions based on their stake, eliminating the need for computationally intensive puzzles and reducing energy consumption compared to proof of work.

- BEACON CHAIN

The Beacon Chain was the blockchain that introduced proof-of-stake and validators to Ethereum. It ran alongside the proof-of-work Ethereum Mainnet from December 2020 until the two chains were merged in September 2022 to form the Ethereum of today

- NODE

A "node" is any instance of Ethereum client software that is connected to other computers also running Ethereum software, forming a network.

- CLIENT

A client is an implementation of Ethereum that verifies data against the protocol rules and keeps the network secure.

- CONSENSUS CLIENT

Consensus clients (Prysm, Teku, Nimbus, Lighthouse, Lodestar) run Ethereum's proof-of-stake consensus algorithm allowing the network to reach agreement about the head of the Beacon Chain. Consensus clients do not participate in validating/broadcasting transactions or executing state transitions. This is done by execution clients.

- EXECUTION CLIENT

Execution clients (formerly known as "Eth1 clients"), such as Besu, Erigon, Go-Ethereum (Geth), Nethermind, are tasked with processing and broadcasting transactions and managing Ethereum's state. They run the computations for each transaction using the Ethereum Virtual Machine to ensure that the rules of the protocol are followed.

- MAINNET

Short for "main network," this is the main public Ethereum blockchain. Real ETH, real value, and real consequences. Also known as layer 1 when discussing layer 2 scaling solutions. (Also, see testnet).

13.2. Form for node owners [63]

We have sent a questionnaire to a number of node managers to retrospectively verify the hypotheses we have adopted regarding the hardware, based on the information provided by the CCRI. We hope to receive initial feedback on this study by October 2023.

How many nodes do you run? *

If you have more than one node, for the next questions, please give answer corresponding to your average node configuration.

What kind of equipment are you using to run your node*

- Single board computer (Raspberry Pi style)
- Personal computer (new)
- Personnel computer (second hand)
- Cloud VM or Container
- Physical Server (new)
- Physical server (second hand)
- Autre :

What is the exact model of your equipment or the service configuration (please give as many details as possible)

How old is your equipment (0 to 10 years)?

0	1	2	3	4	5	6	7	8	9	10

Where is your equipment located (Country)?*

If you know it, give is the average data traffic of your node (upload plus download) in GB and the observation period (day; week ; month ; year)

Which execution client do you use? *

- Akula
- Bor
- Besu
- Erigon
- Geth
- Nethermind
- Openethereum
- Reth
- Autre :

Which version?

Which execution layer sync mode do you use?

- Full sync
- Fast sync

Which consensus client do you use? *

- Lighthouse
- Lodestar
- Nimbus
- Prysm
- Teku

Which version?

Which consensus layer sync mode do you use?

- Optimistic sync
- Checkpoint sync

If you know it, give the average energy consumption of your node in kWh and the observation period (day; week ; month ; year)

(Optional) How many validators do you run?

[63] Available at https://docs.google.com/forms/d/1QIEMSnciqWt4vdYyqARCAqb1FqnylGnqGCjlI18vAfg/prefill

13.3. Data used for each scenario

		Scenario 1			Scenario 1'			Scenario 1''		Scenario 2			Scenario 2'			Scenario 2''		
	Parameter	Medium	Lower bound	Upper bound	Medium	Lower bound	Upper bound	Medium	Lower bound	Upper bound	Medium	Lower bound	Upper bound	Medium	Lower bound	Upper bound	Medium	Lower bound
Token emission and life	Nb Emission	1	1	1	1	1	1	1	1	10	10	10	10	10	10	10	10	10
	Nb Investors	10	10	10	10	10	10	10	10	3	3	3	3	3	3	3	3	3
	Nb Trades	20	20	20	20	20	20	20	20	10	10	10	10	10	10	10	10	10
	Payoff frequency per year	2	2	2	2	2	2	2	2	1	1	1	1	1	1	1	1	1
	Product maturity in year	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Blockchain	Energy per gas unit: Wh	1.73E-04	5.54E-05	8.32E-04	3.46E-04	1.11E-04	1.73E-03	7.21E-04	2.31E-04	4.16E-04	1.73E-04	5.54E-05	8.32E-04	3.46E-04	1.11E-04	1.73E-03	7.21E-04	2.31E-04
	Carbon Footprint per gas unit (gCO2e)	7.63E-05	1.95E-05	4.16E-04	1.53E-04	3.90E-05	8.66E-04	3.18E-04	8.13E-05	2.08E-04	7.63E-05	1.95E-05	4.16E-04	1.53E-04	3.90E-05	8.66E-04	3.18E-04	8.13E-05
	Average consumption of a node (W)	62.44	20.00	150.00	62.44	20.00	150.00	62.44	20.00	150.00	62.44	20.00	150.00	62.44	20.00	150.00	62.44	20.00
	Number of nodes	12 000	12 000	24 000	24 000	24 000	50 000	50 000	50 000	12 000	12 000	12 000	24 000	24 000	24 000	50 000	50 000	50 000
	Usage energy consumption (GWh)	6.57E+00	2.10E+00	3.16E+01	1.31E+01	4.21E+00	6.57E+01	2.74E+01	8.77E+00	1.58E+01	6.57E+00	2.10E+00	3.16E+01	1.31E+01	4.21E+00	6.57E+01	2.74E+01	8.77E+00
	Usage Carbon Footprint (tCO2e)	2.90E+03	7.41E+02	1.58E+04	5.79E+03	1.48E+03	3.29E+04	1.21E+04	3.09E+03	7.89E+03	2.90E+03	7.41E+02	1.58E+04	5.79E+03	1.48E+03	3.29E+04	1.21E+04	3.09E+03
	Annualized gas consumption	3.79451E+13	3.79451E+13	3.79451E+13	3.79451E+13	3.79451E+13	3.79451E+13	3.79451E+13	3.79451E+13	3.79451E+13	3.79451E+13	3.79451E+13	3.79451E+13	3.79451E+13	3.79451E+13	3.79451E+13	3.79451E+13	3.79451E+13
Node Data Traffic	Internet Data energy consumption (kWh/GB)	0.00375	0.00375	0.00375	0.00375	0.00375	0.00375	0.00375	0.00375	0.00375	0.00375	0.00375	0.00375	0.00375	0.00375	0.00375	0.00375	0.00375
	Daily node traffic (GB)	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
	Internet node traffic annual consumption (GWh)	8.21E-01	8.21E-01	1.64E+00	1.64E+00	1.64E+00	3.42E+00	3.42E+00	3.42E+00	8.21E-01	8.21E-01	8.21E-01	1.64E+00	1.64E+00	1.64E+00	3.42E+00	3.42E+00	3.42E+00
Energy Mix	Energy Mix Node location weighted (gCO2e/kWh)	441	352	500	441	352	500	441	352	500	441	352	500	441	352	500	441	352

Operations (GAS UNIT)	Issuance	Create product	5 273 861	5 273 861	5 273 861	5 273 861	5 273 861	5 273 861	5 273 861	5 273 861	52 738 610	52 738 610	52 738 610	52 738 610	52 738 610	52 738 610	52 738 610	52 738 610	52 738 610
		Initiate subsrciption	2 752 170	2 752 170	2 752 170	2 752 170	2 752 170	2 752 170	2 752 170	2 752 170	8 256 510	8 256 510	8 256 510	8 256 510	8 256 510	8 256 510	8 256 510	8 256 510	8 256 510
		Payment Received	1 099 090	1 099 090	1 099 090	1 099 090	1 099 090	1 099 090	1 099 090	1 099 090	3 297 270	3 297 270	3 297 270	3 297 270	3 297 270	3 297 270	3 297 270	3 297 270	3 297 270
		Payment Transferred	590 270	590 270	590 270	590 270	590 270	590 270	590 270	590 270	1 770 810	1 770 810	1 770 810	1 770 810	1 770 810	1 770 810	1 770 810	1 770 810	1 770 810
	Coupon payment	Initiate coupon	36 192 820	36 192 820	36 192 820	36 192 820	36 192 820	36 192 820	36 192 820	36 192 820	180 964 100	180 964 100	180 964 100	180 964 100	180 964 100	180 964 100	180 964 100	180 964 100	180 964 100
		Payment Received	10 990 900	10 990 900	10 990 900	10 990 900	10 990 900	10 990 900	10 990 900	10 990 900	16 486 350	16 486 350	16 486 350	16 486 350	16 486 350	16 486 350	16 486 350	16 486 350	16 486 350
		Payment Transferred	5 902 700	5 902 700	5 902 700	5 902 700	5 902 700	5 902 700	5 902 700	5 902 700	8 854 050	8 854 050	8 854 050	8 854 050	8 854 050	8 854 050	8 854 050	8 854 050	8 854 050
	Secondary market transactions	Initiate trade	5 585 860	5 585 860	5 585 860	5 585 860	5 585 860	5 585 860	5 585 860	5 585 860	27 929 300	27 929 300	27 929 300	27 929 300	27 929 300	27 929 300	27 929 300	27 929 300	27 929 300
		Payment Received	2 198 180	2 198 180	2 198 180	2 198 180	2 198 180	2 198 180	2 198 180	2 198 180	10 990 900	10 990 900	10 990 900	10 990 900	10 990 900	10 990 900	10 990 900	10 990 900	10 990 900
		Payment Transferred	1 180 540	1 180 540	1 180 540	1 180 540	1 180 540	1 180 540	1 180 540	1 180 540	5 902 700	5 902 700	5 902 700	5 902 700	5 902 700	5 902 700	5 902 700	5 902 700	5 902 700
	Redemption	Initiate redemption	3 640 333	3 640 333	3 640 333	3 640 333	3 640 333	3 640 333	3 640 333	3 640 333	36 403 330	36 403 330	36 403 330	36 403 330	36 403 330	36 403 330	36 403 330	36 403 330	36 403 330
		Payment Received	1 099 090	1 099 090	1 099 090	1 099 090	1 099 090	1 099 090	1 099 090	1 099 090	3 297 270	3 297 270	3 297 270	3 297 270	3 297 270	3 297 270	3 297 270	3 297 270	3 297 270
		Payment Transferred	590 270	590 270	590 270	590 270	590 270	590 270	590 270	590 270	1 770 810	1 770 810	1 770 810	1 770 810	1 770 810	1 770 810	1 770 810	1 770 810	1 770 810
TOTAL		Total Gas Unit	77 096 084	77 096 084	77 096 084	77 096 084	77 096 084	77 096 084	77 096 084	77 096 084	358 662 010	358 662 010	358 662 010	358 662 010	358 662 010	358 662 010	358 662 010	358 662 010	358 662 010
		Total Energy (kWh)	13.35	4.27	64.12	26.69	8.55	133.58	55.60	17.81	149.14	62.08	19.89	298.29	124.17	39.77	621.43	258.68	82.86
		Total Carbon Emission kgCO2e	5.89	1.50	32.06	11.77	3.01	66.79	24.52	6.27	74.57	27.38	7.00	149.14	54.76	14.00	310.72	114.08	29.17

		Scenario 3			Scenario 3'			Scenario 3''		
	Parameter	Upper bound	Medium	Lower bound	Upper bound	Medium	Lower bound	Upper bound	Medium	Lower bound
Token emission and life	Nb Emission	30	30	30	30	30	30	30	30	30
	Nb Investors	3	3	3	3	3	3	3	3	3
	Nb Trades	10	10	10	10	10	10	10	10	10
	Payoff frequency per year	1	1	1	1	1	1	1	1	1
	Product maturity in year	5	5	5	5	5	5	5	5	5
Blockchain	Energy per gas unit Wh	4.16E-04	1.73E-04	5.54E-05	8.32E-04	3.46E-04	1.11E-04	1.73E-03	7.21E-04	2.31E-04
	Carbon Footprint per gas unit (gCO2e)	2.08E-04	7.63E-05	1.95E-05	4.16E-04	1.53E-04	3.90E-05	8.66E-04	3.18E-04	8.13E-05
	Average consumption of a node (W)	150.00	62.44	20.00	150.00	62.44	20.00	150.00	62.44	20.00
	Number of nodes	12 000	12 000	12 000	24 000	24 000	24 000	50 000	50 000	50 000
	Usage energy consumption (GWh)	1.58E+01	6.57E+00	2.10E+00	3.16E+01	1.31E+01	4.21E+00	6.57E+01	2.74E+01	8.77E+00
	Usage Carbon Footprint (tCO2e)	7.89E+03	2.90E+03	7.41E+02	1.58E+04	5.79E+03	1.48E+03	3.29E+04	1.21E+04	3.09E+03
	Annualized gas consumption	3.79451E+13	3.79451E+13	3.79451E+13	3.79451E+13	3.79451E+13	3.79451E+13	3.79451E+13	3.79451E+13	3.79451E+13
Node Data Traffic	Internet Data energy consumption (kWh/GB)	0.00375	0.00375	0.00375	0.00375	0.00375	0.00375	0.00375	0.00375	0.00375
	Daily node traffic (GB)	100	100	100	100	100	100	100	100	100
	Internet node traffic annual consumption (GWh)	8.21E-01	8.21E-01	8.21E-01	1.64E+00	1.64E+00	1.64E+00	3.42E+00	3.42E+00	3.42E+00
Energy Mix	Energy Mix Node location weighted (gCO2e/kWh)	500	441	352	500	441	352	500	441	352

		Scenario 4			Scenario 4'			Scenario 4''		
	Parameter	Upper bound	Medium	Lower bound	Upper bound	Medium	Lower bound	Upper bound	Medium	Lower bound
Token emission and life	Nb Emission	100	100	100	100	100	100	100	100	100
	Nb Investors	3	3	3	3	3	3	3	3	3
	Nb Trades	10	10	10	10	10	10	10	10	10
	Payoff frequency per year	1	1	1	1	1	1	1	1	1
	Product maturity in year	5	5	5	5	5	5	5	5	5
Blockchain	Energy per gas unit Wh	4.16E-04	1.73E-04	5.54E-05	8.32E-04	3.46E-04	1.11E-04	1.73E-03	7.21E-04	2.31E-04
	Carbon Footprint per gas unit (gCO2e)	2.08E-04	7.63E-05	1.95E-05	4.16E-04	1.53E-04	3.90E-05	8.66E-04	3.18E-04	8.13E-05
	Average consumption of a node (W)	150.00	62.44	20.00	150.00	62.44	20.00	150.00	62.44	20.00
	Number of nodes	12 000	12 000	12 000	24 000	24 000	24 000	50 000	50 000	50 000
	Usage energy consumption (GWh)	1.58E+01	6.57E+00	2.10E+00	3.16E+01	1.31E+01	4.21E+00	6.57E+01	2.74E+01	8.77E+00
	Usage Carbon Footprint (tCO2e)	7.89E+03	2.90E+03	7.41E+02	1.58E+04	5.79E+03	1.48E+03	3.29E+04	1.21E+04	3.09E+03
	Annualized gas consumption	3.79451E+13	3.79451E+13	3.79451E+13	3.79451E+13	3.79451E+13	3.79451E+13	3.79451E+13	3.79451E+13	3.79451E+13
Node Data Traffic	Internet Data energy consumption (kWh/GB)	0.00375	0.00375	0.00375	0.00375	0.00375	0.00375	0.00375	0.00375	0.00375
	Daily node traffic (GB)	100	100	100	100	100	100	100	100	100
	Internet node traffic annual consumption (GWh)	8.21E-01	8.21E-01	8.21E-01	1.64E+00	1.64E+00	1.64E+00	3.42E+00	3.42E+00	3.42E+00
Energy Mix	Energy Mix Node location weighted (gCO2e/kWh)	500	441	352	500	441	352	500	441	352

Operations (GAS UNIT)	Issuance	Create product	158 215 830	158 215 830	158 215 830	158 215 830	158 215 830	158 215 830	158 215 830	158 215 830	158 215 830
		Initiate subsrciption	24 769 530	24 769 530	24 769 530	24 769 530	24 769 530	24 769 530	24 769 530	24 769 530	24 769 530
		Payment Received	9 891 810	9 891 810	9 891 810	9 891 810	9 891 810	9 891 810	9 891 810	9 891 810	9 891 810
		Payment Transferred	5 312 430	5 312 430	5 312 430	5 312 430	5 312 430	5 312 430	5 312 430	5 312 430	5 312 430
	Coupon payment	Initiate coupon	542 892 300	542 892 300	542 892 300	542 892 300	542 892 300	542 892 300	542 892 300	542 892 300	542 892 300
		Payment Received	49 459 050	49 459 050	49 459 050	49 459 050	49 459 050	49 459 050	49 459 050	49 459 050	49 459 050
		Payment Transferred	26 562 150	26 562 150	26 562 150	26 562 150	26 562 150	26 562 150	26 562 150	26 562 150	26 562 150
	Secondary market transactions	Initiate trade	83 787 900	83 787 900	83 787 900	83 787 900	83 787 900	83 787 900	83 787 900	83 787 900	83 787 900
		Payment Received	32 972 700	32 972 700	32 972 700	32 972 700	32 972 700	32 972 700	32 972 700	32 972 700	32 972 700
		Payment Transferred	17 708 100	17 708 100	17 708 100	17 708 100	17 708 100	17 708 100	17 708 100	17 708 100	17 708 100
	Redemption	Initiate redemption	109 209 990	109 209 990	109 209 990	109 209 990	109 209 990	109 209 990	109 209 990	109 209 990	109 209 990
		Payment Received	9 891 810	9 891 810	9 891 810	9 891 810	9 891 810	9 891 810	9 891 810	9 891 810	9 891 810
		Payment Transferred	5 312 430	5 312 430	5 312 430	5 312 430	5 312 430	5 312 430	5 312 430	5 312 430	5 312 430
TOTAL		Total Gas Unit	1 075 986 030	1 075 986 030	1 075 986 030	1 075 986 030	1 075 986 030	1 075 986 030	1 075 986 030	1 075 986 030	1 075 986 030
		Total Energy (kWh)	447.43	186.25	59.66	894.86	372.50	119.31	1 864.29	776.04	248.57
		Total Carbon Emission kgCO2e	223.72	82.14	21.00	447.43	164.27	42.00	932.15	342.23	87.50

Operations (GAS UNIT)	Issuance	Create product	527 386 100	527 386 100	527 386 100	527 386 100	527 386 100	527 386 100	527 386 100	527 386 100	527 386 100
		Initiate subsrciption	82 565 100	82 565 100	82 565 100	82 565 100	82 565 100	82 565 100	82 565 100	82 565 100	82 565 100
		Payment Received	32 972 700	32 972 700	32 972 700	32 972 700	32 972 700	32 972 700	32 972 700	32 972 700	32 972 700
		Payment Transferred	17 708 100	17 708 100	17 708 100	17 708 100	17 708 100	17 708 100	17 708 100	17 708 100	17 708 100
	Coupon payment	Initiate coupon	1 809 641 000	1 809 641 000	1 809 641 000	1 809 641 000	1 809 641 000	1 809 641 000	1 809 641 000	1 809 641 000	1 809 641 000
		Payment Received	164 863 500	164 863 500	164 863 500	164 863 500	164 863 500	164 863 500	164 863 500	164 863 500	164 863 500
		Payment Transferred	88 540 500	88 540 500	88 540 500	88 540 500	88 540 500	88 540 500	88 540 500	88 540 500	88 540 500
	Secondary market transactions	Initiate trade	279 293 000	279 293 000	279 293 000	279 293 000	279 293 000	279 293 000	279 293 000	279 293 000	279 293 000
		Payment Received	109 909 000	109 909 000	109 909 000	109 909 000	109 909 000	109 909 000	109 909 000	109 909 000	109 909 000
		Payment Transferred	59 027 000	59 027 000	59 027 000	59 027 000	59 027 000	59 027 000	59 027 000	59 027 000	59 027 000
	Redemption	Initiate redemption	364 033 300	364 033 300	364 033 300	364 033 300	364 033 300	364 033 300	364 033 300	364 033 300	364 033 300
		Payment Received	32 972 700	32 972 700	32 972 700	32 972 700	32 972 700	32 972 700	32 972 700	32 972 700	32 972 700
		Payment Transferred	17 708 100	17 708 100	17 708 100	17 708 100	17 708 100	17 708 100	17 708 100	17 708 100	17 708 100
TOTAL		Total Gas Unit	3 586 620 100	3 586 620 100	3 586 620 100	3 586 620 100	3 586 620 100	3 586 620 100	3 586 620 100	3 586 620 100	3 586 620 100
		Total Energy (kWh)	1 491.43	620.83	198.86	2 982.87	1 241.67	397.72	6 214.31	2 586.81	828.57
		Total Carbon Emission kgCO2e	745.72	273.79	70.00	1 491.43	547.58	140.01	3 107.15	1 140.78	291.68

13.4. SG-Forge Process document

Document available upon request.

13.5. Methodologies & Best practices document

Document available upon request.

13.6. Scenario document

Document available upon request.

13.7. Audit report

We underwent a comprehensive audit by the Institut Louis Bachelier (ILB), presented below. Their valuable observations were duly considered in the production of the final version of this document.

Audit Report

INSTITUT
Louis Bachelier

SG Forge Carbon Emissions Methodology

July 2023

Institut Louis Bachelier has conducted a thorough audit of the methodology produced by Hanzō, blockchain dedicated department of Lamarck Group, commissioned by SG-Forge. This audit has been performed under the direction of Louis Bertucci (louis.bertucci@institutlouisbachelier.org) with the participation of Stéphane Voisin (stephane.voisin@institutlouisbachelier.org) and Adithya Pradeep (adithya@jeev.earth).

1. Executive Summary

Blockchain and smart contracts have the potential to drive significant efficiencies in the issuance and trading of financial instruments. However, the climate impact stemming from the electricity use of blockchains remains a critical point of concern to be addressed. The transition of Ethereum - the most dominant blockchain protocol for tokenized assets - to the more energy efficient Proof-of-Stake consensus protocol has assuage concerns regarding the energy use of the blockchain. Yet, to date there remains little literature that accurately quantifies the carbon emissions associated with the Ethereum network and the applications built upon it.

As an innovator in the field of digital assets, SG Forge has developed an infrastructure for the issuance and settlement of bonds on the Ethereum blockchain. In this context, Lamarck Group has developed a pioneering methodology for estimating the carbon emissions through the lifecycle of an SG Forge bond issued on the Ethereum blockchain. Institut Louis Bachelier (ILB) was mandated to audit the aforementioned methodology. This report outlines the findings of our audit.

The technology stack of SG Forge infrastructure contains 2 main components: 1) the ethereum blockchain to do book-keeping and related activities, and 2) a cloud infrastructure for other associated activities (origination, price fixing, term validations, etc.). The carbon computation methodology accounts for both aspects, representing the total carbon emissions associated with the issuance of a tokenized security on SG Forge infrastructure. Lamarck Group's methodology is therefore split into the following two components:

1. Ethereum blockchain carbon emissions: This innovative methodology enhances existing methodologies by; 1) accounting for carbon emissions on a per gas unit basis, allowing the detailed carbon assessment of any smart contract execution and 2) estimating the carbon emissions resulting from different usage scenarios by using per gas unit carbon emissions.
2. Cloud infrastructure carbon emissions (Microsoft Azure): standard methodology aligned with GHG protocol recommendations. Here, only Scope 1 and Scope 2 of Microsoft are considered removing the carbon footprint due to the downstream and upstream lifecycle of Microsoft's hardware.

As accurately outlined in Lamarck Group's documentation, this methodology only accounts for the carbon emissions associated with the IT infrastructure leveraged for the development and use of the SG Forge application. Under the GHG protocol, these emissions would fall under SG Forge's Scope 3 emissions. A full carbon accounting exercise would include emissions associated with other enabling activities such as the emissions from the use of electricity in SG Forge's offices, employee commuting, employee IT equipment, sales travel etc. that is dedicated to this product. In this study, SG Forge's Scope 1 & Scope 2 emissions attributable to the product are entirely excluded and only the "use" phase of the product's Scope 3 emissions are taken into account.

Within this defined scope, ILB conducted a rigorous audit of the methodology developed by Lamarck Group. The audit commenced with a deep dive into the SG Forge application and underlying processes. This was followed by a detailed review of the literature and the choice of datasets to determine alignment of Lamarck Group's methodology with best practices. The next phase of the audit involved a review of Lamarck Group's proposed emissions calculation methodology and an examination of the 4 stress-test scenarios. We then undertook a 2-week collaborative phase of suggesting improvements to the methodology. Finally, the end methodology was audited again to ensure robustness and to highlight room for future improvement.

In summary, we find that Lamarck Group's proposed methodology is robust and well-suited for the purpose of assessing a specific Ethereum application. Crypto Carbon Ratings Institute's (CCRI) methodology for estimating carbon emissions of the Ethereum network is found to be the best available at the moment. Using this as a foundational framework, Lamarck Group has further developed a customized methodology incorporating updated data points on Ethereum network statistics from Migalabs and Etherscan. Lamarck Group's methodology enhances basic blockchain carbon accounting methodology by measuring the carbon emissions of single gas units, allowing for detailed assessment of any smart contract execution. This is a significant improvement as most existing methodologies only measure per-transaction emissions, which are by definition highly heterogeneous. Different usage scenarios also help emphasize the relative importance of each aspect of the carbon footprint.

This study is, to the best of our knowledge, the first to consider the carbon footprint of equivalent processes both on-chain and off-chain. While the on-chain activity is currently limited to only book-keeping, the overwhelming majority of the carbon emissions can be attributed to the cloud-based infrastructure. It helps put things into perspective regarding the environmental impact of a specific application on the Ethereum blockchain.

However, there still remains some points of future improvement in the methodology. Albeit being marginal for the overall computation, the number of Ethereum full nodes could be taken as dynamic across a given scenario. Indeed, as a tokenized financial product may live on the blockchain for several years, the number of Ethereum nodes could drastically evolve. Moreover, the lack of granular and detailed data provided by Microsoft induces several assumptions for the methodology. Given that the cloud infrastructure is responsible for the majority of the carbon footprint, this could have a material impact on final calculations. We recognize that given the available data, the assumptions are consistent with the goal of the methodology and are conservative regarding the overall carbon footprint. The final results are more likely to be overestimated than underestimated.

2. Scope of Audit

We have conducted a thorough audit of the methodology, documents and calculations proposed by Lamarck Group. Below we highlight the scope of the audit, as well as what could not be included in the audit due to lack of verifiability.

Within Scope of ILB Audit

- Understanding SG Forge Processes: Based on the documentation provided by Lamarck Group, ILB's audit commenced with a detailed review of SG Forge's process documentation with the goal of understanding the product life cycle in detail.
- Review of Literature: The next step of the audit involved a review of literature spanning the topics of carbon accounting, corporate carbon reporting best practices, and blockchain energy & carbon emissions methodologies. The two main goals of this exercise were 1) to ascertain that the choice of methodologies chosen by Lamarck Group was best in class and, 2) to develop a comprehensive understanding of the best-in-class methodologies.
- Review of Choice of Datasets: Next we scanned the landscape for the best datasets for the purpose of the methodology.
- Collaborative improvement: Over a 2-week period, ILB and Lamarck Group have continuously iterated on improvements to the final methodology over weekly calls and follow up recommendations provided by ILB to Lamarck Group.
- Audit of SG Forge Carbon Emissions Methodology (including scenarios): Finally, based on our understanding of the best practices in the field of carbon accounting for blockchain processes, we conducted a thorough audit of the final carbon emissions methodology developed by Lamarck Group. The findings of this process are outlined in this document.

Out of Scope of ILB Audit

Certain elements of the methodology were excluded from the audit owing to a lack of visibility of the underlying data. We assume that these data points have been accurately captured by Lamarck Group in their emissions methodology. This includes:

- Microsoft Azure Cloud emissions data: The emissions data associated with SG Forge's use of Microsoft Azure services was not directly accessible to ILB. Lamarck Group has extracted this data from SG Forge's Microsoft Azure emissions dashboard.
- Exaion emissions data: We do not have information regarding the volume of use of Exaion services by SG Forge. Based on the reported usage of 1 dedicated SG Forge node and Exaion's use of renewable energy in Normandy, France, Lamarck Group has computed an emissions figure for SG Forge's use of Exaion services. We believe the underlying assumptions and data used are reasonable.

3. Overview of Activities

3.1. Literature review

Over the course of the mandate, ILB has reviewed the following documents with the goal of determining the best methodological framework for accurately estimating the carbon footprint of SG Forge's blockchain infrastructure.

Table 1: Literature review summary

Workstream	Publication	Relevance
Carbon Accounting Methodologies & Guidance	Corporate Value Chain (Scope 3) Accounting and Reporting Standard - GHG Protocol - accessed online in June 2023	High
	GHG Protocol Scope 2 Guidance - GHG Protocol - accessed online in June 2023	High
	A new approach for Scope 3 emissions transparency - Microsoft - accessed online in June 2023	High
	Carbon Footprint reporting methodology - Google - accessed online in June 2023	Medium
Corporate Sustainability Reports	2022 Carbon Emissions Report | Palantir Technologies - Palantir Technologies - accessed online in June 2023	High
	FY22 Atlassian Sustainability Report - Atlassian - accessed online in June 2023	Low
	2023 Sustainability Report | HubSpot - Hubspot - accessed online in June 2023	Low
Blockchain Energy & Emissions Methodologies	Crypto Carbon Ratings Institute • Energy Efficiency and Carbon Footprint of PoS Blockchain Protocols (January 2022) - accessed online in June 2023 • The Merge – Implications on the Electricity Consumption and Carbon Footprint of the Ethereum Network (September 2022) - accessed online in June 2023 • Determining the electricity consumption and carbon footprint of Proof of Stake networks (March 2023)	High
	Cambridge Blockchain Network Sustainability Index - Cambridge - accessed online in June 2023	Medium
	Study of the environmental impact of the Tezos blockchain (December 2021) - Tezos Foundation - accessed online in June 2023	Low

	Ibañez, Juan Ignacio and Rua, Francisco, The Energy Consumption of Proof-of-Stake Systems: Replication and Expansion (January 13, 2023). Available at SSRN: http://dx.doi.org/10.2139/ssrn.4324137	Low
	GUIDANCE FOR ACCOUNTING AND REPORTING ELECTRICITY USE AND CARBON EMISSIONS FROM CRYPTOCURRENCY - Crypto Climate Accord - accessed online in June 2023	Low

3.2. Data Sources

Over the course of the mandate, ILB has cross referenced the choice of data points with the below mentioned sources:

Table 2: Summary of data sources review

Data type	Source	Relevance
Ethereum network statistics, electricity consumption and emissions	Migalabs ● Monitor ETH Nodes Data. Accessed from: https://monitoreth.io/	High
	Etherscan.io ● Node tracker, gas estimation Accessed from: https://etherscan.io/nodetracker ● Gas consumption of contract calls review by sampling some of the contract calls on https://etherscan.io/	Medium
	The Merge – Implications on the Electricity Consumption and Carbon Footprint of the Ethereum Network (September 2022) - Crypto Carbon Rating Institute - accessed online in June 2023	Medium
	Cambridge Blockchain Network Sustainability Index. Accessed from: https://ccaf.io/cbnsi/ethereum	High
National emissions factors	International Energy Agency ● Global Energy & CO2 Status Report 2019. Accessed from: Emissions – Global Energy & CO2 Status Report 2019 – Analysis - IEA - accessed online in June 2023 ● Global Energy Review: CO2 Emissions in 2021. Accessed from: Global Energy Review: CO2 Emissions in 2021 – Analysis - IEA - accessed online in June 2023	Medium
	United States Environmental Protection Agency, eGRID Data Explorer. Accessed from: Data Explorer | US EPA - accessed online in June 2023	Medium
	European Environmental Agency, Greenhouse gas emissions intensity of electricity generation in Europe. Accessed from: Greenhouse gas emission intensity of electricity generation in Europe - accessed online in June 2023	Medium

We find that Ethereum-related data and statistics match the one used by Lamarck Group in their methodologies. While we found deviations in the national carbon intensities of electricity production chosen for the study, the margin of variation was determined to be immaterial.

3.3. Review of Methodological Robustness

Following a thorough review of the literature and data, ILB performed an in-depth review of the carbon emissions methodology developed by Lamarck Group. The review process and findings are presented below.

a. Step 1: Compute Microsoft Azure emissions

Microsoft provides their Scope 1 (MS_1) and Scope 3 (MS_3) carbon equivalent emissions of all SG Forge's cloud infrastructure. Lamarck Group's methodology does not include Scope 3 emissions related to cloud infrastructure. However, emissions related to Scope 2 (MS_2) should be included although not being provided by Microsoft. Lamarck Group uses heuristics to estimate both location-based (MS_{2L}) and market-based (MS_{2M}) Scope 2 emission of the Microsoft cloud infrastructure.

$$MS_{2L} = 38\% \times (MS_1 + MS_3)$$

$$MS_{2M} = 4{,}5\% \times MS_{2L} = 4{,}5\% \times 38\% \times (MS_1 + MS_2)$$

The final figure of Microsoft-related emissions is composed of the Scope 1 emissions provided by Microsoft and Scope 2 estimated according to location-based or market-based heuristic (both are considered).

Comments: The formulae, data sources and calculations are clearly outlined. Microsoft's Scope 2 emissions figures are an estimate and can contain a degree of uncertainty. This is outside the control of Lamarck Group and has been adequately addressed.

b. Step 2: Compute Exaion emissions

There is a single hosted full Ethereum node dedicated to SG Forge infrastructure. As Exaion does not provide any information about the energy consumption and carbon emissions of their products, Lamarck Group's methodology makes some assumptions. In particular it assumes the node power consumption of the node to be 62.44 W, which is the best guess of the CCRI methodology. This number is converted to an average annualized consumption of 547.35 kWh. The energy carbon intensity is estimated to be that of a low "green" French energy mix, that is 35 gCO_2e/kWh.

Comments: Data source for grid intensity is taken directly from Exaion, a subsidiary of EDF the French national electricity provider. We believe the calculations are satisfactory.

c. Step 3: Compute emissions per gas unit of the Ethereum Network

According to existing methodologies (CCRI), Lamarck Group computes the average power consumption of a single Ethereum node, P_{node}, in W and obtains 1) an Upper Bound, 2) a Best Guess, and 3) a Lower Bound. The number of nodes in the Ethereum network, N_{ETH}, is taken constant and observed on independent service providers (MigaLabs). The Annualized Ethereum Energy Consumption, E_{ETH}, in kWh is computed from the estimated power consumption (Upper Bound, Best Guess and Lower Bound) and the estimation of the number of nodes:

$$E_{ETH} = P_{node} \times N_{ETH} \times 365.25 \times 24$$

The global Ethereum energy carbon intensity, CI_{ETH}, is computed by taking the estimated nodes location and the energy mix of the corresponding country. The annualized carbon emissions of the Ethereum network, $CO2_{ETH}$, is estimated by

$$CO2_{ETH} = E_{ETH} \times CI_{ETH}$$

The annualized Ethereum network gas consumption, G_{ETH}, is estimated using independent service providers (Etherscan). The Ethereum carbon emission per gas unit, $CO2_{ETH/GAS}$, is computed as

$$CO2_{ETH/GAS} = CO2_{ETH} / G_{ETH}$$

Comments: We believe that this is a point of innovation of this methodology. The per gas unit energy consumption and emissions are a valuable addition to the existing body of knowledge on the topic.

d. Step 4: Compute emissions associated to a specific smart contract

Average gas consumption of a specific contract can then be observed on the blockchain through an independent provider (Etherscan). Regarding SG Forge's infrastructure, the gas usage of the Token Factory contract, $G_{TokenFactory}$, as well as the main Token contract, $G_{Tokenization}$, are of importance. The gas consumption of the token contract depends on the number of contract calls to be performed, which in turn depend on the number of subscribers, transfers and redemptions on each token. Assumptions are made for different scenarios (number of issuances, number of subscribers per issuance, number of transactions per subscriber, number of coupon payments per issuance). For a given scenario, the corresponding amount of gas is computed given the historical gas consumption of each contract call.

Using the per gas unit carbon emission from the previous step, carbon emissions associated with a given scenario, $COE2_{scenario\_i}$, is computed as

$$CO2_{scenario\_i} = G_{Tokenization/scenario\_i} \times CO2_{ETH/GAS}$$

Including that of the Token Factory contract, the total carbon emission associated to the use of the Ethereum network, $CO2_{Ethereum/Scenario\_i}$, is computed as

$$CO2_{Ethereum/Scenario\_i} = (G_{Tokenization/scenario\_i} + G_{TokenFactory}) \times CO2_{ETH/GAS}$$

$$CO2_{Ethereum/Scenario\_i} = CO2_{scenario\_i} + G_{TokenFactory} \times CO2_{ETH/GAS}$$

Comments: After reviewing the calculator and the final report, we find that the computation is well performed. The computation tools provided allow for the computation of carbon emissions of any smart contract calls.

e. Step 5: Compute total emissions

The total carbon emissions associated to the tokenization process implemented by SG Forge is computed as the sum of the 3 previous components, that are 1) carbon emissions associated with Microsoft Cloud Azure, 2) Exaion hosted full Ethereum node and 3) emissions derived from the use of the Ethereum network.

Comments: The carbon footprint of the test and development phase are presented separately from the main results. This last step is performed across all studied scenarios.

4. Findings

4.1. Strengths of the methodology

Lamarck Group's methodology for estimating the carbon emissions of SG Forge's tokenization product and the corresponding stress tests are determined to be robust. We find that Lamarck Group has performed a thorough review of literature and available data sources to inform their choice of input data and foundational methodology. Building upon CCRI's methodology, Lamarck Group makes a substantial improvement by calculating energy consumption and emissions on a per gas unit basis. This permits detailed assessment of any smart contract regardless of their functionality. Lamarck Group has also been rigorous in trying to fill gaps left by data unavailability. For instance, despite the fact that Microsoft Azure reports its Scope 2 emissions to be 0, Lamarck Group went the extra mile to create an estimate of the emissions in line with best practices.

Important Remark

As rightfully highlighted in the result section of the methodology, it turns out that the overwhelming majority of the carbon emissions comes from the cloud infrastructure rather than the use of the Ethereum blockchain. We would like to emphasize that this study performed in this methodology document is, to the best of our knowledge, the first document and methodology assessing both the blockchain and the cloud-based infrastructure of the same process. This product-driven approach has the benefit of showing the relative importance of both types of infrastructure. Although the extent of the activities of SG Forge performed on the Ethereum blockchain are somewhat limited, this is reminiscent of the fact that the blockchain, if parsimoniously used, only marginally affects the carbon footprint of an existing process. There are two main intuitions behind this fact. First, the blockchain is a shared platform. It is never idle, and Proof-of-Stake does not waste energy per se, so the overall consumption is very efficient, in terms of energy spent by operation. Second, as each unit of computation (i.e. gas) can be expensive, there is a strong incentive to design programs and smart contracts that are highly efficient and consume as little gas units as possible.

4.2. Proposed Areas of Improvement

In the following we present several proposed areas for improvement for future work.

a. Node count on the Ethereum network

As the total carbon emissions associated with the Ethereum blockchain are directly proportional to the number of Ethereum full nodes, the node count is of first importance. This methodology takes a constant node count as input in the calculation for a given scenario, but presents results for different node counts in each of the usage scenarios.

The underlying mechanisms impacting the node count are briefly discussed in the methodology, but there is room for further discussions. The two main incentives to run a full node are 1) verify, monitor and audit the blockchain, and 2) run a validator node to participate in the consensus algorithm. While the latter is governed by financial incentives (although the validation process could be delegated to another node), the former is more challenging to estimate. Indeed, increased adoption, in particular from institutions, could significantly increase the number of active Ethereum full nodes, just like SG Forge is running a dedicated node through Exaion.

We believe that the assumptions made in this methodology, of x2 and x4 node counts, are relevant given potential future adoption. Going further, the node count could be taken as dynamic in each scenario, as tokenized products may live 1 or 2 years of the blockchains, leaving room for adoption and increased number of nodes. Overall, the assessment of the energy consumption of an Ethereum application is related to the amount of gas consumed and the number of nodes. Moreover change in block size, albeit rare, will also have an impact on the global energy consumption.

b. Cloud-based emissions

One of the main results of the methodology is to show how total emissions change across different scenarios. As rightfully indicated in the methodology, the usage scenarios only affect the usage of the Ethereum blockchain (number of calls to the smart contract) and keep the cloud infrastructure energy consumption (i.e. carbon emissions) constant. While the usage of the blockchain is directly proportional to the number of operations (subscriptions, trades, coupons and redemptions), it is true that the cloud infrastructure will not be proportional as it is usually not running at full capacity. However, it is likely that to accommodate a 10x increase in the number of issuances, the cloud infrastructure is likely to scale accordingly.

Given the lack of specific usage data from Microsoft Azure services, it would have been challenging to estimate the load on the existing infrastructure, so it made sense to take constant carbon emissions across all the scenarios.

However, we note that given that emissions related to the use of Microsoft Azure services accounts for over 75% of the platform’s emissions in the reference case, this could have a material impact on the final emissions figure, for scenarios with significant increase in adoption.

c. Granularity of Microsoft Azure data

Microsoft Azure only reports overall service usage, for the whole SG Forge infrastructure. Everything is therefore included in the carbon emissions associated with the cloud infrastructure, including use of the service not directly related to the tokenization infrastructure.

With reports of higher granularity of Microsoft, it would be possible to refine the methodology and increase the level of precision of the final carbon emissions computations.

d. Scope 2 emissions: Location-based vs Market-based approach

As adequately discussed in the methodology document, the absence of Scope 2 reporting from Microsoft Azure forced an estimation of the carbon emissions related to electricity consumption. According to GHG protocol, there are 2 ways to report such emissions: 1) Market-based and 2) Location-based. While the methodology highlights both measures, as it is usually reported by technology companies, we note that the International Sustainability Standard Board (ISSB) no longer considers market-based approach best practice.

Furthermore, in the absence of granular reporting from Microsoft, the methodology had to use heuristics to estimate both market-based and location-based scope 2 emissions. The used heuristics, which is standard in the literature, estimate the location-based measure to be more than 20x larger than the market-based. Given that the cloud infrastructure accounts for the majority of the carbon emissions of the tokenization process, the impact of selecting location-based instead of market-based is highly significant (as correctly displayed in the final result of the methodology).

e. Other proposed area of improvements

Throughout the course of the audit, there were a number of minor points that were raised and suggested to Lamarck Group. Those points were adequately addressed by Lamarck Group and taken into account for the final draft of the methodology. We do not list these points here.

It is worth noting that the field of carbon accounting is still rapidly evolving, leaving room for a significant order of uncertainty outside the findings outlined above. Additionally, the field of energy and emissions calculations for the blockchain are still more nascent. As rightly noted by Lamarck Group in their document, this leaves the methodology with some limitations owing to the general uncertainty around the topic. Given the pioneering nature of this study, we believe that Lamarck Group has done a commendable job in developing this methodology. The final results however must be interpreted keeping in mind the nasency of this field of study and the room for future improvements.

5. Conclusion

Lamarck Group's methodology for estimating the carbon emissions of SG Forge's tokenization product and the corresponding stress tests are determined to be robust. The evolving standards in the field of carbon accounting and the nascent nature of carbon accounting applied to the Ethereum blockchain, mean that it is important to keep in mind that there remains room for uncertainty in the reported emissions figures. In its choice of data sources and foundational literature, Lamarck Group's choices are seen to be very well informed. The calculations of Ethereum's energy consumption and consequent emissions on a per gas unit basis is a key contribution to the existing body of knowledge on the topic. The shortcomings of the methodology are largely due the lack of available data. In conclusion, we believe that this methodology is a pioneering piece of work. With improved data quality and consensus on carbon accounting standards the methodology can be further improved in the future.

A verification of the proper application of the CCRI methodology was also conducted by the CCRI.

CCRI

Statement on Methodology Document prepared by Hanzo for SG-Forge

We at CCRI are pleased to offer our expertise to review SG-Forge's pioneering report on the sustainability metrics of tokenized financial products. As a leading player in the European banking sector, we hope SG-Forge's commitment to understanding and minimizing the environmental impact of its Security Token activities will inspire other financial institutions to follow suit.

We were honored to see the report employing the methodology we developed to quantify carbon emissions of tokenization on Ethereum. Though the study restricts its scope and makes calculated assumptions, such as adopting a purely transaction-based allocation approach, it effectively balances comprehensiveness with specificity. As the transaction-based approach typically overestimates the amount of emissions compared to more sophisticated approaches considering also coin holdings, it establishes a cautious baseline for further studies.

Significantly, the report incorporates our recent findings on the impact of Ethereum's Merge, which reduced the network's carbon emissions by more than 99%. The Merge provides a powerful argument in favor of blockchain's viability as a sustainable technology, especially when contrasted with other technologies examined in the report, which are more carbon intensive. Furthermore, Ethereum’s reduced carbon intensity showcases that advanced financial instruments can be more environmentally sustainable than in the past.

As transparency on climate impacts is the vital first step towards more sustainable financial instruments, SG-Forge's efforts to quantify the environmental impact of its blockchain-based financial products are highly commendable. We at CCRI are proud we could contribute to this valuable undertaking by providing feedback on draft versions of this document and are optimistic that it will foster a greater emphasis on sustainable practices across the financial sector.

— CCRI (Crypto Carbon Ratings Institute), Munich, September 15, 2023.

14.7 Acknowledgments

We would like to thank all stakeholders who have made a significant contribution to the success of this study.

Firstly, we are grateful to our client SG-Forge for its continuous support and strong involvement in the development of the carbon emissions calculation methodology. Its commitment has been essential in the completion of this study.

We also extend warm thanks to MigaLabs and Leonardo Bautista Gomez for providing high-quality data on Ethereum nodes and dedicated collaboration throughout the project.

We acknowledge the cooperation of Microsoft and Exaion and their effort in overcoming the limitations in available data. We remain open to reevaluating our calculations based on any data updates they may provide.

Our appreciation also goes to the Crypto Carbon Ratings Institute (CCRI) for their breakthrough studies on Ethereum carbon footprint and their thorough review and validation, which strengthened the credibility of our approach.

Finally, we express our gratitude for the meticulous audit conducted by the Institut Louis Bachelier (ILB) and their valuable feedback, which has been instrumental in shaping the evolution of the final deliverable.

Collectively, the efforts of these stakeholders have been essential in successfully completing this study and achieving reliable results. We sincerely appreciate the active collaboration, expertise, and unwavering support each party has provided throughout this journey.

Prepared for

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