IC SUSTAINABILITY REPORT 2022

Internet Computer Footprint

CARBON CROWD

DFINITY

Assessed by FINGREEN AI

Table Of Contents

Executive Summary

Since the dawn of blockchains there have been grave concerns about their carbon consumption. While the discussion over the past decade revolved around the Proof-of-Work vs Proof-of-Stake debate, **recent events (the Ethereum merge) shift the focus more towards that of replication vs utility.** As blockchains now leverage additional scalability and efficiency measures, more careful study is needed.

To start, we set out to measure the electricity consumption and carbon footprint of the Internet Computer and develop a sustainability strategy (as requested in NNS proposal #55487). Further, we aim to develop a broader, industry-wide, strategy for decarbonising future blockchains. The report concludes that, as of September 2022:

- The direct electricity consumption of the IC is 1,053,462 kWh/year
- The yearly scope 2 carbon footprint of the IC is ~275.34 tCO_2e
- The marginal electricity consumption of a single transaction on the IC is 0.005 Wh/tx
- The IC blockchain currently consumes less electricity than 100 households per year (EIA, 2021)

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Introduction

Lisbon, in early September, hosted a group of around 100 individuals in a small venue with one topic under discussion—the climate crisis. Bubbly enthusiasm and optimism were at odds with the scale of the crisis under scrutiny. Attempting to address the world's myriad of challenges can create an atmosphere of dread, so why the difference here? Quite simple. Project after project was tangibly demonstrating how blockchain technology could be used to coordinate resources, and reliably solve climate related problems.

Pizzas were served with basil grown in a vertical farm on site. The farm uses NFTs as subscriptions, with the NFT owner receiving a plant every month. A community reforestation project demonstrates the power of blockchain as a tool for rewarding coordinated action, and a few carbon credit heavyweights waded into the nuance of the voluntary carbon market, and how distributed ledgers can be used to ensure quality, while enhancing additionality. Blockchain was demonstrating itself to be, in a series of different use cases, a powerful tool for tackling the climate crisis.

Yet, as the importance of this new technology comes to bear, it is critical we remain clear-eyed about its drawbacks. The energy intensity of blockchains and their associated carbon footprints have been under scrutiny for years. Proof-of-Work (PoW) consensus mechanisms, used by Bitcoin and until recently by Ethereum, require enormous computational power to progress, and are therefore extremely energy intensive. Ethereum's "Merge", transitioning it to the less energy consumptive Proof-of-Stake (PoS) model, sees the majority of the blockchain industry now working in much less energy intensive ways. While progress has been made, there is still a long way for the blockchain industry to go to be considered sustainable.

The conversation becomes more nuanced when one considers how much decentralisation is needed to gain the trust guarantees expected from blockchains. Every node validating every transaction or computation incurs wasteful replication and is costly both for the user and for the climate. **What was once a Proof-of-Work vs Proof-of-Stake debate now becomes one of replication vs utility.** A middle ground has emerged where many blockchains leverage extra techniques (sharding, rollups, parachains, etc) to scale and gain efficiency but also cut on their carbon footprint. Incorporating scaling solutions, while beneficial, adds complexity to the ecosystem and care must be taken in the computation and the interpretation of reported sustainability policies and results.

This report looks to compute the carbon footprint of the Internet Computer (IC). As the IC incorporates scaling mechanisms directly in the core protocol, it is one of the simpler blockchain platforms to get a realistic carbon footprint for. Earlier this year, the IC ecosystem adopted a community-authored proposal (**NNS Proposal #55487**) to establish a carbon footprint and sustainability policy for the **Internet Computer** blockchain.

Introduction (Cont'd)

Soon after, our team at **Carbon Crowd** began to develop a strategy to decarbonise the underlying digital infrastructure of the Internet Computer. That strategy is now complete, and we are now ready to help the IC with its technical implementation.

Internet Computer Footprint: IC Sustainability Report 2022 documents the IC's current electricity usage and carbon footprint, and includes a series of proposals for the network's decarbonization. It was researched and written by Carbon Crowd with extensive support from the DFINITY Foundation, a major contributor to the IC, with special thanks to DFINITY senior research scientist Aisling Connolly. The depth of data the foundation provided shows its determination to understand the IC's environmental impact and develop technology that benefits everyone. The report's findings were reviewed by **Fingreen AI**, an ESG risk-analytics expert.

The Study

This study was conducted on the Internet Computer (IC), and in order to fully interpret the results it is necessary to understand the underlying infrastructure. The IC is made up of a number of subnets, a subnet often being a group of 13 nodes. Each node is a physical server running in a data centre somewhere in the world. Each smart-contract is scoped to a single subnet, meaning there is an uneven distribution of smart-contracts over subnets and thereby differing workloads per subnet. Additionally, the IC has a number of boundary nodes which are responsible for dispatching incoming queries to each of the subnets. For the purpose of the study we consider them equivalent to a worker node.

The study was limited to scope 2 emissions, but does discuss the scope 3 emissions in appendix 1. It is limited to the IC infrastructure and excludes the DFINITY foundation, which runs additional infrastructure including the IC Dashboard and monitoring infrastructure. The limitations of the report are described below in more detail, they primarily relate to lack of clarity around certain data. Follow-up reports should focus on improving the quality of such data.

The methodology, developed by Carbon Crowd, has gone through several internal and external reviews. It, too, is a work in progress and is expected to evolve as new standards develop in the field. The methodology was designed to grow into a real-time measurement process for the underlying infrastructure in such a way that the emissions-profile of the IC can be predicted on a day-to-day, or even hourly, basis.

The Study (Cont'd)

Accurate measurement of each of the inputs for this methodology are critical to a reputable output. Special attention should be paid to the sources of the data collected, and further improvements on measurement techniques and data-sources. For emissions data the regional grid-mix is used as an approximation, this report relies on sources ranging from the GHG Protocol (IEA, 2011) to regional data (EPA, 2022) submitted yearly.

The reported results and comparisons focus on scope 2 emissions. There is a brief discussion on the comparative performance of similar blockchain and 'traditional corporate' solutions. Appendix 1 summarises briefly related scope 3 emissions.

Scope

When performing sustainability analysis it is common to bound the study to a particular scope. There are three scopes, and they include: (GHG Protocol, 2022)

- Direct emissions
- Emissions from electricity, steam, heat and cooling
- Assets not owned by the organisation (indirect emissions)

The target scope for this report is scope 2 which includes direct power-consumption by the infrastructure of the IC. Included in the report are the nodes for the IC, boundary nodes and regional information for these nodes.

Appendix 1 includes a discussion on scope 3 and embodied emissions for the IC.

Limitations

A number of limitations currently exist for the model that was developed using the methodology outlined below. These primarily relate to the ability to accurately measure certain data, and measure other sets of data with large amounts of granularity. Below, we describe the most prevalent limitations of the model. In the Proposal section strategies are outlined for how to resolve these issues in the future.

Front-end consumption. It is infeasible to measure, without some form of telemetry, the electricity consumption of the frontend applications being served by the IC. For example, the amount of energy required to run or display a website on a mobile phone. Our figure for this is estimated, based on the research of the work of Sustainable Web Design organisation (Sustainable Web Design 2022).

Network usage. The total energy spent by the transfer of data around the geographical distribution on the network is not possible to measure without hard data on the data-throughput of the IC. This is true both for intra-IC communication and to boundary nodes caching query responses, among other data transfers. Due to this, an estimate has been used based on the work of the Sustainable Web Design organisation. Please refer to Appendix 1 for more information on this.

Node power-consumption. We obtained measurements for nodes only in a subset of subnets. By measuring nodes from 17 of 35 subnets, we get an 'average of averages' for node power consumption. This has been used as a baseline power-consumption profile. In addition, an upper and lower bound for power-usage has been included to account for any errors in measurement. Given that hardware specifications are set for nodes (Dell PowerEdge R6525 as of Sept 2022) we assume similarity in the power-profiles of nodes across all subnets.

Electricity grid mix. Grid mixes for specific data centres are unavailable as this information is not publicly available. Therefore we use regional electricity grid mix information (Climatiq, 2022).

Power usage effectiveness (PUE) has been omitted from our methodology. This is primarily due to variations in the results we were able to uncover for data centres. Omitting this can have a varying effect on the final outcome, up to 50% inaccuracy on direct power-consumption (Data Centres Dynamics, 2022). See Appendix 1 for more information.

Measurement

We obtained single node measurements from 17 of the 35 subnets running in the IC, and from that derived an average of averages for the power-consumption of the nodes. This came out to **Ne = 232W.**

We compiled data from the IC dashboard which reports in which region each node is running, this consists of **518 actively running nodes.**

Our emissions factor was initially calculated by averaging the emissions-factor of each region that nodes were operating in (0.34 kg/kWh). **We further refined this to account for the number of nodes running in each region coming to a weighted average of 0.262 kg/kWh.**

Methodology

Our methodology makes use of four variables, listed below.

Metric	Unit
The Geographical distribution of nodes	Nr
Emissions factor for each node’s region	Ef
Per-node energy Consumption	Ne
Weighted emissions factor per region	Nr.Ef.Ne

Methodology (Cont'd)

The nodes per region (Nr) is publicly accessible on the IC dashboard, ie. how many nodes are running in each region.

The emissions-factor (Ef), (the amount of carbon emissions (in kg) measured per kWh of electricity used by the asset) of all operating regions is estimated using the average emissions-factor of that region (Climatiq, 2022).

Per-node energy consumption (Ne) is based on an average of averages (see Limitations for more context) of nodes across 17 separate subnets, then extrapolated out to the entire IC infrastructure.

Worked Example

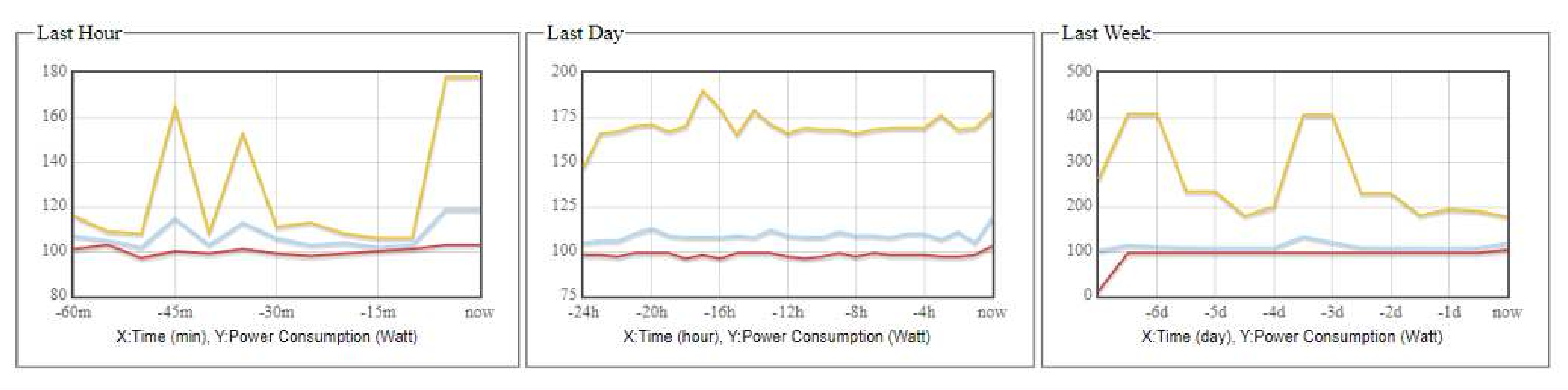
Note that the below node is using 232W (the average node-utilisation we measured), we specify the actual values used in the table below.

Using the 'an1' (Flanders, Belgium) region as an example which has 22 (Nr) nodes with a regional emission-factor of '~0.16' (Ef) kg/kWh. Assuming each node is drawing 0.232kW (Ne), then the total emissions/hour for this region is:

*22 * 0.16 * 0.232 = 0.81664 kg/kWh*
which can then be converted to tCo2e/year;
*(0.81664/1000) * 8760 = 7.154 tCo2e/year*

Power Consumption Graph And History

Power Statistics	Last Hour	Time	Past 24 Hr	Time	Past 7 Days
Average (W)	106	None	109	None	112
Minimum (W)	97	2022/08/15 13:32:14	96	2022/08/15 14:14:31	96
Maximum (W)	178	2022/08/15 14:14:31	190	2022/08/15 14:14:31	96



Above, statistics have been collected on a single operating node. Minimum and maximum readings are used as upper and lower bounds. Metrics were gathered separately over a number of servers and a calculated average over these nodes was used to arrive at 0.232kW (232W). Note that 232W is not present on the figure 1 as this is only a single node.

Table 1: The Total Power Usage

Average Hourly Energy Consumption Per Node (KWh)	0.232
Total no. of nodes - active	518
Total no. of nodes - active & standby	726
Annual consumption of active nodes (kWh)	1,052,741.76
Annual consumption of all nodes (kWh)	1,475,464.32

A differentiation is made between active and standby nodes to provide two different results. The first is the energy-consumption of the IC for the 'compute' that is currently being provided. The second includes the standby nodes that are consuming electricity, but which have not yet been assigned to a subnet, and therefore are not directly contributing to the blockchain. The reason for the first measurement is to allow a more representative comparison between the Internet Computer and similar blockchains.

Using data pulled from the Internet Computer dashboard, it is possible to find the region of all the nodes running on the IC. This is then correlated with the average emissions-data for the corresponding region to calculate an estimated emission for each node. The effective emissions-factor returned is 0.26 for the regions where the IC runs nodes.

Table 2: Emissions Factor And Associated Carbon Footprints

Average emissions-factor (kg/kWh)	0.262
Total - active nodes (tCo2e/yr)	275.34
Total - active + standby nodes (tCo2e/yr)	416.28

Figure 2 below represents the total direct emissions of the 'active' nodes. That is, only the nodes actively contributing to the functioning of the IC (518 as of this measurement). Figure 3 is the same calculation, but includes both the 'active' and 'standby' nodes. This includes an additional 208 nodes that are not included in the comparisons in Figure 2 due to them not actively contributing to the running of the IC.

Figure 2: Total Active Node Emissions

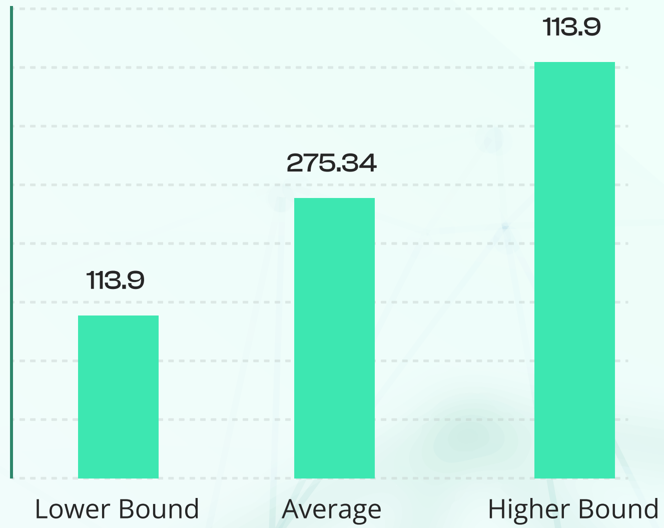
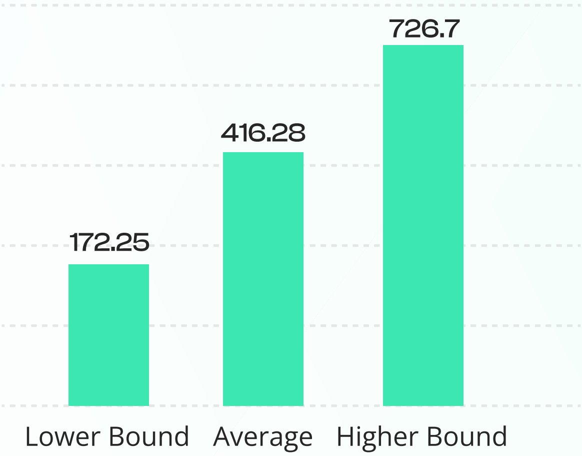


Figure 3: Total Active + Standby Node Emissions



Using the above data, the total emissions of the IC were compared to other blockchains.

The current industry standard for blockchain comparisons is energy-usage per transaction. The current transaction rate from the internet-computer dashboard was used, which was represented as 5,700 TX/s. Table 3 below represents the energy consumption of each transaction on the IC. Figure 5 provides a comparison (CCRI, 2022).

Table 3: Energy-Consumption Per Transaction On The IC

Active network (Wh/tx)	0.0058565302
Active + standby network (Wh/tx)	0.0082081871

Figure 4: A Comparison Of The Energy Consumption Per Transaction Between Blockchains

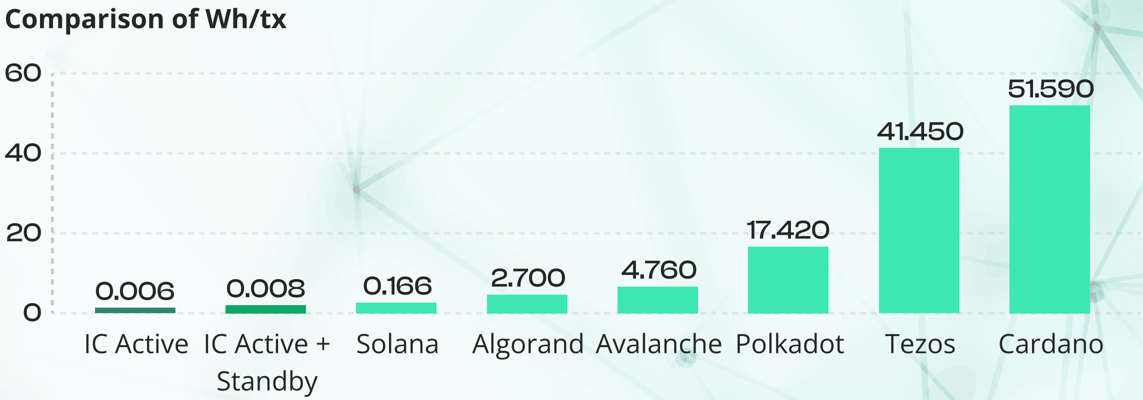
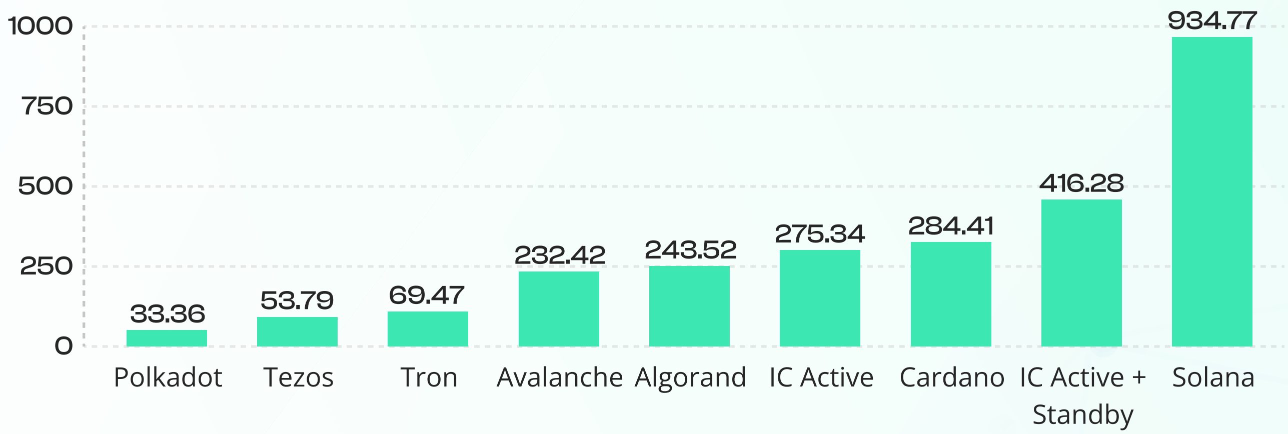


Figure 4 clearly illustrates that the energy-usage per transaction on the IC is low when compared to other blockchains. Note that no distinction is made between update and query calls in this comparison. A more in-depth study is required to discover the call-profile of each call type for a more accurate estimation. We suspect that as query calls need only be executed on a single node, there is a large savings on mitigation of redundant compute.

Figure 5: Comparison Of Carbon Consumption Between Blockchains



Comparison of Carbon Consumption

Note that the above comparison does not take into account the relative sizes between blockchains, nor additional scalability or efficiency tools, and should be treated accordingly.

Future Projections

DFINITY plans to start onboarding additional nodes into the IC underlying infrastructure early next year which will impact the total emissions of the IC. We estimate that each additional node added to the IC will produce in the range of 0.2-0.9tCo2e/year based on the region these nodes are deployed into (exclusive of scope 3). This is clearly a large range, and can be fairly easily optimised towards more efficient data-centres without much difficulty.

Near Term Projections

The current status of the IC shows that while 518 nodes are active, another ~800 are awaiting onboarding into subnets. By the end of 2022, the IC intends to be running 1090 nodes (DFINITY forum, 2022) of which ~30% will be standby nodes. If this projection is realised, we estimate the carbon emissions to increase to between 242 and 1023 tCo2e per year. As the IC scales via adding subnets, the energy cost per node will remain quite stable. As such, a core focus should be on improving node efficiency to improve the output from a single node.

Longer Term Projections

Blockchains aim to power web3, so it's important to study how they fare in the larger tech industry. Two cornerstone organisations supporting web2 are Cloudflare and Amazon who have carbon footprints of 14k and 5.27m respectively in 2020. Capturing 1% of these markets requires blockchains to have less than 140 - 52,700 tCo2e/year.
Running 10,000 IC nodes yielding 110,000 transactions per second would cost 2224 to 9387 tCo2e/year. Achieving this capacity would be 15 times greater than the existing Visa network. It is not unfathomable that the IC, and the blockchain industry, can compete with big tech, so it's imperative that sustainability policies are set accordingly.

Proposals

1. Proposal to develop **real-time measurements** of the IC's energy consumption and associates carbon footprint

Proposals

- Implement real-time measurement of IC's energy consumption for each active and standby node in the network
- Generate a real-time associated carbon footprint for each active and standby node in the network
- Add real-time energy consumption and carbon footprint reporting to the publicly available dashboards
  - Aggregates may need to be used for security purposes
- Prepare reporting to comply with the EU Corporate Sustainability Reporting Directive (CSRD), even if only voluntarily and not a regulatory requirement.

Motivation

It is technically feasible to produce real-time energy consumption and emissions data for the entire network. Given that we know where each of these nodes is running, it is then possible to produce an associated carbon footprint using a codified version of the above methodology, plus real-time energy grid-mix data.

The IC should implement both of these metrics onto the publicly available dashboard in order to:

- give a transparent view into the network's energy consumption carbon footprint on a day-to-day basis
- help the community understand the cumulative effect of carbon emissions over time
- improve the traceability and accountability of future efforts to decarbonise the IC

Further, it is more likely than not that the Corporate Sustainability Reporting Directive (CSRD) will have implications for the Internet Computer and/or Dfinity foundation. Determining exactly how they will be impacted is beyond the scope of this report. It is, however, in the interest of the IC to improve their environmental reporting ahead of these changes to reduce regulatory risk. The first set of standards are set to be adopted in October 2022, highlighting the urgency of understanding the requirements for the ICs sustainability reporting (European Commission, 2020).

Proposals (Cont'd)

2. Proposal to **develop a fully decarbonised subnet** on the Internet Computer

Proposals

- Develop a fully decarbonised subnet by running an entire subnet's nodes entirely on renewable energy

Motivation

The clearest and most impactful way for the IC to reduce its ongoing environmental impact is to run all its nodes in data centres that are powered by renewable energy. A phased approach should be taken to achieve this, given the scale of the task. As a first step, the IC should implement a single subnet that runs entirely with nodes that consume renewable energy. Once this 'proof of concept' is completed, the feasibility of moving the entire networks to zero emission subnets can be explored. Both technical and economic factors need to be considered, among others.

Further, the IC plans to introduce the capability to select the subnets that computations occur on. Once successfully implemented, users could select to run on the decarbonised subnets. This will allow projects and businesses, whether motivated by regulatory reasons or otherwise, to make use of all the IC capabilities without compromising on their ESG objectives, and perhaps even surpassing them.

Taken together with increased environmental regulation from the EU, such as the upcoming CSRD, developing a zero emission subnet will prepare the IC for developing strategies to satisfy future, as yet unknown, regulatory obligations.

3. Proposal for a dedicated resource to **establish a sustainability leadership group** to champion sustainability initiatives within the IC

Proposals

- Create a dedicated working group to propose, plan, implement and report on progress for decarbonisation and other sustainability related activities on the IC
- Ensure a role for Dfinity and the IC community within the working group
- Assign a budget to incentivise the working group and maintain its operations

Motivation

There is a clear business case for the development of a more sustainability focused blockchain. Climate tech startups have suffered less with regards to raising funds than other industries in the recent economic downturn, and are more likely to choose the IC as their network of choice if it leads by example. Consumers are increasingly conscious of environmental sustainability when choosing which goods and services to purchase, and employees show the same preferences when deciding where to work. Developing a thriving, genuine and effective sustainability techstack and culture within the IC would be good for the IC community, IC investors and the planet.

Proposal (Cont'd)

Motivation (Cont'd)

It is unrealistic to believe this kind of activity will occur without some form of incentivisation and ongoing support. Accurately measuring emissions, redesigning systems to be more energy efficient, replacing hardware and encouraging sustainability conscious people to create their projects on the IC will require resources. The strategy developed should include a role for both Dfinity itself (due to their extensive knowledge of the IC) and the IC community more broadly. In this way, efforts to propose, plan, implement and report on progress towards decarbonisation and other environmentally conscious activities will have a higher chance of success.

4. Proposal to **offset carbon debt of the IC** to bring the network to carbon neutrality

Proposals

- Use direct air capture (DAC) or high-quality nature based carbon credits with provable additionality and high chance of permanence to offset the carbon footprint of the IC, including its carbon debt

Motivation

Offsetting the carbon debt of the IC would bring the IC to carbon neutrality, and compensate for past emissions. Although offsetting emissions is not a long term strategy for climate action, it is a valid method for compensating unavoidable emissions that have already been released. This proposal suggests offsetting the carbon footprint of the IC, including its carbon debt, as a starting point in its journey towards sustainability. Bringing the IC to climate neutrality is the first step in developing a more sustainability focused blockchain, and this report can be used to determine the size of the commitment needed.

The choice of credits used in any offsetting operations is incredibly important. The single most effective method, with regards to both additionality and permanence of removal, is DAC. This technology removes carbon directly from the atmosphere and stores it in rocks, concrete, or other durable materials. In this way, events such as forest fires or illegal logging which can impact the permanence of nature based carbon removals can be avoided.

To be sure, there is an important place for nature based carbon removals, or avoidance in which land that would be cleared of trees is protected. The additional benefits of habitat and biodiversity restoration from nature based solutions should not be understated. Further, they are generally more affordable than the limited credits produced by the nascent DAC industry. Whichever method used, the choice of credits should be heavily scrutinised.

5. Tackle low-hanging-fruit to **immediately reduce the carbon intensity** of the IC network

Proposals

- Immediately replace the highest intensity nodes with lower intensity nodes that are currently on standby

Motivation

Very simply, by immediately replacing the 28 nodes with the highest carbon intensity with the lowest nodes on standby, the emissions of the IC could be reduced by up to 9%. This should be done immediately.

Moonshot Proposals 🚀

Dynamic Cycle Costs Incorporating Real-Time Emission Costs

Incorporate real-time emissions-data for each subnet running on the IC. Each subnet should then have different cycle-costs which incorporate the emissions used. There should be a queryable contract which provides forecast emission-factors for the next 24 hours (allowing scheduling of batch-jobs). This should be the first step towards developing the tools for the community to incorporate environmental decisions into their projects.

Smart Query Routing

Prioritise routing query traffic (which doesn't require full compute-replication) to less carbon-intensive nodes/regions. This can be done with the boundary-node routing logic taking into account the emission-factors of each node in a subnet.

Smart Contract Accountability Tracking

By tracking cycle burn-rates for all contracts, it is possible to directly approach the highest-impact projects and work to reduce their carbon footprint. This information can be publicly tracked and available to promote transparency and accountability within the ecosystem.

Incremental Sustainability Report And Overview

Incorporate an incremental sustainability report, with a yearly 'checkpoint' report to measure and assess progress towards decarbonisation.

Conclusion

The IC is an energy-efficient network, yet still has a substantial emissions footprint that will continue to grow alongside adoption. During a single year, the IC was calculated to consume ~740,000 kWh of energy and emit 275 tonnes of carbon dioxide. That is roughly equivalent to 100 average US homes.

There is a strong business case to be made alongside ethical arguments for the IC to increase the scope of its decarbonisation and broader sustainability activities. A number of initiatives, of various sizes and complexity, can be implemented to begin reducing the carbon intensity of the IC network. This report has packaged what it views as the most important and feasible as proposals which can be submitted by the IC community, or directly acted on by Dfinity. It has further outlined a number of 'moonshot proposals', that would be more difficult to implement but would further contribute to decarbonisation efforts.

Growing urgency for environmental accountability across the world, both from governments and people, will increase pressure for institutions to develop and execute on sustainability strategies. The IC should act now to avoid being caught off-guard by regulation, and steer the narrative of the high energy intensity of blockchains. The unique capabilities of the IC blockchain, as well as the high level of expertise and willingness to contribute both within DFINITY and the IC community more broadly, mean that all the ingredients for effecting deep, positive change are present.

The report above provides a snapshot of the sustainability profile of the IC blockchain. This is the first step in a journey towards decarbonisation for the IC, but also for other blockchains that realise the importance of acknowledging, and reducing any negative externalities of their operations.

Appendix

Appendix 1

Carbon Crowd built this methodology with the aim of capturing not only the direct emissions of the IC blockchain, but a more holistic overview of the ICs emission-profile. For this we include the emission-cost of manufacturing the servers, disposal costs, data-transfer overheads and end-user electricity consumption. There are several prior research publications that explore this topic in more detail which we leverage in our model (Sustainable Web Design, 2022).

When we began comparing our data with similar reports on blockchains we didn't want to provide an inaccurate image of the IC. Specifically, other reports we reviewed only included direct emissions of the nodes responsible for blockchain operations. This report was scoped to the same parameters as these other publications to provide a baseline for comparison. We don't believe this is the full story though, so have published our final results (figures 6 and 7) of our estimate of the total emissions of the IC.

We want the IC (and blockchains as a whole) to fully own their entire emissions-footprint, and providing a holistic overview of the entire emissions-profile for the underlying infrastructure is a critical step.

We don't include the PUE in the main body of the report, but wish to address the complexity in measuring this. For this report we were not able to determine the exact data-centres running each of the nodes so were unable to get an accurate PUE estimate. The PUE for data-centres can range from 1.02-1.50 depending highly on the region and age of the data-centre. This opens the possibility of a large margin of error which we need and want to account for in our model. It should be noted that similar reports on blockchains also don't account for PUE, even when measuring direct power-consumption of target nodes.

Network Boundaries

Segment Name	Segment % Breakdown
Consumer device emissions	52
Network emissions	14
Data centre emissions	15
Production emissions	19

Appendix 1 (Cont'd)

This breakdown is derived from a meta-study (Sustainable Web Design, 2022) of several different research initiatives calculating emissions from web services. This accounts, at least more accurately, for the entire 'lifecycle' of the emissions generated when computation is done at a given data centre. This is, to a degree, open to interpretation as some parties will include the materials and manufacturing used to produce the data centre/ cables/chips etc or "embodied emissions" in the calculation of emissions from data centre 'compute' whilst others will not.

Consumer device use: end users interacting with a product or service. This accounts for an estimated 52% of the system. Returning visitors are assumed to be 25%, loading 2% of data (due to caching). Caching metrics were not gathered, so we assume no caching.

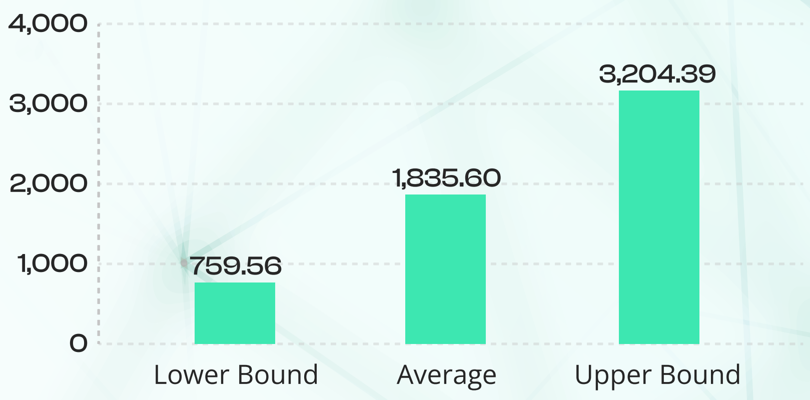
Network use: data transferred across the network. This accounts for an estimated 14% of the system.

Data centre use: energy required to house and serve data. This accounts for an estimated 15% of the system.

Hardware production: embodied energy used in the creation of embedded chips, use of data centres, use of networks, and the use of consumer communication devices. This accounts for an estimated 19% of the system.

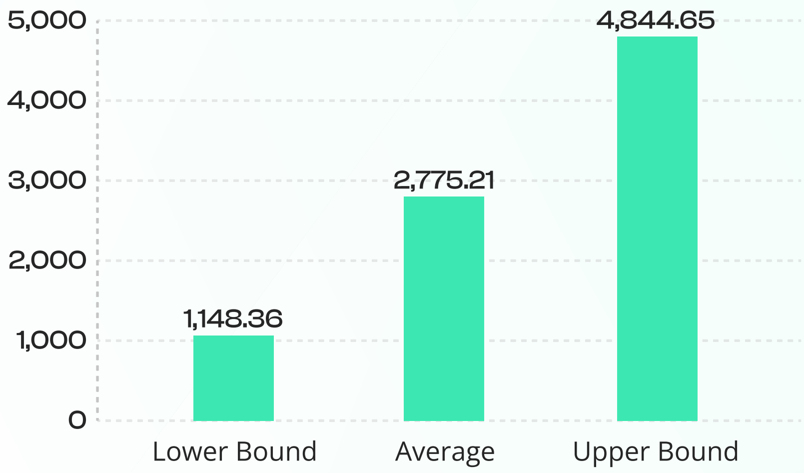
The results can be seen below, with an estimated 85% (Sustainable Web Design, 2022) increase in emissions that can be accounted for beyond the direct (Scope 2) emissions. Scope 3 includes emissions from the hardware manufacturing "embodied" process, data-transfer and end-user activities. Including accurate data on these processes is challenging and requires an extensive audit, we hope to include Scope 3 emissions in future reports. For the above reasons, the Scope 3 predictions have a wider margin for error, and should not be considered as high fidelity data as the included Scope 2 calculations.

Figure 6: Scope 3 Tonnes Of Co2 Emitted Per Year



Appendix 1 (Cont'd)

Figure 7: Scope 3 Tonnes Co2 Emitted Per Year (Incl. Standby)



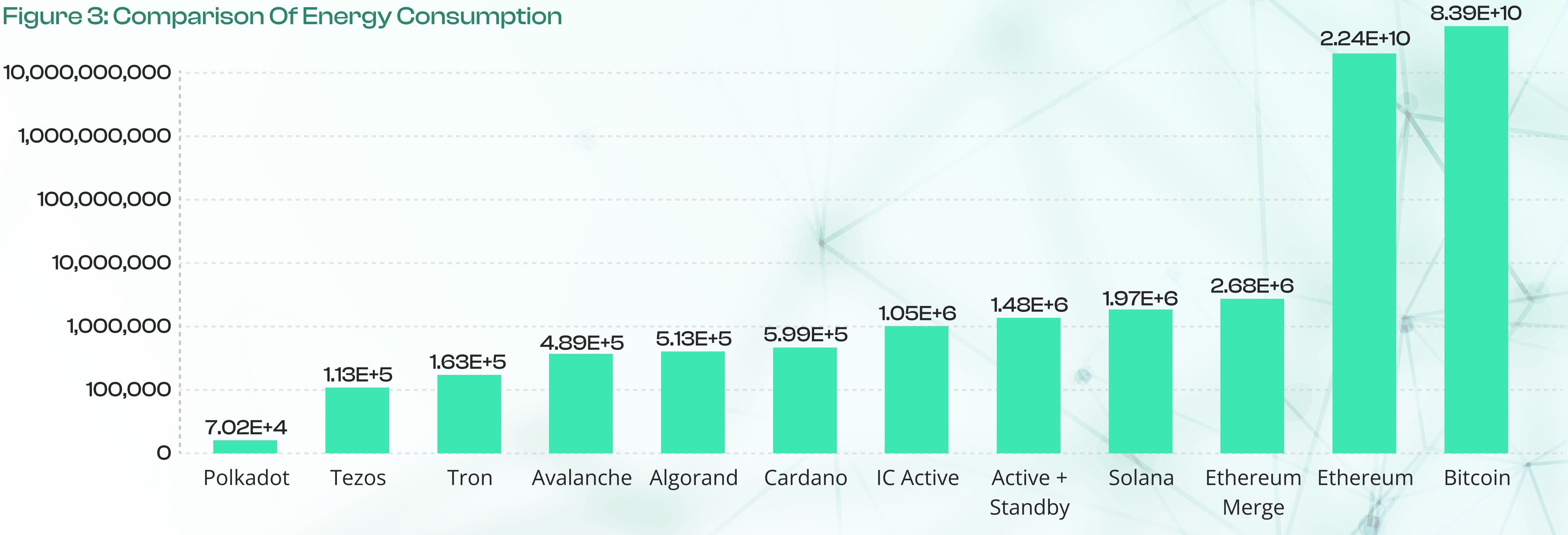
Appendix 2

Below is a comparison of the IC's power-consumption in the context of other blockchains. Note that these comparative numbers come from the report compiled for the Tron blockchain by the CCRI (CCRI Tron, 2022), all the same disclaimers apply.
We deliberately do not include this in our main body as this does not take into account the market-adoption, size, or capacity of each blockchain. As an example, the IC acts as a full-stack technology solution, meaning that storage, security, communication, and computation are built directly into the system. In the case of all other systems, the carbon cost of 3rd party solutions are not accounted for. A fair comparison would see further study accounting for the carbon cost of storage (e.g. IPFS or AWS), security (firewalls), communication (e.g. Moralis or Infura) and computation (layer 2 solutions) in addition to the cost of running the underlying chain.

Looking at these graphs, we need to keep in mind that the IC is running most of their servers in datacenters on enterprise hardware. These machines tend to consume more than a consumer device due to built-in redundancies. Additionally, from load-testing, the infrastructure is currently running at around 50% capacity (DFINITY medium 2022), so we can expect utilisation to improve.

Ethereum Merge is based on the 99.988% figure from CCRI.
The above calculations only relate to the direct power consumption of the nodes themselves running the IC.

Figure 3: Comparison Of Energy Consumption



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