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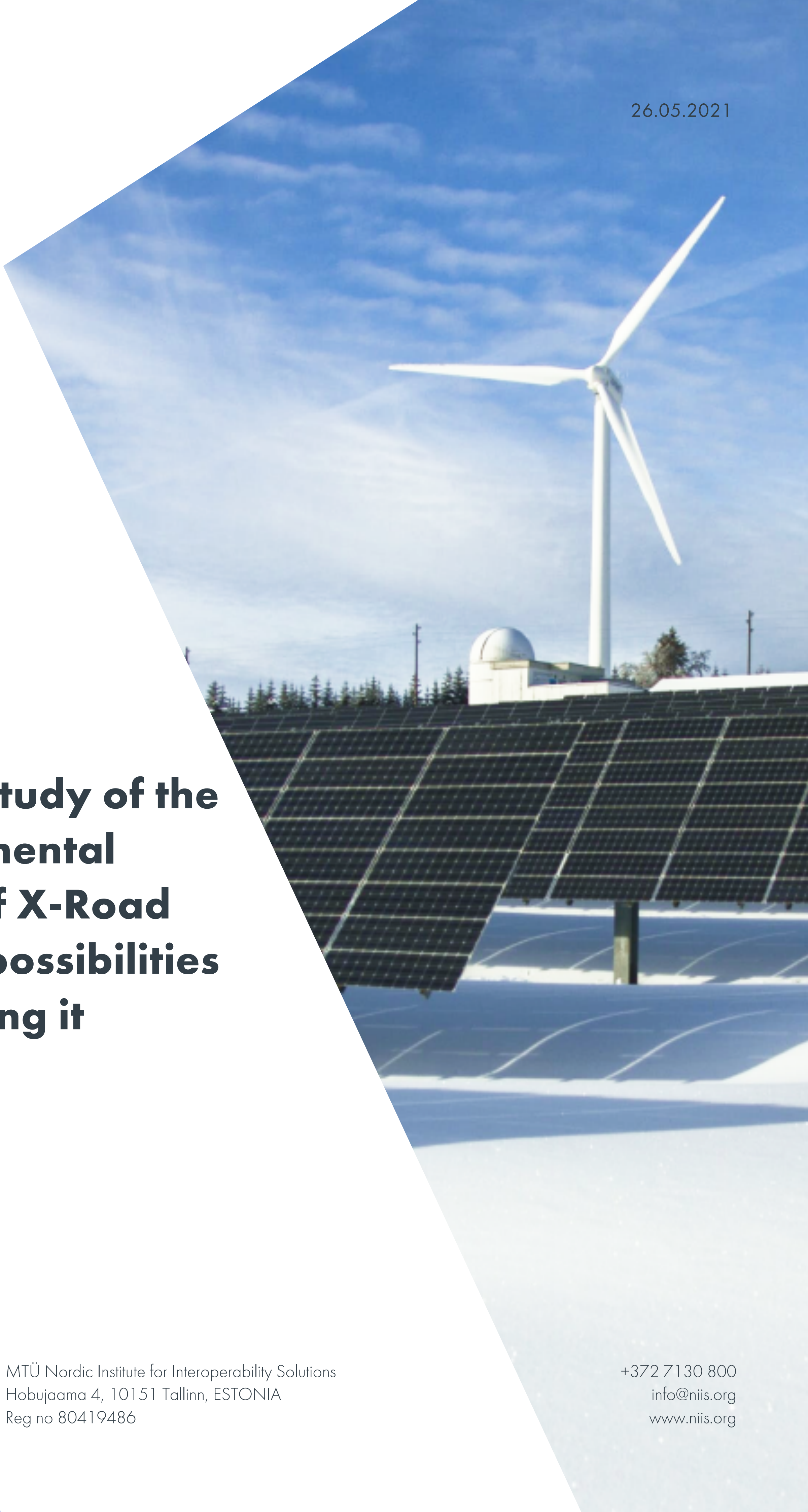

Report: study of the environmental impact of X-Road and the possibilities of reducing it

Public Report

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Table of contents

Terms and Abbreviations

Carbon dioxide equivalent[1]: Carbon dioxide equivalent (CO2eq) stands for a unit based on the global warming potential (GWP) of different greenhouse gases. The CO2eq unit measures the environmental impact of one tonne of these greenhouse gases in comparison to the impact of one tonne of CO2.

Carbon emissions: The carbon dioxide released into the atmosphere, largely when fossil fuels are burned.

Carbon footprint[2]: The total amount of greenhouse gases (including carbon dioxide and methane) that are generated by our actions.

Carbon neutral: Net zero carbon emissions by balancing emissions with removal.

Cloud computing[3]: The on-demand availability of computer system resources, especially data storage (cloud storage) and computing power, without direct active management by the user.

Device power consumption: The power consumed by a device.

Device utilization: The actual load a device handles relative to the peak load the device can handle. It is expressed as a percentage.

DVV (Digi- ja väestötietovirasto, Finnish Digital Agency): Governing authority of Finnish X-Road instance.

Electricity carbon intensity: The emission rate of the electricity generation mixes which is dependent on the region.

Energy efficiency: The usage of less energy to achieve the same level of activity.

Energy rating[4]: An energy rating is simply a way of measuring and showing how energy efficient an appliance is, according to how much energy it consumes.

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[1] https://climatepolicyinfohub.eu/glossary/co2eq

[2] https://www.nature.org/en-us/get-involved/how-to-help/carbon-footprint-calculator/#:~:text=A%20carbon%20footprint%20is%20the,highest%20rates%20in%20the%20world.

[3] https://ieeexplore.ieee.org/document/9044834

[4] https://www.ovoenergy.com/guides/energy-guides/a-guide-to-energy-saving-white-goods.html#:~:text=What%20is%20an%20energy%20rating,how%20much%20energy%20it%20consumes.

Equipment specifications[5]: The specifications of servers, storage equipment, and networking devices used for the analysis. This includes number of cores, processor power, storage capacity, and power draw at different utilizations.

Information systems: The Information System produces and/or consumes services via X-Road and is owned by an X-Road member. For a service consumer Information System, the Security Server acts as an entry point to all the X-Road services. A service provider Information System implements a REST and/or SOAP service and makes it available over the X-Road.

NIIS (Nordic Institute for Interoperability Solutions): Organisation that ensures the development and strategic management of X-Road and other components for E-government infrastructure.

Once-Only Principle[6]: Agreement that allows public administrations in Europe to reuse, or share, data and documents that people have already supplied, in a transparent and secure way.

Power use effectiveness (PUE)[7]: The ratio of total amount of energy used by a computer data centre facility to the energy delivered to computing equipment. PUE is the inverse of data centre infrastructure efficiency.

RIA (Riigi Infosüsteemi Amet, Estonian Information System Authority): Governing authority of Estonian X-Road instance.

Server virtualization[8]: A process that creates and abstracts multiple virtual instances on a single server.

Storage area network (SAN): A type of dedicated network for data storage based on interconnected storage devices.

X-Road[9]: X-Road is an open-source software and ecosystem solution that provides unified and secure data exchange between organisations. The basic idea of X-Road is that members of an ecosystem exchange data through access points (Security Servers).

X-Road Central Server[10]: Contains the registry of X-Road members and their Security Servers. Besides, the Central Server contains the security policy of the X-Road instance that includes a list of trusted certification authorities, a list of trusted time-stamping authorities, and configuration parameters.

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[5] https://www.microsoft.com/en-us/download/details.aspx?id=56950
[6] https://ec.europa.eu/cefdigital/wiki/display/CEFDIGITAL/Once+Only+Principle
[7] https://searchdatacenter.techtarget.com/definition/power-usage-effectiveness-PUE
[8] https://searchservervirtualization.techtarget.com/definition/server-virtualization#:~:text=Server%20virtualization%20is%20a%20process,instances%20on%20a%20single%20server.&text=Server%20virtualization%20also%20masks%20server,servers%2C%20processors%20and%20operating%20systems
[9] https://x-road.global/
[10] https://x-road.global/architecture

X-Road governing authority[11]: Authority, that sets the requirements for using X-Road and establishing the procedure for using X-Road, managing, and regulating participants of X-Road.

X-Road instance[12]: A legal, organizational, and technical environment, enabling universal internet-based secure data exchange between the members of X-Road and limited to the participants administered by one governing authority.

X-Road member[13]: Participant of X-Road entitled to exchange data/messages on X-Road.

X-Road operational monitoring[14]: Technical solution that allows to collect and review information about data exchange of the Security Server such as which services have been called, how many times, what was the size of the response, etc.).

X-Road Security Server[15]: The Security Server mediates service calls and service responses between information systems.

[11] https://www.x-tee.ee/docs/live/xroad/terms_x-road_docs.html#2-participants-of-x-road
[12] https://www.x-tee.ee/docs/live/xroad/terms_x-road_docs.html
[13] https://www.x-tee.ee/docs/live/xroad/terms_x-road_docs.html#2-participants-of-x-road
[14] https://www.x-tee.ee/docs/live/xroad/pr-opmon_x-road_operational_monitoring_protocol.html
[15] https://x-road.global/architecture

Introduction

Nordic Institute for Interoperability Solutions (NIIS) has set a long-term goal to make X-Road the most sustainable data exchange solution in the world. The short-term goal is to focus on the direct and tangible environmental impacts of the X-Road software. X-Road is an open-source software and ecosystem solution that provides unified and secure data exchange between X-Road members.

The purpose of this research is to assess the current emissions profile across X-Road's operations and services to give targeted recommendations for emissions reduction and sustainable business practices that may be integrated into future decision making.

The first chapter highlights the main causes of environmental impacts by an X-Road instance and explains the use-cases that were selected for a more detailed evaluation. The key function of X-Road is to provide secure data exchange between X-Road members over the public internet. Therefore, the carbon footprint is calculated for the 1) energy consumption by the infrastructure used by members, 2) data exchange and 3) data storage for most common X-Road use-cases in Estonia and Finland.

The second chapter takes a deeper look into carbon footprint evaluation for the selected use-cases and discusses the calculation tool that was developed to estimate the total carbon emissions of an X-Road instance (without life cycle assessment calculations).

The third chapter gives recommendations and KPIs (to NIIS, governing authorities, X-Road members) for improving sustainability in all X-Road related operations, drawing from the calculator outputs as well as interviews from industry experts. Additionally, to report the outcome for the work is a simplified X-Road carbon footprint calculator tool, that can be used for easy evaluation for the whole X-Road instance or for a single Security Server.

The project team is a combination of the sectoral experience provided by Gofore and academic competence provided by Stockholm Environment Institute Tallinn (SEI). Gofore's experts have experience with X-Road core development processes, X-Road implementations, and X-Road service developments. Gofore is developing a methodology, metrics and toolkit that enables organisations to embed sustainability into everyday work and in parallel embrace Good Growth as a focus for strategy and innovation. SEI Tallinn is a national office of a SEI global, a leading sustainability think tank ranked #1 globally in the environmental field by Uni Penn ranking. The experts of SEI Tallinn have considerable experience in building and socializing climate and energy policy scenarios, carbon footprint calculations and life-cycle impact assessments.

1. Environmental impacts of X-Road instance

1.1. Indirect impacts of X-Road

Our experts mapped the environmental impacts of X-Road instance. Impacts that are not caused by using X-Road's services are not in the scope of this study. It is important to note that X-Road might have positive indirect impacts on subsystems and these hypotheses are explained in Table 1.

Table 1. Environmental impacts related to X-Road, but not caused by X-Road

Subsystem	Description	Equipment examples that require emissions measurement	Indirect impacts of X-Road
Data centres	Building housing servers used to carry out a large variety of functions (e.g., e-mail, financial transactions, social media, etc.) and data storage. Data centers often require air conditioning units, power supply units, and other technologies to support these computer systems. Servers within data centers can be considered as end devices, which provide services accessed via the Internet.	Servers, storage equipment, power and cooling equipment, etc, energy footprint of a Security Server and data usage	Potentially positive impact. X-Road allows access to data that remains to be distributed after the transaction. That might decrease the need for additional data centers.
IP core network	Internet Service Provider (ISP) equipment which form regional, national, and global networks. This typically includes equipment that uses Internet Protocol (IP), the principal communications protocol which allows for the routing and relaying of data across networks	IP core/metro/edge switches and routers, transmission link elements (copper, fiber optic, etc.), and supporting infrastructure for cooling, power, etc.	Potentially positive impact. X-Road works on public internet and therefore avoids the need for building secure lines.
On site networking device	Customer Premise Equipment (CPE), equipment used to access the Internet and provides a link to the user's edge device, based on the customer's premise (e.g., in the home or office building). Often used to maintain a constant on-demand connection. Home/on-site networking equipment can also form a Local Area Network (LAN)	Routers Modems etc	Irrelevant, because the access to public internet will not be set up because of X-Road
User device	Hardware needed to draw functionality from internet	Laptops, ipads, consoles etc.	Irrelevant, because X-Road is a machine-to-machine solution
Energy security infrastructure	Equipment to ensure energy supply consistency and prevent surges.	Generators, power surge hardware	Irrelevant, because X-Road Security Server does not require higher level SLA than the integrated information systems

Using X-Road paves the way for better security with less infrastructure (e.g., data centers, IP core network etc.) – especially when X-Road is implemented together with the Once-Only Principle. In that case, X-Road is an enabler for less infrastructure that will result in reduced environmental impacts. Still, without changes in existing patterns of how data is managed and stored, X-Road only causes additional infrastructure to be deployed. X-Road's capability to provide high security services for data exchange on public internet makes it quite suitable and sustainable solution for stakeholders.

1.2. Direct impacts of secure data transaction

Secure data transaction between two X-Road members is depicted in the following figure.

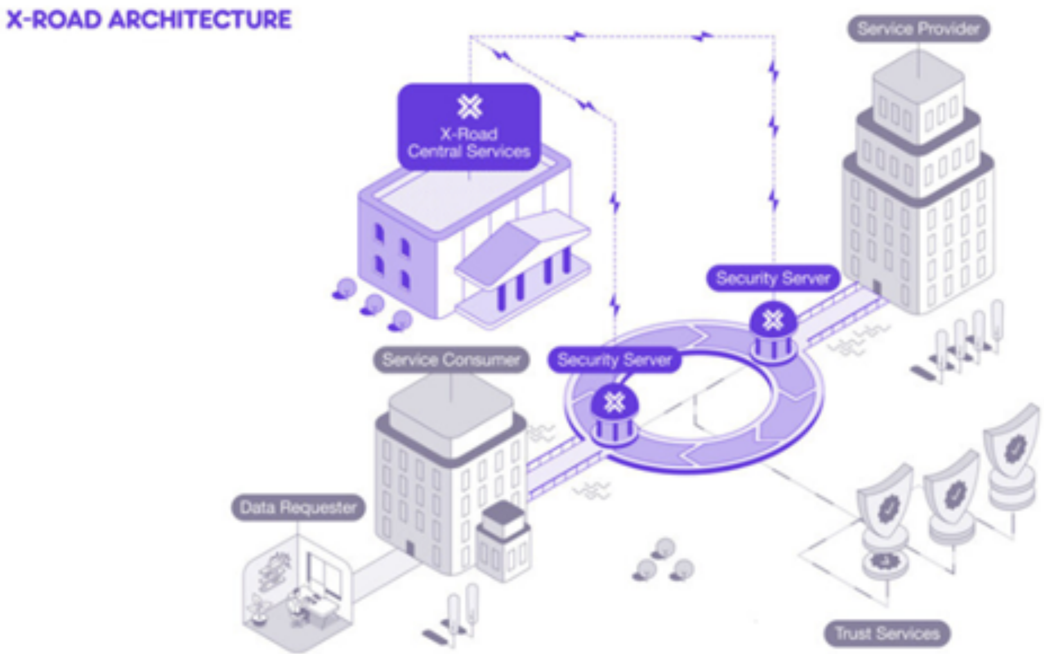

Figure 1. X-Road architecture

The main infrastructural components for secure data transaction are:

1. Central Services provided by Central Server
2. Security Servers that interact during data exchange transaction

Data exchange primarily happens between Security Servers of a service provider and service consumer, where different X-Road services are used. The Central Server provides the registry of X-Road members, security policy and a list of trusted certification authorities and other important parameters but however, it does not have an active role in the data exchange process. The certification authority issues authentication and sign certificates which makes the data transaction secure and Information systems owned by members (consumer/provider information system) allow for consuming and producing messaging and other services. Central Server is not considered in the environment footprint calculations as its impact is quite minor. Information systems and certification authorities that provide trust services are also not included in the footprint calculations mainly because X-Road utilizes them as services while having no direct impact.

The key operation considered for carbon footprint calculations is the exchange of messages and services between two X-Road members over the Security Servers. Relevant environmental impacts of an X-Road instance can roughly be described in the following categories:

- Lifecycle of the components used by infrastructures that allow X-Road's operations
    - Infrastructure for running a Security Server that can be on premises or in public cloud.
    - Physical device that might be necessary for holding the certificates that assure the identification of the members.
- Energy consumption of the Security Server infrastructure used by X-Road members or governing authorities.
- Energy consumption in addition for exchanging messages/ using X-Road services.

The analysis of the life cycle of different components is not a part of current study. However, recommendation for best practices will be provided. A detailed analysis of X-Road's infrastructure will pave way to identify crucial areas where effective recommendations can be given. This will be covered in chapter 3. Environmentally friendly options must be always considered side-by-side with security requirements. The software provider (NIIS) can widen the options by building support for more use-cases. For example, in last years the support of cloud native services have been improved. At the same time, some security requirements might be set by X-Road governing authority which might result in a limited number of options for X-Road members.

1.3. Use cases for X-Road carbon footprint calculation

In order quantify and compare the impact of X-Road's operations, different use cases need to be considered. Building on the experiences of Estonia and Finland (Table 1**Error! Reference source not found.**), we plan to showcase the changes to carbon footprint calculations when change in the following parameters are considered:

- Infrastructure level
  - server used: infrastructure on-premises VS on public cloud.
  - trust level: physical signing device is required.
- Service level:
  - data load/size of the message across different services.
  - message log requirements (metadata or whole message).

Table 2. Overview of X-Road reference architecture in Estonia and Finland

		Estonia	Finland
Infrastructure level	Server	173	290
Service level	Message log requirements	Full message	Message meta-data only

The first infrastructure level use case will directly quantify and compare the emissions of X-Road's operations with physical infrastructure on premises vs when using public cloud. All related emissions will be calculated, and a detailed comparison will be made to see the differences between impacts in both scenarios.

For the second type of use case where service levels are only considered, different services will be considered with different level of data use. A map of emissions related to each service will highlight the contrast of every service in X-Road's operations. Ultimately a message log requirement is another variation of the service level that will be considered.

1.4. Methodology for emission models

The proposed methodology closely follows the conceptual description of CLEER, an online carbon calculator. CLEER was specifically designed for quantifying energy and emissions savings resulting from the migration of localised data services onto the public cloud. The full CLEER methodology, which is published and verifiable, is composed of 13 distinct modules covering different possible sources of emission. Two of these, namely those detailing the data centre operational emissions and those associated with data transfer, have respectively been identified as the most important within the emissions boundary of the current project. It is noted that the calculation framework is independent of data centre type, ensuring that a consistent framework can be applied in all use cases. Moreover, all variables within the model come with pre-defined values that can be used as default in case of limited data variability.

1.4.1. DATA CENTRE OPERATIONAL USE

As defined within CLEER there are 9 different hardware components. This includes 5 different IT types of devices (server types, HDD storage – k = 1-5) and 4 different infrastructure types (lighting, cooling, etc., k= 6-9) that are considered. Infrastructure components can also be replaced by a centre wide PUE (power usage effectiveness) value. Moreover, additional hardware components of relevance can be included in the methodology if the average power use of the device is known.

Stage 1: determination of direct energy use by device

Within CLEER the operational energy use for a given IT device, k, within facility, j, is defined as:

Equation 1

$$e_{jk} = N_{jk} W_{jk} h_{jk}$$

Where e_{jk} is the direct device energy use, N_{jk} is the number of devices, W_{jk} is the average power use of device and h_{jk} is the annual operating hours of the device

Extension

Should the power use per device not be known, it can be estimated from the standardised database SPECpower_ssj2008. Here, the power consumption is described whilst idle (Devices such as servers also consume a non-negligible proportion of power while idle) and at full utilisation. A linear extrapolation can be performed to determine the power use at a certain utilisation (typical values are 5-10 % for a small data centre ~40 - 50 % for a large cloud vendor). The reduced power consumption associated with higher utilisation can be leveraged by reducing the number of devices included in the calculation (e.g. increasing the utilisation from 10 to 40 % would reduce the number of servers by a factor of 4).

Stage 2: Total energy use by data centre

The sum of device energy use is then multiplied by the infrastructure energy use as defined below for a single data centre, or server closet:

Equation 2

$$E_{operations,j} = (1 + \sum_{K=6-9} e_{jk})(\sum_{K=1-5} e_{jk}) = PUE(\sum_{K=1-5} e_{jk})$$

The first term in brackets is the PUE. This defines the ratio of electricity required by the data centre to the amount used by the relevant IT devices. Values can range between ~2.5 for a single server (e.g., only 40 % of electricity is actually used by the IT equipment) to ~1.1 for large cloud-based data centres (Google average 1.09).

The carbon emissions are determined by multiplying the energy for the data centre, Ej, by a location-specific emissions factor Gj to determine the annual emissions.

Stage 3: Conversion to carbon emissions in tonnes of CO2e (CO2 equivalent)

Equation 1

$$Emissions_{operations,l} = E_j G_j$$

The emissions per instance are then determined by dividing the annual emissions by the number of instances per year.

1.4.2. NETWORK SYSTEMS OPERATIONAL ENERGY USE

Given the complexity involved in calculating the exact network segments involved in data transfer, it is suggested to use a simplified approach based on average values. An average value often used as standard (Aslan et al, 2017) determined the energy intensity for fixed line data transmission, Te, of 0.06 kWh/GB in 2015[16]. As discussed in the same document,

[16] https://onlinelibrary.wiley.com/doi/pdf/10.1111/jiec.12630

efficiency gains would put the current value of Te as 0.0075 kWh/GB. Hence, the energy expenditure associated with an X-Road data transfer, q, of size Dq shall be calculated as:

Equation 2

$$Emissions_{transfer,i} = T_e D_q G$$

Here G is the emissions factor for electricity generation for the relevant country (Estonia or Finland). In cases of data transfer, between Estonia and Finland, an average value shall be used.

This chapter incorporated, which aspects are crucial and what is not in the scope. A list of abbreviations has been included to provide background information about the analysis that is explained in the latter part of this chapter. After highlighting the subsystems that are not considered, the study proceeds on to explain the critical operations that are part of the calculations. A small explanation of the selected use-cases sets the expectations of how the environmental impact analysis will be drawn. Lastly, a standardized robust methodology is explained that consists of two models. These models will cover the main operations of an X-Road instance and help to conclude accurate environmental emissions.

2. Carbon footprint of X-Road

2.1. General methodology for emission models

The carbon footprint calculation started with a thorough desk review which gave a better insight of the current calculation methods that are employed across different studies and sectors. Once a good understanding was developed, a series of discussions were initiated between SEI and the X-Road's software programmers and engineering team to identify the exact user cases, technical specifications of X-Road's infrastructure, and X-Road's key operations. The next step was to determine and quantify the agreed variables and create a baseline dataset that outlined initial assumptions and details relevant to the X-Road use cases, key operations, and services. This process required constant review and feedback through several iterations, so the initial model was improved, and user cases were correctly calibrated. In turn, the steps required for the calculations were finalized, allowing the draft model to be built.

Figure 2. 3 sources of carbon emission in X-Road's operations

This model was further refined in subsequent steps based on new literature findings, updated assumptions testing among the internal team, and interviews with end-users and industry experts. Three main sources of carbon emission were identified, including infrastructure, data transaction and data storage as shown in figure 2. In this context, the infrastructure component included the Security Server required to process incoming data and enable secure data exchange which was hypothesized to be the most energy intensive process within the value chain.

This is because multiple processors can collectively contribute to vast amounts of heat emission and energy consumption. In contrast, as previously discussed, work by Aslan et al suggested that data transaction would only minorly contribute to the total emissions, subject to the amount of data transferred. Their work pointed to an average data transmission efficiency of 0.06 kWh /GB for fixed line transmission, a value that was also seen empirically to half every 2 years. This notwithstanding, the relative importance of data transfer could increase if other modes of transmission were used, since the energy intensity over mobile networks is reported as being 50 x greater than fixed line transmission according to the

ICT sector guidance by the GHG protocol[17]. To compensate, data storage was considered as a separate component to account for the recording of all the transactions occurring over X-Road servers.

The calculation methodologies for all three segments are elaborated upon in the following sub-chapters, along with results for the Estonian and Finnish X-Road instances.

[17] https://ghgprotocol.org/sites/default/files/GHGP-ICTSG%20-%20ALL%20Chapters.pdf

2.2. Emission factors

An emission factor is a value that attempts to relate the quantity of a pollutant released into the atmosphere because of a normalized unit of a discrete activity associated with the release of that pollutant[18]. To calculate the total CO_2 emissions, electricity emission factors are used for different regions, depending on the energy intensity of the electricity generated and used to power a given activity or process. In general terms, coal, gas, or shale oil generated power feature the highest energy intensities (and emissions factors) in the EU. Deriving electricity-specific emission factors involves calculating the total emissions from the generation of electricity within a country and dividing that figure by the total amount of electricity produced by the country[19]. Such factors allow to roughly quantify the total emissions produced from consuming a certain amount of electricity. Different countries employ diverse sources of electricity production which contribute varying amounts to the total emissions. According to the IEA, Estonia had 70% of electricity generation by fossil fuels while Finland had only 18% in 2019[20]. This contrast directly depicts that the Finnish electricity mix has substantially less fossil fuel-based energy and hence less emissions when compared to Estonia.

Given the emissions boundary of the project and the nature of energy use in the IT sector, taking these pre-defined electricity emission factors then allows the total emissions to be calculated based on the amount of electricity consumed because of X-Road operations. CO_2 equivalent emissions are taken as a standard to calculate emissions as it gives a complete picture of the total emissions into the environment. Carbon dioxide equivalent or CO_2e means the number of metric tons of CO_2 emissions with the same global warming potential as one metric ton of another greenhouse gas[21]. Emission factors for CO_2 equivalent per kWh of electricity consumed are given in the following table (based on data collected in 2019).

[18] https://www.epa.gov/air-emissions-factors-and-quantification/basic-information-air-emissions-factors-and-quantification#:~:text=An%20emissions%20factor%20is%20a,the%20release%20of%20that%20pollutant.&text=Such%20factors%20facilitate%20estimation%20of%20emissions%20from%20various%20sources%20of%20air%20pollution.

[19] https://ecometrica.com/assets/Electricity-specific-emission-factors-for-grid-electricity.pdf

[20] https://www.iea.org/data-and-statistics?country=WORLD&fuel=Energy%20supply&indicator=ElecGenByFuel

[21] https://www3.epa.gov/carbon-footprint-calculator/tool/definitions/co2e.html#:~:text=CO2e,in%2040%20CFR%20Part%2098.

Table 2. Electricity emission factors by country[22]

Country	Electricity emission factor (kg of CO_2e/kWh)
Estonia	0.72328
Finland	0.13622
Iceland	0.00011
Germany	0.37862
Latvia	0.30333

"Example:
A data center that consumes 50,000 kWh of electricity would lead to approximately 36 tons of CO2e in Estonia and 6.8 tons of CO2e in Finland."

[22] https://www.carbonfootprint.com/docs/2020_06_emissions_factors_sources_for_2020_electricity_v1_1.pdf

2.3. Carbon footprint of X-Road Security Server infrastructure

The main physical infrastructure that enables secure data exchange through X-Road is the Security Server. According to multiple expert interviews, the Security Server contains a processor and RAM as the main energy consuming components. This has been benchmarked with other experts as well as the available literature. It was further understood based on these interviews and the consortium's own knowledge that the physical signing device, which could be approximated as a simple USB device, would have a negligible influence on the energy consumption relative to the Security Servers, and was therefore not subsequently considered in the calculations.

The main experts that were interviewed were representatives of Estonian and Finnish governing authorities. Riigi Infosüsteemi Amet (RIA) is the Estonian instance governing authority that promotes and manages secure data exchange between institutions[23]. Digi- ja väestötietovirasto (DVV) is the Finnish instance governing authority that promotes the digitalisation of society, secures the availability of information, and provides services related to customer's life events[24]. According to the surveys conducted with RIA and DVV, it was unanimously agreed that a processor with 4-8 cores and a RAM of 4-16 GB storage space in a Security Server suffices for X-Road's operations. As the infrastructure is distributed across different facilities at multiple locations, it is almost impossible to track exact models of all the processors and RAM and hence a general assumption needs to be taken.

The main components of a server are processor (or CPU), RAM, hard drive controller and input/output ports for devices[25]. For simplification, only CPU and RAM are considered as these components are responsible for almost all the energy consumption. All the mentioned studies in the following sub-chapters take this assumption. Energy consumption in CPU and RAM is not static. It depends on a range of factors ranging from CPU utilization, the number of active cores, frequency, amount of data being processed, RAM usage etc. Hence, it is extremely important to model the energy consumption of the Security Servers that is dynamic and reflects X-Road's operations.

2.3.1. METHODOLOGY TO CALCULATE THE CARBON FOOTPRINT OF A SECURITY SERVER

To model the energy consumption of a server, numerous studies (mentioned in the following sub-chapters) have been considered so a robust calculation methodology can be adopted. The calculations are divided between the energy

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[23] https://www.ria.ee/en.html
[24] https://dvv.fi/en/about-the-agency
[25] https://www.dummies.com/programming/networking/components-of-a-server-computer/#:~:text=The%20major%20components%20on%20the,keyboards%2C%20mice%2C%20and%20printers.

consumption of a processer and that of a RAM. Hence the calculations are split into two parts where a model for each component is developed.

Processor (CPU)

Numerous studies have modelled the energy consumption of a processor. Detailed work was conducted by the university of Potsdam[26], where energy consumption based on frequency and active cores of a processor is discussed[27]. A robust (albeit simpler) power estimation model of [28]processor is given in a study conducted by COMSATS and Manchester Metropolitan university[29], where CPU utilization and power consumption in idle mode is presented. Moreover, in the" United States Data Center Energy Usage Report" [30] and "The Carbon Reduction Opportunity of Moving to Amazon Web Services[31]" have employed their calculation methodologies using SPECpower_ssj2008. SPECpower_ssj2008 exhibits the correlation of using CPU utilization and the amount of power consumed. This correlation can be used to calculate the energy consumption of a Security Server in a simple manner. CPU utilization of X-Road's operations can be obtained without much effort and this exercise has been conducted by NIIS from their test environment.

Despite the potential for greater precision enabled by work looking at other parameters, such as in reference 20, it was also considered that parameters such as frequency and active number of cores of a processor are difficult to obtain over an inconsistent period of time, especially given the distributed nature of the X-road environment. To ensure the greatest comparability between different users and use cases, it was therefore decided to focus on CPU utilization as a single proxy for server power consumption. In this way, accurate results can be obtained and applied across the X-road network.

Published results from SPECpower_ssj2008 are used for the calculations. A Fujitsu server with a model "FUJITSU Server PRIMERGY RX1330 M4[32] is used as an example to explain how power consumption varies with CPU utilization. The server employs an Intel® Xeon® E-2288G Processor with 16M Cache, 3.70 GHz and eight cores, and was published in the database in 2019. There is only one processor chip in the server. This model is selected as a reference as it is similar to the specifications described by the X-Road members. However, it is important to state that a different reference server can be selected based on the specifications of other servers that may be used by X-Road members. The performance

[26] Takouna, Ibrahim & Dawoud, Wesam & Meinel, Christoph. (2011). Accurate Multicore Processor Power Models for Power-Aware Resource Management. 10.1109/DASC.2011.85.
[27] B. Gul et al., "CPU and RAM Energy-Based SLA-Aware Workload Consolidation Techniques for Clouds," in IEEE Access, vol. 8, pp. 62990-63003, 2020, doi: 10.1109/ACCESS.2020.2985234.
[28] https://www.spec.org/power/
[29] B. Gul et al., "CPU and RAM Energy-Based SLA-Aware Workload Consolidation Techniques for Clouds," in IEEE Access, vol. 8, pp. 62990-63003, 2020, doi: 10.1109/ACCESS.2020.2985234.
[30] https://www.osti.gov/servlets/purl/1372902
[31] https://d39w7f4ix9f5s9.cloudfront.net/e3/79/42bf75c94c279c67d777f002051f/carbon-reduction-opportunity-of-moving-to-aws.pdf
[32] https://www.spec.org/power_ssj2008/results/res2019q4/power_ssj2008-20191203-01014.txt

result of this server model shows the amount of power consumption for different values of target load (which is taken as CPU utilization). Assuming all the energy consumption comes from the processor, the following table displays the benchmarked result summary.

Table 3. CPU power consumption at different utilization levels of the benchmarked security server (FUJITSU Server PRIMERGY RX1330 M4).

Target Load (CPU utilization)	Average Active Power (W)
100%	57.4
90%	50.6
80%	44.7
70%	40.1
60%	35.8
50%	31.6
40%	28.3
30%	25.6
20%	23.2
10%	20.7
Active Idle	16.8

The values from table 4 can be modelled as a directly proportional relationship between CPU utilization and Average Active Power. When the server is in Active Idle mode, it still consumes 16.8 W of power. Assuming this linear relationship between the two parameters, we can form the following equation:

Equation 3

$$P_{processor} = (CPU_{utilization} * m + P_{idle}) * num\_chips\_ss$$

Where $P_{processor}$ is the Power of the processor, $CPU_{utilization}$ is the CPU utilization in an hour, m is the slope of utilization vs. active power, P_{idle} is the power when the processor is idle and num_chips_ss is the total number of processor chips.

The value of m can be calculated by taking the maximum active power at 100% and the power when the processor is in Active Idle mode. From table 4, the value of m will be approximately 0.41 $W/CPU_{utilization}$, meaning the power consumption will go up by 0.41 watts for every 1% increase in CPU utilization.

"Example:
For 2 processors (2 CPU chips) with a CPU utilization of 32.5% for an hour, a slope of utilization m of 0.5 W/CPU$_{utilization}$ and P$_{idle}$ of 20.5 W, the total processor power consumption using equation 5 will be 73.5 W. Assuming the same power for the whole day will give a value of 1764 Wh (where the value for one hour has been multiplied by 24 hours)."

RAM

Energy consumption by RAM could correspond to up to 25% of the total consumption of a server[33]. As energy consumption by RAM is dependent on the amount of data processed, the type of operations that are undertaken by X-Road will definitely affect this value. Hence, a separate energy calculation model is developed based on existing literature. This model can utilize data that can be provided by X-Road members.

The RAM energy consumption model is based on a study conducted by Pedro H. P. Castro et al, where a joint CPU-RAM energy efficient approach for cloud data centers is employed [34]. The energy calculations for RAM are only taken from this study, although they also reported a very similar methodology for CPU as described above. This study consists of a level of detail to employ a durable calculation model. For RAM, two sources of power consumption are responsible. One is Background power, which does not depend on either the type or the number of commands run by the system and the other is Operational power, which comes from read or write commands involving RAM.

Background power

The Background power depends only on memory states and on the frequency of the operation. For simplicity's sake, two states known as active standby and active powerdown are taken. The Background power consumption then can be defined as:

Equation 4

$$E_{bg} = CPU\% * E_{Act_{sb}} + (1 - CPU\%) * E_{Act\_pd}$$

[33]K.Lim,J.Chang,T.Mudge,P.Ranganathan,S.K.Reinhardt,T.F.Wenisch,Disaggregatedmemoryforexpansionandsharinginbladeservers,SIGARCHComput.Archit.News37(3)(2009)267–278.[20] Google,Googlecluster-usagetraces,https://code

[34] Castro, Pedro & Barreto, Vívian & Corrêa, Sand & Granville, Lisandro & Cardoso, Kleber. (2015). A joint CPU-RAM energy efficient and SLA-compliant approach for cloud data centers. Computer Networks. 94. 10.1016/j.comnet.2015.11.026.

Where E_{bg} is the background power consumption, $CPU\%$, varying from 0 to 1 is the CPU utilization during a time window, E_{Act_Sb} is the Active Standby and E_{Act_Pd} is the Active Powerdown.

The Active Standby and Active Powerdown power depend on the type of RAM that is being used and is treated as a constant. The term (1 – CPU%) refers to the time when the CPU is idle.

Operational power

Operational power is a product of memory bandwidth and the power required to run a particular command. The operational power consumption can be defined as:

Equation 5

$$E_{Oper} = RAM_B * \frac{(E_{B,r} + E_{B,w})}{2} * CPU\% * U(0,1)$$

Where E_{Oper} is the operational power consumption, RAM_B is the peak transfer rate of a DDR3 RAM at 1333 MHz, $E_{B,r}$ is the operational power of the read command, $E_{B,w}$ is the operational power of the write command and $U(0,1)$ represent the % time spent on read/write commands involving RAM.

U(0,1) represents the choice of a random value from a uniform distribution as no public data is available. However, for simplicity, U(0,1) is taken as the same value as the CPU utilization.

Total power consumption by RAM

Total power consumption by RAM is the sum of the Background and Operational power and is given by the following formula:

Equation 6

$$E_{RAM} = E_{Bg} + E_{Oper}$$

Where E_{RAM} is the total power consumption, E_{Bg} is the Background power and E_{Oper} is the Operational power.

"Example (For a DDR2 RAM at 1333 MHz):

A RAM with E_{Act_Sb} of 5.36 Watt, E_{Act_Pd} of 3.28 Watt, $E_{B,r}$ of 0.939 W/(GB/s), $E_{B,w}$ of 1.023 W/(GB/s), a RAM_B of 10.7 GB/s, CPU% of 56% and an average of 56% of read/write command (assuming CPU% same as read/write command) will have an average power of 7.74 watts. Assuming the same power for the whole day will give a value of 185.68 Wh of energy consumption (where the value for one hour has been multiplied by 24 hours)."

Total energy consumption of a Security Server

The total power consumption of a Security Server is taken as the sum of these individual components describing the power consumption of a processor and of RAM for a given operation. CPU utilization values for one week with a temporal resolution of one hour are recorded. Daily average values can be calculated from hourly ones for one week which can we used to calculate the total energy consumption for one day.

Data exchange services typically repeat in a weekly pattern. Hence, it is assumed that the energy consumption of all weeks in a year can be derived from those taken for one week. If accurate energy calculations are performed for one week, multiplying it by the total number of weeks in a year will present the energy calculation for the whole year.

A final factor to consider is the energy consumption of the supporting infrastructure. According to the CLEER model discussed in the previous part of this report, the total energy consumption by a data centre is the product of PUE and the sum of energy consumption by all devices. Hence, to compensate for cooling, lighting, electrical equipment etc that are placed to facilitate the Security Server, a product of the energy consumption by the Security Server and PUE is taken.

The value of PUE can vary greatly between different types of data centre and can benefit greatly from the economies of scale. For example, Google report an average PUE across their data centres of 1.11[35], meaning that on average 90 % of the energy drawn is used directly by the IT infrastructure. In contrast, servers located on site can have PUEs of 2 or more[36].

Finally, the total energy consumption by a Security Server for one year can be defined by the following formula:

Equation 7

$$E_{Security\ Server} = PUE \ * \ Weeks_{year} * (E_{processor} \ + \ E_{RAM})$$

[35] https://www.google.com/about/datacenters/efficiency/

[36] Bashroush, R. and Lawrence, A. (2020) *Beyond PUE: Tackling IT's wasted terawatts, Uptime Institute Intelligence*

Where $E_{Security\ Server}$ is the total energy consumed by a Security Server in a year, PUE is the Power use effectiveness, $Weeks_{year}$ is the total number of operational weeks in a year, $E_{processor}$ is the total energy consumed by a processor of a Security Server in a week and E_{RAM} is the total energy consumed by a RAM of a Security Server in a week.

"Example:
If the energy consumption of the processor Is 1764 Wh and energy consumption of RAM is 170.4 Wh, the total energy consumption of the security sever will then be the sum of two values and hence 1934.4 Wh for a single day. Assuming a uniform energy consumption over a week, multiplying 1934.4 by 7 gives the energy consumption of a Security Server for a week. Assuming a PUE of 2 and 52 weeks in a year, the total energy consumed of the Security Server using equation 9 is 1,408 kWh."

Emissions due to Security Server usage

Emission calculations due to Security Server usage follows a simple methodology. Once the total energy consumption has been calculated, a product of the country specific emission factor (either Estonia or Finland) and the total energy consumption is taken. The following formula summarizes the emission calculations:

Equation 8

$$Emissions_{energy,ss} = Energy_{year,ss} * EF_{electricity} * Num\_SS$$

Where $Emissions_{energy,ss}$ is the total emissions due to energy consumption by a Security Server, Num_SS is the total number of Security Servers, $Energy_{year,ss}$ is the total energy consumption of a Security Server in one year and $EF_{electricity}$ is the country specific electricity emission factor.

"Example:
In the previous example, the total energy consumption of a Security Server for a year was 1,408 kWh. Considering an emission factor of 0.72328 kg of CO_2e/kWh, the total emissions due to the Security Server account up to 1,018 kg of CO_2e."

2.3.2. ESTIMATIONS FOR SECURITY SERVERS IN ESTONIA AND FINLAND

The emissions from Security Servers in Estonia and Finland are calculated using the data collected from respective governing authorities. Expert interviews, literature review and a list of general assumptions have allowed to calculate the emissions in a sturdy manner. The following assumptions are undertaken for Security Servers:

- The data is from 2020

- All servers are onsite
- Energy consumption of a Security Server is the sum of CPU and RAM
- Servers repeat a weekly pattern of data processing
- Server model: Fujitsu, Server PRIMARY RX1330 M4 in which CPU model: Intel Xeon E-2288G is taken as a reference
- RAM calculations are based on DDR3 RAM at 1333 MHz
- A PUE of 1.58 is taken for both Estonia and Finland37
- Percentage of read/write commands are taken as the same as CPU utilization %

Table 5 summarizes the collected data for instances in Estonia and Finland. The corresponding calculated emissions are also recorded.

Table 4. Carbon footprint summary of Security Servers for Estonia and Finland

Factor	Estonia	Finland	Comments
Total nyumber of Security Servers	173	290	Numbers given by RIA and DVV
CPU utilization*	12%	3%	Value for Estonia taken from NIIS and Value for Finland taken from DVV
Processor	Server Model: Fujitsu FUJITSU Server PRIMARY RX1330 M4 CPU Model: Intel Xeon E-2288G Maximum Power: 57.4 W Idle Power: 16.8 W #of processor chips: 1	Server Model: Fujitsu FUJITSU Server PRIMARY RX1330 M4 CPU Model: Intel Xeon E-2288G Maximum Power: 57.4 W Idle Power: 16.8 W #of processor chips: 2	Assumption For Finland, it was reported that Intel® Xeon® Gold 6142 processor is used onsite. This model has 16 cores and 32 cores while Intel Xeon E-2288G has exactly half the number of cores. For simplification, 2 number of processor chip were assumed to compensate for the number of cores.

[37] https://journal.uptimeinstitute.com/data-center-pues-flat-since-2013/

Factor	Estonia	Finland	Comments
RAM	DDR3 at 1333 MHz EAct_Sb = 5.36 W EAct_Pd = 3.28 W EB,r = 0.939 W/(BG/s) EB,w = 1.023 W/(BG/s) RAMB = 10.7 GB/s	DDR3 at 1333 MHz EAct_Sb = 5.36 W EAct_Pd = 3.28 W EB,r = 0.939 W/(BG/s) EB,w = 1.023 W/(BG/s) RAMB = 10.7 GB/s	Assumption
PUE	1.58	1.58	Assumption
Emission factor	0.723 kg of CO_2e/kWh	0.136 kg of CO2e/kWh	Use the average factor per country based on emission factors in Table 3 (based on data collected in 2019)
Energy consumption by a processor of a Security Server in a week	3,661 Wh	6,106 Wh	Calculated using equation 5
Energy consumption by a RAM of a security server in a week	621 Wh	565 Wh	Calculated using equation 6,7 and 8
Energy consumption by a Security Server in a week	4,282 Wh	6,671 Wh	Sum of energy consumption by a processor and RAM
Total energy consumption by one Security Server for one year	351,809 Wh	548,089 Wh	Calculated using equation 9 (considering number of weeks to be 52)
Total emissions due to Security Servers in a year	~44,000 kgCO2e	~21,600 kgCO2e	Calculated using equation 10

**Average value taken from hourly values over a week.*

Calculated emissions from Security Servers in Estonia amount to approximately 44,000 kgs of CO2e and in Finland amount to approximately 21,600 kgs of CO2e. Although the energy consumption of Security Servers in Estonia is much lower than in Finland, the vast contrast of emissions exists simply because of the electricity emissions factor. Electricity in Estonia heavily relies of fossil fuels which factor in the high amount of emissions, while in Finland, the electricity has a high share of renewable energy. From the results, it is quite evident that Security Servers consume a lot of electricity thus the emission factor is the main parameter that alters the total amount of emissions.

Another pivotal point is the PUE. The PUE is assumed to be the same for both countries and is taken to be the average value concluded by the uptime Institute, due to an inability within the scope of this project to directly measure the PUE to be applied for each individual security server. However, in reality, data centres where Security Servers are placed, will definitely have a different value. If a lower value is used, electricity consumption directly decreases which in turn reduces the emissions. The converse also applies.

2.4. Carbon footprint of a secure data exchange transaction on X-Road

2.4.1. CHARACTERISTICS OF A DATA EXCHANGE TRANSACTION

Each transaction on X-Road consists of a range of metrics that have varied sizes. These metrics include the protocol, payload, and attachment. Header-size is dependent on the protocol that is used (SOAP or REST). The data size of payload and attachment is under control of the service providers and would be present regardless of the form of data exchange. In contrast, data exchanged over X-Road will comparatively be heavier than a normal data exchange operation as X-Road implements different protocols and services. According to DVV, each transaction can approximately be divided according to the following table.

Table 5. Breakdown of a single data exchange transaction[38]

Metric	%occupancy in a data transaction
Payload	45-65% ~20-50 kb
Metadata	32-51% ~ 21 kb
Protocol	3% (using SOAP) ~ 1.2-1.4 kb

This breakdown makes it possible to compare the effect of using X-Road services for secure data exchange. The amount of data that is added for every transaction is directly proportional to the additional number of emissions due to the exchange taking place on X-Road. Considering the small size of the added data, the total number of transactions will be the deciding factor in determining the additional emissions.

2.4.2. METHODOLOGY FOR NETWORK SYSTEMS OPERATIONAL ENERGY USE

As previously mentioned, an average value for electricity consumed for data transfer over a fixed line is assumed. This is because the highly distributed nature of internet transmission makes it impractical to assign a specific emissions pathway for each transition. For 2021, including the expected efficiency gains, this value is found to be 0.0075 kWh of electricity consumed for 1 GB of data transferred over the local internet. The methodology simply involves taking the product of the total amount of data exchanged over X-Road and the electricity consumption per GB of data transferred. The result is then

[38] Expert interview: Teemu Theqvist

multiplied with the emission factor to get the final emissions. The emissions of data transfer can be calculated using equation 4.

"Example:
A secure data exchange layer has a total of 50,000 GBs of data exchanged in a year. Considering the emissions factor to be 0.72328 kg of CO2e/kWh and an electricity consumption per GB of data transferred to be 0.0075 kWh/GB, the total emissions sum to be 271 kg of CO2e."

2.4.3. ESTIMATIONS FOR DATA TRANSACTIONS IN ESTONIA AND FINLAND

Emissions due to data transaction in Estonia and Finland over X-Road can be estimated with the total value of data exchanged for both instances, respectively. Table 7 summarizes the total data exchanged, electricity emission factors and electricity consumption factor for a GB of data exchanged. The emissions are calculated using equation 4.

Table 6. Carbon footprint summary of Data transaction for Estonia and Finland

Factor	Estonia	Finland	Comments
Specific electricity consumption per GB	0.0075 kWh/GB	0.0075 kWh/GB	Fixed number based on Aslan et al, 2017
Data exchanged	33,000 GBs	25,343 GBs*	Numbers are based on information provided by RIA and DVV
EF – emissions factor	0.723 kgCO2e/kWh	0.136 kgCO2e/kWh	Use the average factor per country based on emission factors in Table 3 (based on data collected in 2019).
Total emissions	179 kgCO2e	26 kgCO2e	

**This number is calculated by average number of transactions (173585330), average size of a transaction (~73 kB) and an assumption that the transactions are only for the population registry (~50% of X-Road's total operations in Finland, twice the amount is taken).*

Calculated emissions for instances in Estonia and Finland directly depend on the amount of Data exchanged over X-Road. 33,000 GBs of exchanged data for Estonia resulted in 179 kgs of CO2e while for Finland, 25,343 GBs of exchanged data resulted in only 26 kgs of CO2e. This difference is evidently the result of the contrast that exists in the values of electricity emission factors between both the countries. Nonetheless, as the total amount of data that is exchanged over X-Road for both instances is quite low, resulting emissions are also marginal.

2.5. Carbon footprint of logging the transaction data on X-Road

According to the information obtained through interviews with X-Road members, data exchanged over X-Road is required to be saved. The extent of data storage depends on several factors and depending on the instance, the requirements of data storage are different. In Finland, only metadata is stored while in Estonia, the whole message is stored by the data provider and consumer. This aspect gives rise to emissions. According to bilateral exchange of information with different X-Road members, data is stored in Hard disk drives (HDDs). If operational monitoring is used in any instance, the amount of data storage will increase. Emissions rising from data storage hence need to be calculated as they are an essential part of X-Road operations.

X-Road transaction data stored in Estonia has varied sizes and locations. According to RIA, Governing Authority of Estonia collects operational monitoring logs which accounted for approximately 5.71 TB of total data in 2020. The last three months of operational monitoring logs are kept online while last five months data is made available as open data. Additionally, every member organization must keep a "message log" of data exchange. A message log is kept by both producer and consumer members for different time duration (e.g., in Finland, the retention period can be up to 7 years).

2.5.1. METHODOLOGY FOR CARBON FOOTPRINT OF STORED DATA

The carbon footprint calculation methodology first involves developing an energy calculation model for data storage in HDDs and then calculating the resulting emissions of the stored data. The emissions are calculated by determining the energy consumption and multiplying them with their respective emission factor. Data stored at distinct locations will have different associated emissions factors, as discussed previously. The amount of data stored and energy consumption by storage devices play a key role in determining the emissions. The data storage energy consumption model is first discussed.

Data storage energy consumption

Calculating the exact energy consumption of an HDD is a complex exercise which is approached through multiple methodologies over a large body of literature. An HDD is an integral part of a PC and allows reading/writing operations. For any program running on a PC, multiple reading/writing operations are carried out over a span of time when a PC is being used. However, storage operations considered here are a bit different. Particularly, data storage (i.e., writing data on an HDD) is of utmost interest as parts of or all data that is exchanged over X-Road is saved over different storage devices. A starting assumption for the methodology here is that each Security Server stores data on a single dedicated HDD. Although this is not the most accurate assumption, concluding on the total number of HDDs for an instance will give acceptable results. By considering the emissions of an idealized HDD for a single reference service provider, an approximation of the total emissions from data storage can be arrived on.

A study conducted by Adam Lewis et al from Athens state university outlines a comprehensive approach that enables accurate energy consumption calculations of data storage in an HDD[39]. The study involves energy consumption while reading and writing data and includes the energy consumed when the HDD disk is in idle mode. From our team's expert knowledge, the energy consumption when the disk is in standby is also added so a modified version of the calculation formula can be given as follows:

Equation 9

$$E_{hdd} = P_{spin-up} * t_{su} + P_{read} \sum N_r + P_{write} \sum N_W + \sum P_{idle} * t_{idle} + \sum P_{standby} * t_{standby}$$

Where E_{hdd} is the disk energy consumption, $P_{spin\text{-}up}$ is the power required to spin-up the disk from 0 to full rotation, t_{su} is the time required to achieve spin up, P_{read} is the power required to read data, N_r is the amount of data read, P_{write} is the power required to write data, N_w is the amount of data written, P_{idle} is the power consumed when the disk is idle, t_{idle} is the time-slice when the disk is idle, $P_{standby}$ is the power consumption by HDD in standby mode and $t_{standby}$ is the time-slice when the disk is in standby mode.

"Example:
An HDD with a spin-up power of 24 W and spin-up time of 10 seconds, writes 40 GBs of data with a specific power required to write data of 5.4 x 10^{-6} Wh/mb, stays idle for 2000 hours in a year at a power consumption of 2.5 W and goes into standby mode for another 2000 hours in a year at a power consumption of 0.25 W will have a total energy consumption of 5.5 kWh in a year (assuming no data is read from the disk)."

Emissions due to data storage

The emission calculation directly involves multiplying the total energy consumption due to data storage by the electricity emission factor. The following equation represents the calculations:

Equation 10

$$Emissions_{storage} = EF_{electricity} * \sum E_{hdd}$$

Where $EF_{electricity}$ is the electricity emission factor, E_{hdd} is the energy consumed for data storage and $Emissions_{storage}$ is the total amount of emissions due to data storage.

[39] Lewis, Adam & Ghosh, Soumik & Tzeng, Nian-Feng. (2008). Run-time Energy Consumption Estimation Based on Workload in Server Systems. HotPower.

"Example:
An HDD in Estonia that consumes 11 kWh in a year with an electricity emissions factor of 0.72328 kg of CO2e/kWh will emit around 8 Kgs of CO2 equivalent emissions."

2.5.2. ESTIMATIONS FOR LOGGING IN ESTONIA AND FINLAND

Data storage emissions for both the Estonian and Finnish instances is calculated using information from their respective governing authorities. A list of assumptions is taken from literature sources and expert interviews that help to calculate the most accurate results. The following list of assumptions are used for the storage calculations:

- All data is stored in HDDs.
- Every Security Server is connected with 1 dedicated HDD ~ Total HDDs will equal to the total number of Security Servers
- HDDs run 24/7 all year round
- In a typical year, the HDDs stay 4380 hours in idle mode (approx. half of the year) and the other half they are in standby mode (approx. 4380 hours)
- Seagate® BarraCuda® 3.5-inch HDD is considered as a typical model for an HDD
- Reading from HDDs is omitted for simplification.

Table 8 summarises the assumed and collected data along with corresponding emissions for storage.

Table 7. Carbon footprint summary of Data storage for Estonia and Finland

Factor	Estonia	Finland	Comments
HDD	Seagate® BarraCuda® 3.5-inch HDD	Seagate® BarraCuda® 3.5-inch HDD	assumption
Total # of HDDs	173	580**	Data from RIA and DVV
Total amount of data stored	49,000 GBs	2,168 GBs*	Data from RIA and DVV
$EF_{electricity}$	0.723 kg of CO2e/kWh	0.136 kg of CO2e/kWh	Use the average factor per country based on emission factors in Table 3 (based on data collected in 2019).
Idle hours of HDD in a year	4380 H	4380 H	assumption
Sleep mode hours of HDD in a year	4380 H	4380 H	assumption
Total energy consumption due to data storage	2084 kWh	6986.2 kWh	Calculated using equation 11
Total emissions due to data storage	1507 kgCO2e	950 kgCO2e	Calculated using equation 12

**The value is calculated by adding message metadata and compressed metadata from DVV's three servers. As the data is for 30 days, it is assumed that similar amounts of additional data will be saved in the following days for the whole year. Lastly, an assumption that the stored data only represents the population registry (~50% of X-Road's total operations in Finland), thus twice the amount is assumed.*

*** Almost all Security Servers in Finland use some kind of SAN (storage area network) storage, so twice the amount of HDDs are taken as the number of Security Servers.*

A vast difference between the amount of data stored in Estonia and Finland exists mainly due to the storage requirements between both countries. Table 8 exhibits the total amount of data that was stored in both countries and the corresponding emissions. Although 49,000 GBs of data was stored in Estonia that resulted in 1,507 kgs of CO2e, the resulting emissions from storing 2,168 GBs of data in Finland results in a value of 950 kgs of CO2e. The sole reason for such a high value of emissions for Finland is attributed to the number of HDDs. The HDDs operate 24/7, either in idle mode or standby mode thus consume a significant amount of energy. Even though the difference in emission factors exists for both countries, the number of HDDs used in calculating the emissions for Finland are almost 3 times than those used in Estonia.

2.6. Carbon footprint estimation for X-Road instances in Estonia and Finland

The total carbon footprint calculations for the Estonian and Finnish instances combines all the calculated emissions for each part of the X-Road value chain together. Combing the total emissions allows to visually identify the main source of emissions and the leading factors that contribute to the results. The emission calculations help to identify the total contribution of each instance. All assumptions have previously been explained along with the numbers that are acquired mostly from X-Road governing authorities. The following table summarizes the total emissions of the Estonian and Finnish instances.

Table 8. Estimated carbon footprint summary of X-Road operations in Estonia and Finland.

Factor	Estonia	Finland
PUE	1.58	1.58
Number of Security Servers	173	290
Electricity emission factor	0.723 kg of CO2e/kWh	0.136 kg of CO2e/kWh
Amount of data exchanged	33,000 GBs	25,343 GBs
Amount of data stored	49,000 GBs	2,168 GBs
Data transfer energy consumption	0.0075 kWh/GBs	0.0075 kWh/GBs
Number of HDDs	173	580
Total energy consumption by servers	60856.5 kWh	158949 kWh
Total energy consumption due to data transfer	247.5 kWh	190 kWh
Total energy consumption due to data storage	2084.1 kWh	6,986
Total CO2e emissions due to servers	43,999 kgCO2e	21,617 kgCO2e
Total CO2e emissions due to data transfer	179 kgCO2e	26 kgCO2e
Total CO2e emissions due to data storage	1,507 kgCO2e	950 kgCO2e
Total CO2e emissions	45,685 kgCO2e	22,593 kgCO2e

The total CO2e emissions for both instances amount up to 45,685 kgs of CO2e for Estonia and 22,593 kgs of CO2e for Finland. The results include emissions from all three main operations (i.e., infrastructure, transaction and storage). As discussed earlier, although the Finnish instance has a lot more Security Servers than the Estonian instance (difference of 117), the difference in the electricity emission factor is the key reason for the number of emissions in both regions. A comparison between the emissions of the three main operations allows to identify the areas which solely contribute to the total emissions.

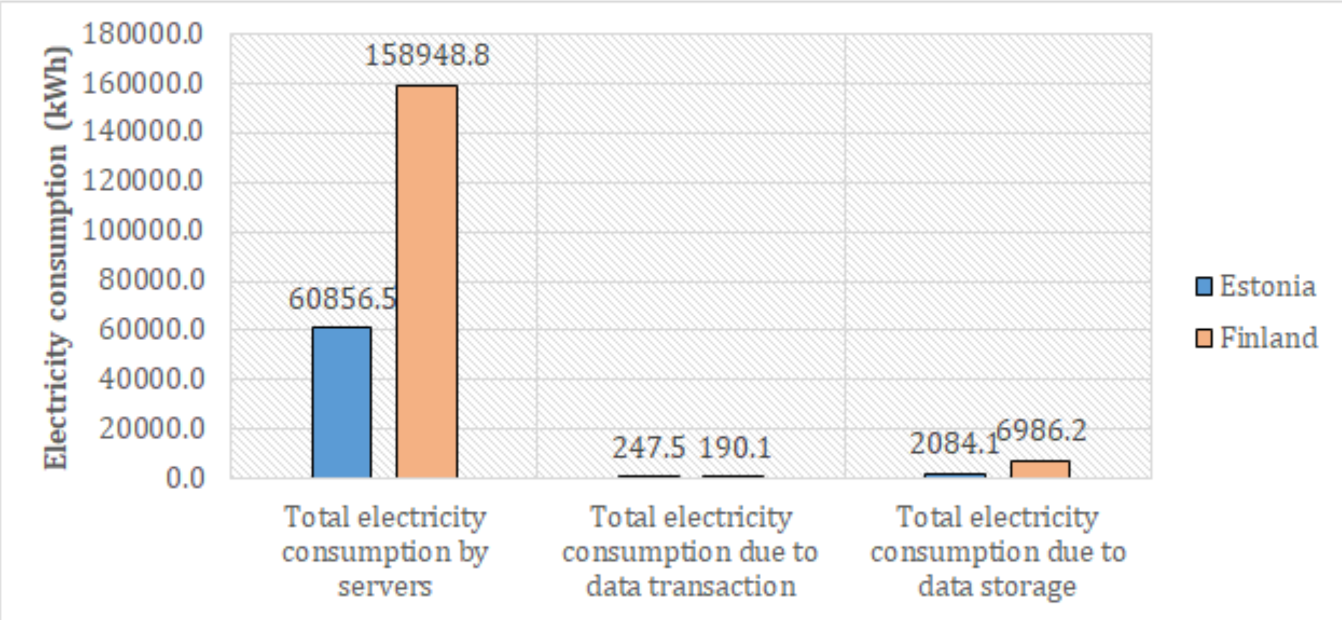

Figure 3. Electricity consumption by main operations in the Finnish and Estonian X-Road instances

Figure 3 illustrates the energy consumption of all three main operations of X-Road for the Finnish and Estonian instances. The electricity consumption by the Security Servers in comparison to data transaction and storage is substantially high and dominates the total share. Electricity consumption by Security Servers in Finland consumed 158,949 kWh while data transaction consumed a mere 190 kWh and data storage 6,986 kWh. Electricity consumption by Security Servers in the Estonian instance also accounts for the biggest share with a total consumption of 60,857 kWh, while data transaction and storage amount to a marginal value of 247.5 kWh and 2,084 kWh respectively. Resulting emissions from the electricity consumption are depicted in figure 4 and 5.

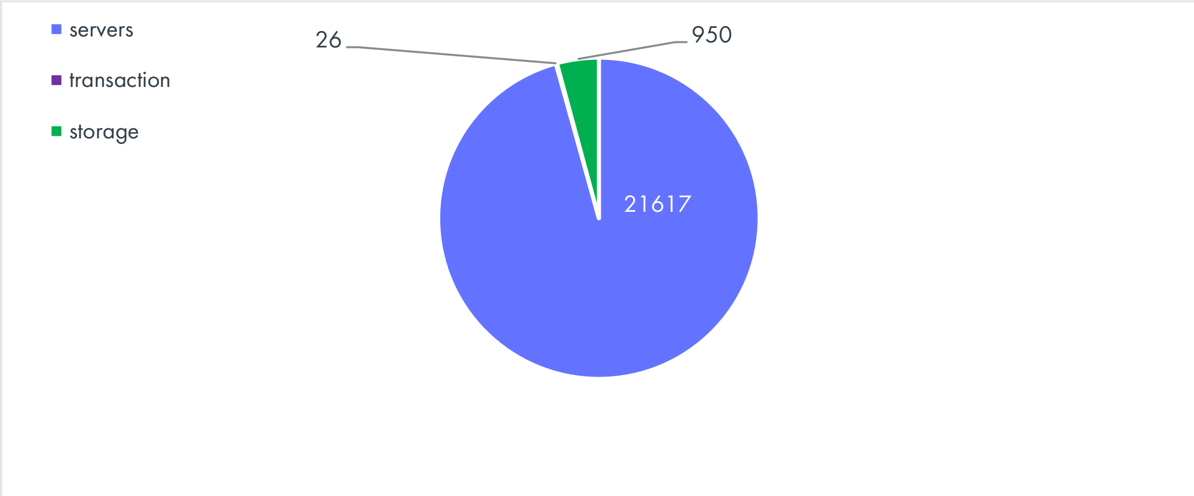

Figure 4. Emission by main operations in the Finnish instance

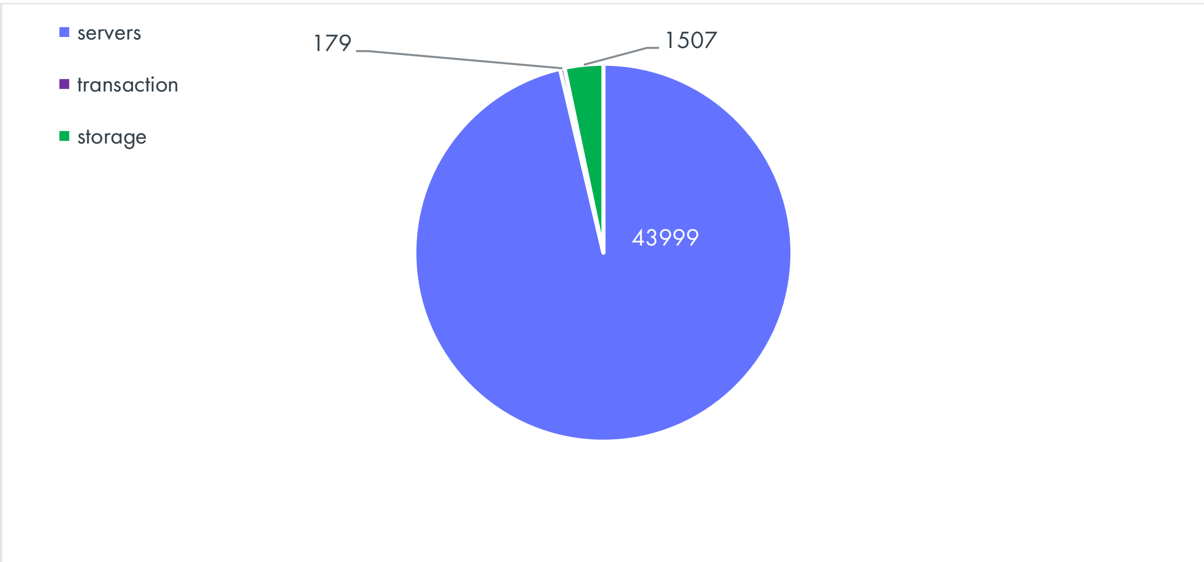

Figure 5. Emission by main operations in the Estonian instance

Emissions from servers also contribute to 96% of the total emissions which amount to 21,617 kgs of CO2e for the Finnish instance and 43,999 kgs of CO2e for the Estonian instance. This directly points to the primary place of focus to make X-Road's operations more sustainable. Data storage contributes a mere 3% that amount to 1,507 kgs of CO2e for Estonia and 950 kgs of CO2e for Finland. The remaining are from data transaction (less than 1%) for both instances.

This chapter explained the calculation methodology in quite detail which comprised of a range of sources, literature and assumptions. Calculations were broken down into simpler components and specific calculations models were developed for each component. Considering the complex nature of the calculations, the best possible assumptions were taken to conclude on acceptable results. Data from Estonian and Finnish authorities was taken for each Instance to calculate the overall emissions. The assumptions for each instance are clearly explained for the reader to grasp the concept behind the calculations. The calculated results are exhibited and critically analysed to identify the key areas where significant emissions occur. The results help to give key recommendations, which are covered in the next chapter.

3. Carbon footprint of X-Road Recommendations for reducing environmental impact of X-Road

The carbon footprint calculator for X-Road services shows that main factors that impact emissions performance are:

- the emissions relating to the electricity used to power the infrastructure,
- the CPU utilization of a Security Server,
- the amount of data exchanged,
- the amount of data stored in HDDs.

It must be acknowledged that the operational and business value of X-Road expands in line with the number of users using its services, meaning its core mission is to grow its userbase and service appeal. While this core principle cannot be changed, the recommendations listed in this section aim to reduce the added emissions of X-Road and support design efficiencies and thinking of its services to reduce the emissions footprint of the Security Server, transaction, and storage operations.

In addition, it is noteworthy that X-Road is one of the cornerstones of e-governance, enabling the developing of a data-driven economy, innovation, open and visible decisions, while keeping data available on a need-to-know basis and protecting privacy of citizens. Using secure electronic data exchange methods and services facilitates significant saving of time and other resources of governmental institutions, private organisations, citizens and other interested parties by reducing the need of physical presence of data processing, in turn, saving an enormous amount of emissions.

These recommendations aim to reflect the areas within the control of X-Road product owners, X-Road governing authorities and its members. We acknowledge that decisions impacting the carbon footprint of X-Road are dependent on the individual circumstances and choices of its users, for example, using a Security Server drawing power from highly carbon intensive power sources. The decision to purchase renewables or offset power emissions are often made for the entire organization, not for one specific service (such as X-Road usage).

To support managerial outcomes, our recommendations also include management tools for monitoring and managing carbon emissions, as well as best practices aimed at supporting decision makers to create the business case for lowering emissions across the entire organisation.

To tailor this section, recommendations have been grouped into four areas that are relevant to different stakeholder groups who are invested in, or impacted by, the X-Road, including:

1. X-Road product owners, including NIIS, members of NIIS, X-Road Technology Partners, programmers and designers who improve X-Road solution or give trainings about X-Road,
2. X-Road governing authorities, including those responsible for implementing regulations guiding use of X-Road instances,
3. X-Road members (e.g., Population register),
4. The broader public.

3.1 Recommendations for the further development of X-Road and its components

While NIIS cannot control how X-Road is used, it can provide options and advice to enable its services to offer easy-to-deploy environmentally friendly options.

NIIS, as product owner of X-Road, could adopt KPIs relating to the functionality of X-Road and demonstrating how the software supports emissions reduction. For example, monitoring the carbon footprint of an X-Road transaction (including Security Server, transaction and storage footprint) in the most optimized setting (for example development environment of NIIS) for energy efficiency and functionality. We realise that the critical support functions are already embedded into the system, for example the support for cloud environments that enable both virtual server and container-based deployments. Next steps could aim to raise user awareness and provide the existing options in a more user-friendly way. These options are described in detail in the following table.

Table 9. Summary of recommendations for further development of X-Road and its components

Recommendation	Impact
1.1 Provide convenient options to disable or reduce message-logging	The estimated carbon footprint of message logs in an X-Road instance was 3% of the annual emissions. Of the total stored data, about 45-65% comprised of payload. Carbon emissions due to data storage can be avoided by completely disabling the message logging or reducing the size of data that is logged (omitting payload in the logs).
1.2 Provide convenient options to disable or increase timestamping interval	The impact of a timestamp to carbon emissions is relatively small, however may become significant depending on the volume and size of exchange requirements.
1.3 Provide means for making the carbon footprint of the X-Road instance easily accessible and visible for X-Road governing authorities.	Automated carbon footprint evaluation for the X-Road governing authority will help to increase the awareness about the environmental impacts of X-Road. However, the central monitoring component also uses energy so inherently, itself will create environmental impact.
1.4 Provide means for making the carbon footprint of the Security Server easily accessible and visible for the X-Road member.	Automated carbon footprint evaluation for the X-Road member will help to increase the awareness about the environmental impacts of X-Road. However, the monitoring component also uses energy so inherently, itself will create environmental impact.

3.1.1. RECOMMENDATION 1.1: PROVIDE CONVENIENT OPTIONS TO DISABLE OR REDUCE MESSAGE-LOGGING

Description

Currently there are three possible configurations for message logs:
a) message log for metadata and payload
b) message log for metadata only
c) no message log.

A Security Server will not support logging the attachments if SOAP-protocol is used. Current message log disabling function is not documented.

From the business perspective it would be easier to decide the logging requirements on a service level, instead of subsystem level, and allow the service providers decide the requirements for each service.

Potential improvements

a) Describe the options for message logging in the Security Server User Guide.
b) Improve the Security Server UI with all three message log configuration options on a subsystem level.
c) Advise in a Security Server user guide, how to configure a Security Server and its subsystems based on service requirements (services with similar logging requirements could be grouped under the same subsystem or different subsystem can be used for each service).

Considerations

Message log configuration effects to security and evidential value of the logs:
a) reducing and disabling message log would mean, that the ability to verify the transactions afterwards will decrease, but the runtime security will not be affected.
b) message log that contains payload can be considered itself as a security threat.
c) The current solution does not store all attachments, so even in maximum logging, the whole message is not logged.

3.1.2. RECOMMENDATION 1.2: PROVIDE CONVENIENT OPTIONS TO DISABLE OR INCREASE TIMESTAMPING INTERVAL

Description

A prerequisite for X-Road implementation is the availability of the timestamping service. Timestamping service is not part of X-Road core software. Timestamping service can be provided by the X-Road governing authority (Finnish example) or purchased as a service from third parties (from private sector on Estonian example).

Currently, timestamping can be disabled only if the message log element is not installed. Disabling or reducing the sequence of timestamping would decrease the strength of verification. Without a time-stamp the log would not be able to provide a complete signed and timestamped document (Associated Signature Container [ASiC]).

The Security Server supports time-stamping each message separately in real-time or time-stamping in intervals, when there is active traffic. The interval is configured on the Central Server by the X-Road operator. The default configuration in Finland is for one minute interval, in Estonia in 48 minutes interval. Estimated data amount per one time stamp in Estonia and Finland in 2020 were 3.6 kB.

Potential improvements

a) Describe the options for disabling message logging and time-stamping in the Security Server user guide together with explanations of its effects to security and evidential value of the logs.
b) Develop new functionality to allow disabling timestamping even if the message log is in use.

Considerations

The ability to use X-Road without a time-stamping service would ease the on-boarding of new members on X-Road and setting up new instancesfrom the administrative and financial perspective. Not all countries have access to a suitable time-stamping service with reasonable cost.

3.1.3. RECOMMENDATION 1.3: PROVIDE MEANS FOR MAKING THE CARBON FOOTPRINT OF THE X-ROAD INSTANCE EASILY ACCESSIBLE AND VISIBLE FOR X-ROAD GOVERNING AUTHORITIES.

Description

X-Road governing authorities can enforce automatic installation of operational monitoring addon to all Security Servers. Both Estonia and Finland have done it. The use of the central Operational Monitoring Collector component, allows to collect, store, and analyse monitoring data from Security Servers. Estonia uses the central component and it provided very useful information for carbon footprint evaluation of the Estonian instance. Finland does not use this component and therefore the estimations for the instance are very rough or in some cases even do not exist.

Due to performance issues of the central component, it required an additional effort by RIA to analyse the historical data.

Potential improvements

a) Improve the performance of central Operational Monitoring Collector component.
b) Develop operational monitoring dashboard or similar visualization tool for easy access to information necessary for carbon footprint calculation for the members (potentially as part of Security Server UI) and for X-Road governing authorities (potentially as part of Central Server or central Environmental Monitoring Collector UI).
c) Consider integrating carbon footprint calculator with the dashboard and make it capable of showing the environmental impact of the instance.
d) Consider enforcing operational monitoring addon on Security Server only if the data is collected centrally.
e) Consider improving operational monitoring functionality that would give information about the set-up of a Security Server (public cloud / on-premises, Linux host / Docker) and/or its configuration (local / remote etc.)

Considerations

It is not reasonable to start using operational monitoring for environmental reasons. Rather, when the solution is already used, then it could give particularly good input for carbon footprint evaluation. Making this easy for the user allows NIIS to build the awareness about sustainability topics.

3.1.4. RECOMMENDATION 1.4: PROVIDE MEANS FOR MAKING THE CARBON FOOTPRINT OF THE SECURITY SERVER EASILY ACCESSIBLE AND VISIBLE FOR THE X-ROAD MEMBER.

Description

Environmental monitoring provides input data that is necessary for carbon footprint calculations of X-Road. Currently administrator must gather and analyse the data to be able to use it in the calculator. The software stack to collect, store, analyse and visualize the data is not currently available as an easy-to-implement open-source product.

Potential improvements

a) Improve environmental monitoring solution so that it would give a CPU average use and the amount of data exchanged.
b) Consider integrating the carbon footprint calculator with the environmental monitoring dashboard and make it capable of showing the environmental impact related to the Security Server.
c) Consider providing single central monitoring tool that would collect, store, analyse and visualize both operational and environmental monitoring data.

Considerations

It is not reasonable to start using environmental monitoring to have better input for carbon footprint evaluation. Rather, when the solution is already used, then its data could also be used for carbon footprint evaluation.

Making this easy for the user allows NIIS to build awareness about sustainability topics.

3.2 Recommendations for the governing authority and instance requirements

X-Road governing authorities are stakeholders with the power to set the rules and system constraints that support the uptake of environmentally friendly options for the X-Road member community. Conversely, these actors can prohibit their use and therefore should carefully consider when and why these options may be not allowed. A good example is restricted usage of public cloud servers where there may be limited private cloud server options.

The recommended KPI for sustainability on X-Road instance governance level relates to the carbon footprint per average transaction (including Security Server, transaction and storing footprint) and monitoring changes in time. It is to be expected that the volume of transactions per year will increase, meaning that efforts to evaluate singular transactions should be undertaken and quickly mainstreamed to scale impact. Recommendations tailored for these stakeholders are listed in the table below, before being discussed in ensuing text.

Table 10. Summary of recommendations for the governing authorities

Recommendation	Impact
2.1 Provide recommendations to the members that describe when and how it is allowed to use the Security Server in a public cloud	Energy consumption of a Security Server in a public cloud is claimed to be 88% less as compared to having an onsite infrastructure[40]. This is due to better CPU utilization and better efficiency. Thus, shifting Security Servers to the public cloud can drastically drop the emissions.
2.2 Requirements and recommendations for message log management and timestamping may be less optimal for energy saving. We recommend allowing environment-friendly options to be trialled and results discussed.	Based on the Estonian user case, message logging was determined to create 3 % of total emissions of Estonian X-Road instance, of which 45-65% of it is caused by logging of the payload. This may seem small, however becomes significant with exponential growth in the volume of traffic.

[40] https://d39w7f4ix9f5s9.cloudfront.net/e3/79/42bf75c94c279c67d777f002051f/carbon-reduction-opportunity-of-moving-to-aws.pdf

3.2.1. RECOMMENDATION 2.1: PROVIDE RECOMMENDATIONS TO THE MEMBERS THAT DESCRIBE WHEN AND HOW IT IS ALLOWED TO USE THE SECURITY SERVER IN A PUBLIC CLOUD

Description

When the X-Road instance is implemented in one country, several laws, regulations, and security policies regulate the usage of cloud-based resources. X-Road governing authorities can provide recommendations that explain the business case for change for users and decision-makers regarding cloud usage.

Potential improvements

a) Provide guidelines to X-Road members that explain, when and how could X-Road Security Server be used in a public cloud.

b) Enable the use of cloud-based secure signing devices.

Considerations

Requirements set by X-Road governing authority may disable the use of public cloud. When these are set, then the reasoning should be provided with the requirement.

3.2.2. RECOMMENDATION 2.2: REQUIREMENTS AND RECOMMENDATIONS FOR MESSAGE LOG MANAGEMENT AND TIMESTAMPING

Description

X-Road governing authorities of Estonia and Finland have a working practice where all message logs are time-stamped.

For example, in Estonia the requirement is to assure time-stamping frequency in every 48 minutes[41]. The use of a qualified time-stamping service and qualified signing certificate will support creating an advanced or qualified electronic seal. At the same time, non-qualified certificates are supported in the Estonian production environment[42]. The Act that regulates the use of X-Road in Estonia[43] requires messages to be logged in the message log but does not define the content of the log (metadata, payload, attachments). The logging of attachments is not supported by the core software.

[41] https://abi.ria.ee/xtee/en/x-tee-juhend/kuidas-kasutada-x-teed/x-tee-keskkonnad

[42] https://abi.ria.ee/xtee/et/x-tee-juhend/kuidas-kasutada-x-teed/x-tee-keskkonnad

[43] § 8 (3), https://www.riigiteataja.ee/akt/127092016004?leiaKehtiv

The time-stamping service can be provided for free by the X-Road governing authority (example from Finland) or bought as a service from private sector (example from Estonia). In both cases, the requirement sets the expectation that time-stamping service must be available for each member.

Potential improvements

a) Investigate the use of message logs and identify the use-cases when it is important to verify the message transactions or exchange data content with highest trust level.
b) Consider removing the requirement for message log or requirement for electronic seal. Allow the decision-making by the members based on the data that is exchanged over X-Road.
c) Guide members, when and what should be logged in a message log of a Security Server and update the requirements accordingly. Include the environment and security considerations in recommendations because a message log that contains payload and/or attachment might be a security risk itself.

Considerations

Disabling or reducing the sequence of timestamping would decrease the strength of verification. Without a time-stamp the log would not be able to provide complete signed and time-stamped document (Associated Signature Container [ASiC]).[44]

Ability to use X-Road without a time-stamping service would ease setting up new instances. Not all countries have access to a suitable time-stamping service.

Ability to use X-Road without time-stamping service might ease the on-boarding of new members in cases where timestamping requires a separate service agreement and is related to costs.

[44] https://x-tee.ee/docs/live/xroad/ug-ss_x-road_6_security_server_user_guide.html

3.3 Recommendations for X-Road members to lower the carbon footprint of secure data exchange

X-Road members can decide whether to use the environment-friendly options based on their business requirements in line with their service offering and requirements set by governing authorities. The recommended KPIs for adoption by X-Road members is to map the carbon footprint of their average transactions (including Security Server, transaction and storing footprint) and changes over time.

Table 11. Summary of recommendations to X-Road members

Recommendation	Impact
3.1 Optimize CPU utilization of the Security Server to reduce the infrastructure requirements	Energy consumption by Security Servers contributed to almost 96% of the total annual emissions for both instances. The high number of Security Servers with a low CPU utilization whilst running 24/7 qualify as a major reason for the high emissions. Optimizing CPU utilization to achieve higher percentages while reducing the physical number of Security Servers to process the same amount of data can reduce the emissions significantly.
3.2 X-Road Security Server in public cloud	Energy consumption of a Security Server in public cloud is claimed to be 88% less as compared to having an onsite infrastructure[45]. This is due to better CPU utilization and better efficiency. Thus, shifting Security Servers to the public cloud can drastically drop the emissions.
3.3 Consider changing message log configurations	Less logging reduces the carbon footprint of the message log. Data storage in online environments consumes a lot of energy as compared to storage in HDDs. One GB of data in public cloud storage could consume around 3.1 kWh of as compared to 0.000005 kWh of electricity when stored it in HDDs[46].
3.4 Increase the granularity of X-Road services	More granular services reduce the carbon footprint of the transaction and a message log. Might indirectly improve the performance of the Security Server.

[45] https://d39w7f4ix9f5s9.cloudfront.net/e3/79/42bf75c94c279c67d777f002051f/carbon-reduction-opportunity-of-moving-to-aws.pdf
[46] https://medium.com/stanford-magazine/carbon-and-the-cloud-d6f481b79dfe

3.3.1. RECOMMENDATION 3.1: OPTIMIZE CPU UTILIZATION OF THE SECURITY SERVER

Description

Security Server's CPU utilization plays an important role in the amount of energy consumed. Even when a Security Server is idle, it still consumes a significant amount of power. Most Security Servers operate in a low range of CPU Utilization (5-15%) and process a limited amount of data. Several Security Servers are used with low CPU utilization.

Potential improvements

1) Optimize the number of Security Servers. Consider reducing the number of Security Server infrastructure by using same Security Server or a hosted Security Server in situations where the utilization is low. Consider dynamic scalability of Security Servers when utilization is high occasionally.
2) Optimize CPU Utilization so more data is processed, and less infrastructure is required.
3) Turn off server capacity when it is not needed. e.g., based on schedule (nights and weekends might be slower) or based on metrics like CPU utilization.

Considerations

The optimization of the Security Server must go hand in hand with security considerations and availability requirements.

3.3.2. RECOMMENDATION 3.2: X-ROAD SECURITY SERVER IN PUBLIC CLOUD

Description

Cloud service providers give the opportunity to users to shift their onsite Security Server infrastructure to the public cloud. This allows the users to remotely use an optimized Security Server that allows for greater efficiency in operations.

Potential improvements

1) Consider using Security Server in a public cloud

2) Consider using Security Server Sidecar.

Considerations

The decision for choosing public cloud cannot be based on CO_2 emissions reasons only. Most commonly, the Security Server is hosted in the same environment with the related information systems and/or databases. The main factor for choosing the environment is then based on regulations and requirements that apply to the data, that the system uses or stores. It is therefore necessary to consider the requirements set by the X-Road governing authority and local or sector specific regulations for the specific data.

When public cloud is seen as a feasible option, then also the skillset of the organization and experience with Docker or public cloud platforms must be considered.

3.3.3. RECOMMENDATION 3.3: CONSIDER CHANGING MESSAGE LOG CONFIGURATIONS

Description

Storing data of transactions is necessary, when there is a need to keep a record of the data exchange transaction happening over X-Road. This data can be stored either in a local or remote database. Message logs are usually managed in an online database in the same environment with the Security Server (public cloud or on-premises). By default, these are kept there for 30 days, after which they are moved from the database to file archives, that can be offline.

The content of the message log may affect the requirements for storage duration. For example, if the message log includes payload, then it might include personal and/or health data.

Potential improvements

1) Carefully select what is stored in the message log (subsystems can have different settings).
2) Limit the storage duration for the message log in a database.
3) Select the most environmentally friendly option for long-term storing based on the used infrastructure. Use physical HDDs for storing the file archives or prefer so called cold storage.
4) Delete any data that is not needed any more and automate their removal when possible. For example, utilize the data lifecycle management tools that remove all files from folder Y that are older than an agreed number of days.
5) If a Security Server runs in the public cloud, then it is possible to limit the number of replications, considering any durability requirements. A lower number of replications causes less emissions.

Considerations

The logging decision cannot be based on CO_2 emissions reasons only. The defining factor for logging requirements must be related to the data content and use of data through X-Road data services. Additionally, there is a need to consider the requirements set by the X-Road governing authority, local or sector-specific regulations, and data content of the logs. Need for considering if logging requirements might be fulfilled by other systems (e.g., the connected service has built-in logging feature).

Logs play an important role in data security and each X-Road member needs to secure that sufficient logs are available. The analysis of logs provides information that allow to detect errors and anomalies, calculate KPIs and improve data services. At the same time, if logs include confidential data, then they might themselves be a security threat when misused.

When a Security Server is maintained in the public cloud, then it is more convenient to use it for storage as well. Public cloud has convenient tools for managing the logs and archiving them after necessary time. HDD might be a convenient choice when the Security Server is maintained on premises.

3.3.4. RECOMMENDATION 3.4: INCREASE THE GRANULARITY OF X-ROAD SERVICES

Description

The analysis of the X-Road services was not part of the current analysis. As a rule, the more granular the services, the better.

Services can be developed using technologies such as GraphQL that enable the client to define the exact set of properties included in the response instead of returning a fixed data set. This way it is possible to minimize the amount of data that is transferred. More granular services might improve the chances for using the same X-Road service by different data consumers and reduce the need for service developments.

Considerations

Every X-Road service is unique, and decisions can only be made case by case. More granular services might also decrease the security risks.

3.4 Best practice general recommendations

Best practices holistically identify the recommendations for key areas which result in the most emissions. These practices can be undertaken by any stakeholder to whom they apply. The following practices takes all the critical areas into account and sets a narrative towards greater sustainability for X-Road.

Table 12. Summary of general recommendations for reducing the carbon footprint

Recommendation	Impact
4.1 Usage of renewable energy for X-Road infrastructure	Security Servers account for the biggest source of emissions followed by data storage. The infrastructure energy consumption is quite intensive as compared to other operations. Using renewable energy to run the infrastructure can practically result in zero emissions.
4.2 Power efficient devices	With energy efficient equipment, resulting energy consumption will be less. This in turn will lead to less emissions. The equipment recommendations mainly pertain to Security Servers as they hold the greatest share of energy consumption in X-Road's operations.
4.3 Optimized data compression algorithms	Reduced size of data will result in less amount of electricity being consumed. This will ultimately result in lower emissions.
4.4 Purchasing Carbon offset certificates	Purchasing Carbon offset certificates helps fund new projects that will reduce carbon emissions. This allows carbon emissions to be somehow balanced out.

3.4.1. RECOMMENDATION 4.1: USAGE OF RENEWABLE ENERGY FOR X-ROAD INFRASTRUCTURE

Description

All electrical components that are used to ensure smooth X-Road operations (Security Servers, HDD etc.) which use electrical energy should switch to the use of renewable energy. If a member has physical infrastructure on their premises, they should switch to the usage of renewable energy. Similarly, if members and other stakeholders are using shared or distant infrastructure (e.g., Cloud), they should prefer using infrastructures that consume renewable energy as much as possible.

Usage of renewable energy can be through decentralized/personal systems or using grid electricity in a region which has an extremely low emission factor (e.g., grid in Iceland).

Considerations

It might be a requirement to have on-premises infrastructure that could be part of a data centre in a location which uses grid electricity. Depending on the location, grid electricity might have a high share of fossil fuel energy. It might be sometimes impossible for X-Road members to switch to renewable energy as the Infrastructure and its electrical connection are not in control of the members.

3.4.2. RECOMMENDATION 4.2: POWER EFFICIENT DEVICES

Description

As onsite infrastructure results in the most emissions, it is imperative to consider having equipment that consumes the least amount of energy and ensures smooth operations.

The following recommendations can be considered:
1) Replacing old and inefficient equipment with new efficient ones.
2) Whenever purchasing new equipment, always check the power rating. The lower the power rating, the lesser the energy consumption.

Considerations

Financial costs need to be considered to upgrade equipment. If the equipment is not under the influence of members, they cannot be upgraded.

3.4.3. RECOMMENDATION 4.3: OPTIMIZED DATA COMPRESSION ALGORITHMS

Description

Data compression allows more amount of information to be sent in less amount of space. Data compression algorithms can compress data before being exchanged with other members resulting in reduced size of each transaction. This in turn will reduce the size of the overall transactions over X-Road.

Considerations

Data compression algorithms might not be used by the development team.

3.4.4. RECOMMENDATION 4.4: PURCHASING CARBON OFFSET CERTIFICATES

Description

Projects that remove/avoid emissions from the atmosphere receive Carbon Offset certificates. These certificates can be purchased by members to offset their emissions and become more sustainable.

Considerations

This process involves financial transactions thus this option needs to be carefully considered and compared with the amount of emission reduction.

Summary

This report examines the environmental impacts of X-Road, by describing a tailored calculation methodology to assess its carbon footprint. While the original analytical approach is based on our understanding of best practice from peer reviewed literature, the result was calibrated using estimations from Estonia and Finland user cases to ensure relevance and rigour.

The project was divided into three phases, with results and methods published for feedback by a steering committee and technical experts. The phases were as follows:

1. Establishing an emissions boundary and mapping the main causes of environmental impacts of the X-Road instance.
2. Building a Carbon Footprint calculator for X-Road, based on best practice and X-road user cases.
3. Defining recommendations for improving sustainability of X-Road.

Based on the mapping of the environmental impacts of X-Road it was decided that the carbon footprint calculator will focus on the following activities:

1. Calculating a footprint of a Security Server as an enabler for X-Road transactions,
2. Calculating a footprint of a single secure data exchange transaction over public internet using X-Road,
3. Calculating a footprint to assess data storage of the transaction data in an X-Road message log.

The calculator was implemented to ensure a high degree of flexibility while obtaining directional results that could be accepted with high confidence. This ensured validity across the instances in Finland and Estonia, as well as the varying circumstances and technical literacy of different X-Road customers.

The study included test calculations for X-Road instances in Estonia and Finland. The results of the calculator give a clear picture of the total carbon footprint in both cases, as well as the relative weight of the considered components. The key findings were as follows:

1. Around 96 % of total emissions are related to the operations of X-Road Security Servers.
2. Data transmission and storage provide much more marginal contributions to the total carbon footprint (around 1 % and 3 %, respectively).
3. The annual carbon footprint for Estonia and Finland was approximated as 45,685 KgCO_2e and 22,593 KgCO_2e, respectively.
4. The discrepancy between the two countries relates mostly to the difference in average grid emission factor. This reflects the larger percentage of low carbon electricity sources in the Finnish grid and the relative reliance in Estonia on oil shale for electricity generation.

The results of the calculator demonstrate where the highest emissions originate and recommend ways to manage or mitigate these via different stakeholder groups. Each group has different levels of access and influence over the way how X-Road is used, ranging from the end user (e.g. X-Road member), to the governance body overseeing regulations guiding the service application (e.g. X-Road governing authority). NIIS, the product owner and developer of X-Road, is also targeted. The recommendations can briefly be summarised as follows:

1. The future development of X-Road should ensure flexibility for stakeholders to disable or reduce the burden of certain components (e.g.message logging, timestamping), subject to potential performance and security requirements, and to integrate a transparent monitoring of emissions into the environment where possible.
2. X-Road governing authorities should provide clear information on the range of parameters available to members, such as permission to host servers on the public cloud and requirements for message logs and/or timestamping.
3. X-Road members should implement X-Road efficiently. For example, this could include ensuring equipment is efficient and server utilisation is maximised. Alternatively, servers could be hosted on the public cloud if permitted by local regulations and the governing authority.
4. Where the option exists, infrastructure should be powered using renewable electricity. Moreover, best practice should be followed, such as using power efficient devices and optimised data compression.

The recommendations are well described in section 3 of this report. Some relate to actions aimed at reducing emissions within a single data transaction, for example switching relevant features on and off such as message logging or timestamping. Others relate to the macro, taking a system thinking approach to discuss the building of operational performance monitoring across the entire value chain to create data sets that can input CPU usage and other metrics into emissions calculators to enable an understanding of use patterns over time. Once a reference or baseline is established, end users or service providers can then experiment with their own data sets and data environment by trailing a range of efficiency levers (e.g.cloud storage, bundling, etc.) to determine ease and impact on emissions and services within the context of their specific security and performance requirements.

The use of machine learning and big data analytics to interpret performance and optimise services for emissions reduction is now considered to offer strategic advantages for cost, marketing, and annual reporting. Like other economic sectors, carbon accounting will be mainstreamed across ICT solutions and likely referenced by public procurement agents and end users seeking services in line with their own emissions targets. Creating services that are carbon neutral is anticipated to be of medium strategic advantage for NIIS and in line with EU policies and targets (e.g.Climate Law, Digital Europe initiative, etc).

In terms of recommendations for future research, we suggest that NIIS consider upgrading the calculator to enable it to dynamic monitor or simulate emissions, rather than as a static snapshot of one instance or time series. Translating it into a model with iterative and optimisation functionality will enable users and managers to inform and scale the usefulness of this calculator by inputting real use data. Moreover, it will also promote awareness and peer learning as calculator users experiment with recommended actions. Investing in data visualization at the UX will also enable carbon reporting leading to a strategic green advantage. We hope that this project will set a precedent and serve to increase the visibility of environmental considerations across the digital services sector.

Appendix 1. Data collection

This appendix gives an overview of the data collection, feedback loops and involved parties. All meetings were carried out as Team's meetings.

Goal	External Participants	Time
Test the questionnaire	Gofore: Ilkka Seppälä	10.02.2021 14.30-16.00
Data collection from Finnish X-Road Governing Authority	DVV: Atte Pirttilä, Joonas Aitonurmi CSC: Teemu Thequist, Joni Virtanen, Juhani Nuorteva,	17.02.2021 14.00-15.00
Data collection from Estonian X-Road Governing Authority	RIA: Toomas Mölder	19.02.2021 10.00-11.00
Feedback on methodology and data input opportunities	AWS: Margaret O'Toole, Marcus Johan Lock, Tõnis Pihlakas	01.03.2021 12.00-13.00
Sample CPU utilisation data of test environment	NIIS: Petteri Kivimäki	11.03.2021 14:00-15:00
Carbon Calculator review meeting with Governing Authorities	DVV: Atte Pirttilä, Joonas Aitonurmi CSC: Teemu Thequist, Joni Virtanen, Juhani Nuorteva RIA: Toomas Mölder	17.03.2021 14.00-15.00
Public feedback for phase 2 results	Blog post - The X-Road Carbon Emissions Calculator – Methodology and Results	16.04.2021
Recommendation review meeting with Governing Authorities	DVV: Atte Pirttilä, Joonas Aitonurmi CSC: Teemu Thequist, Juhani Nuorteva RIA: Toomas Mölder, Vitali Stupin, Kevin Kaarma NIIS: Petteri Kivimäki	21.04.2021 14.00-14.30
Carbon Footprint Calculator user testing	NIIS: Raido Kaju	28.04.2021 10.30-11.30
Carbon Footprint Calculator review with Governing authorities	DVV: Atte Pirttilä CSC: Teemu Thequist, Juhani Nuorteva RIA: Toomas Mölder NIIS: Petteri Kivimäki	28.04.2021 14.00-14.45

Goal	External Participants	Time
Recommendations and Carbon Footprint Calculator review with AWS	AWS: *confidential* NIIS: Petteri Kivimäki, Raido Kaju	28.04.2021 16.30-17.30
Planned activity: Introduction of the study	NIIS working group meeting	19.05.2021
Planned activity: Publishing of the outcomes	Blog post	May 2021

Appendix 2. Summary of interviews with X-Road Governing Authorities in Estonia and Finland

Questions	Meeting with DVV on 17.02.2021 Participants:
Number of Security Servers	CSC: Joni Virtanen
Security server by categories	CSC: Juhani Nuorteva
Security server infrastructure	DVV: Aitonurmi Joonas
Physical signing device	DVV: Pirttilä Atte
Top heavy users of X-Road's software	CSC: Teemu Theqvist
Size of REST vs SOAP service	
Definition of "Good service" vs "Bad service"	
Data occupancy averages by type (e.g., payload, metadata, protocol etc.) for a normal transaction using X-Road	

Questions	Meeting with RIA on 19.02.2021 Participants:
How many bytes (or GB) were pushed over X-Road in year 2020?	RIA: Toomas Molder
How many transactions happened on X-Road in 2020?	
How many bytes (or GB) is the log for operational monitoring in year 2020?	
Where is message log data stored? Any specifics about the data center?	
What are the specifications of a typical Security Server?	
What is the average energy usage of a Security Server?	
Definition of "Good service" vs "Bad service"	
Data occupancy averages by type (e.g., payload, metadata, protocol etc.) for a normal transaction using X-Road	

Data for Finland (2020)	
Parameter	**Value**
Number of Security Servers	290
Security server infrastructure	4 CPU cores, 4-8 GB of RAM
Physical signing device	No physical signing devices
Heaviest user	Population register
Total number of transactions	No data
Average payload	20-50kb
SOAP service	1.2-1.4 kb
REST service	~0
Metadata	21 kB
Timestamp	3.6 kB
Averages in a single transaction	49-65% payload, 51-32% metada and 3% protocol overhead using SOAP

Data for Estonia (2020)	
Parameter	**Value**
Number of Security Servers	173
Security server infrastructure	4 CPU cores, 4-8 GB of RAM
Bytes exchanged	37 TB
# of transactions/queries	1,570,741,229
size of operational log storage	5.71TB
what is the size of message log	49.20 TB
Total HDD of Security Servers	12.96 TB