EVALUATING THE ENVIRONMENTAL FOOTPRINT OF X-ROAD®

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DIGITAL SOCIETY SOLUTIONS AND CROSS-BORDER COOPERATION

Nordic Institute for Interoperability Solutions NIIS

Non-profit association to ensure the development and strategic management of X-Road® and other cross-border solutions for digital government infrastructure.

niis.org

X-ROAD®

Open-source software and ecosystem solution that provides unified and secure data exchange between organisations.

x-road.global

Harmony eDelivery Access

A free and actively maintained open-source component for joining one or more eDelivery policy domains.

edelivery.digital

X-Road® is open-source software and ecosystem solution that provides unified and secure data exchange between organisations.

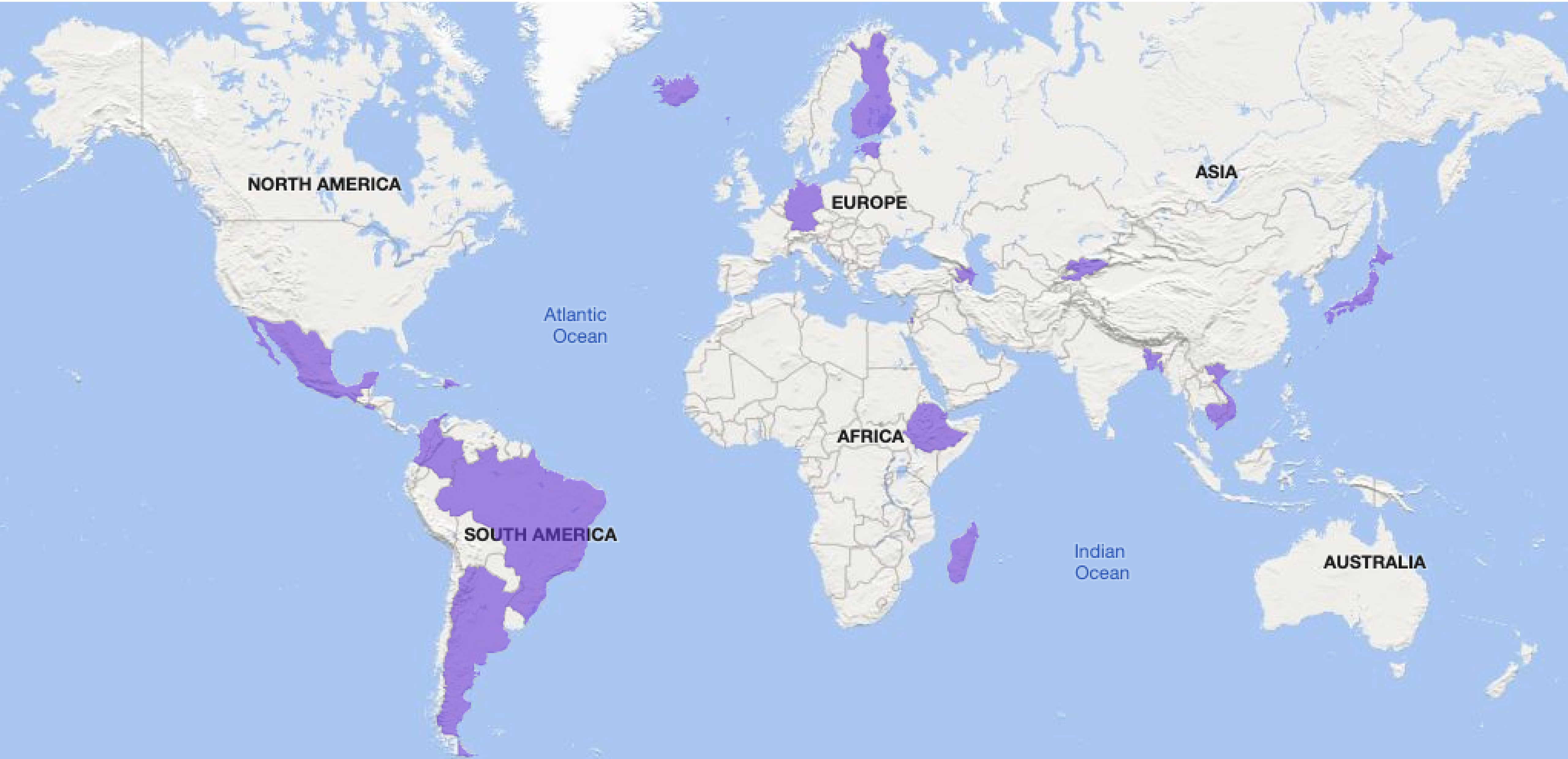
23
ECOSYSTEMS
DEPLOYED BY GOVERNMENTS OR OTHER ORGANISATIONS

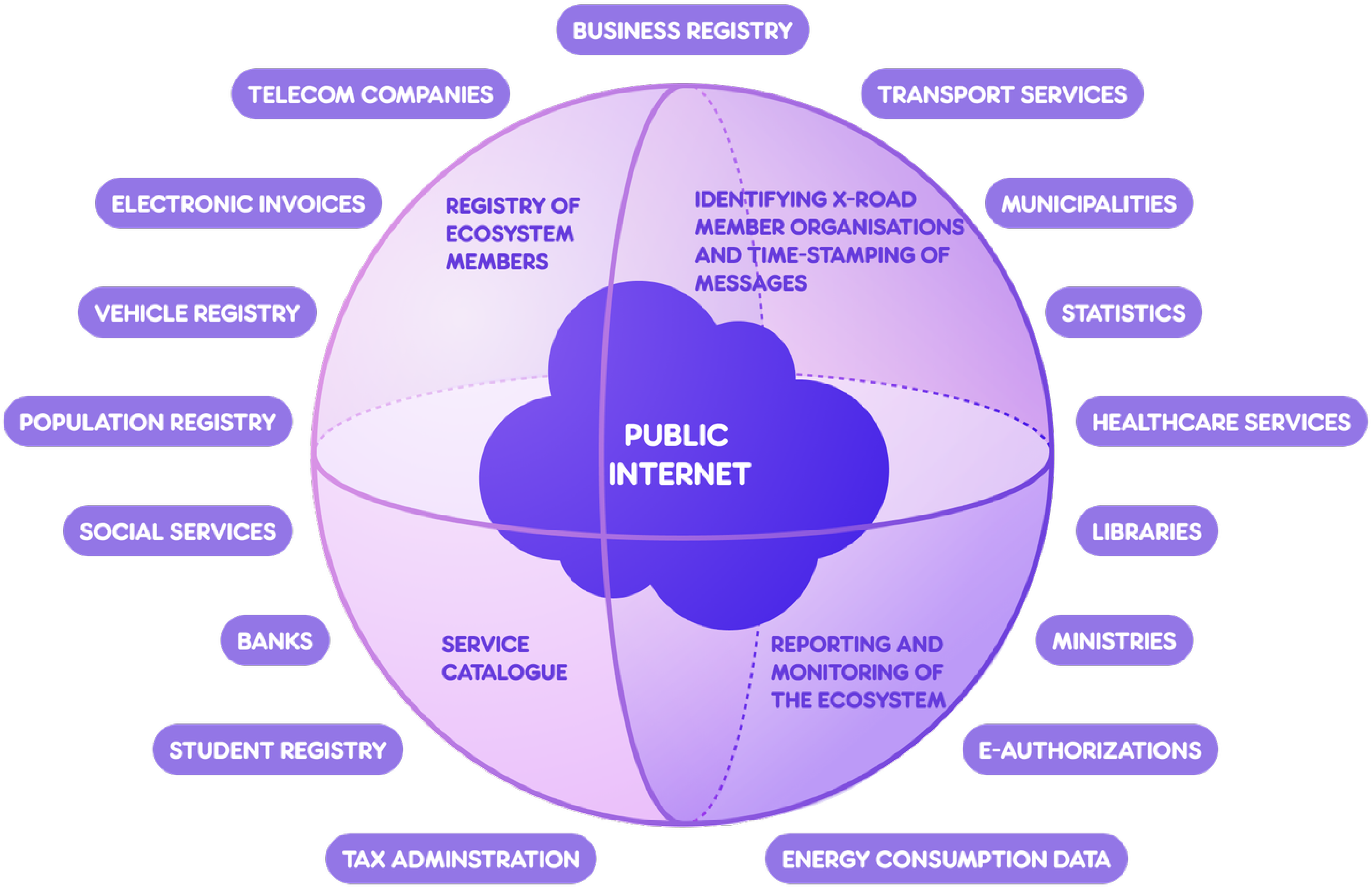
150
COUNTRIES
REPRESENTED IN THE X-ROAD COMMUNITY

3700
MEMBERS
PARTICIPATING IN THE X-ROAD COMMUNITY

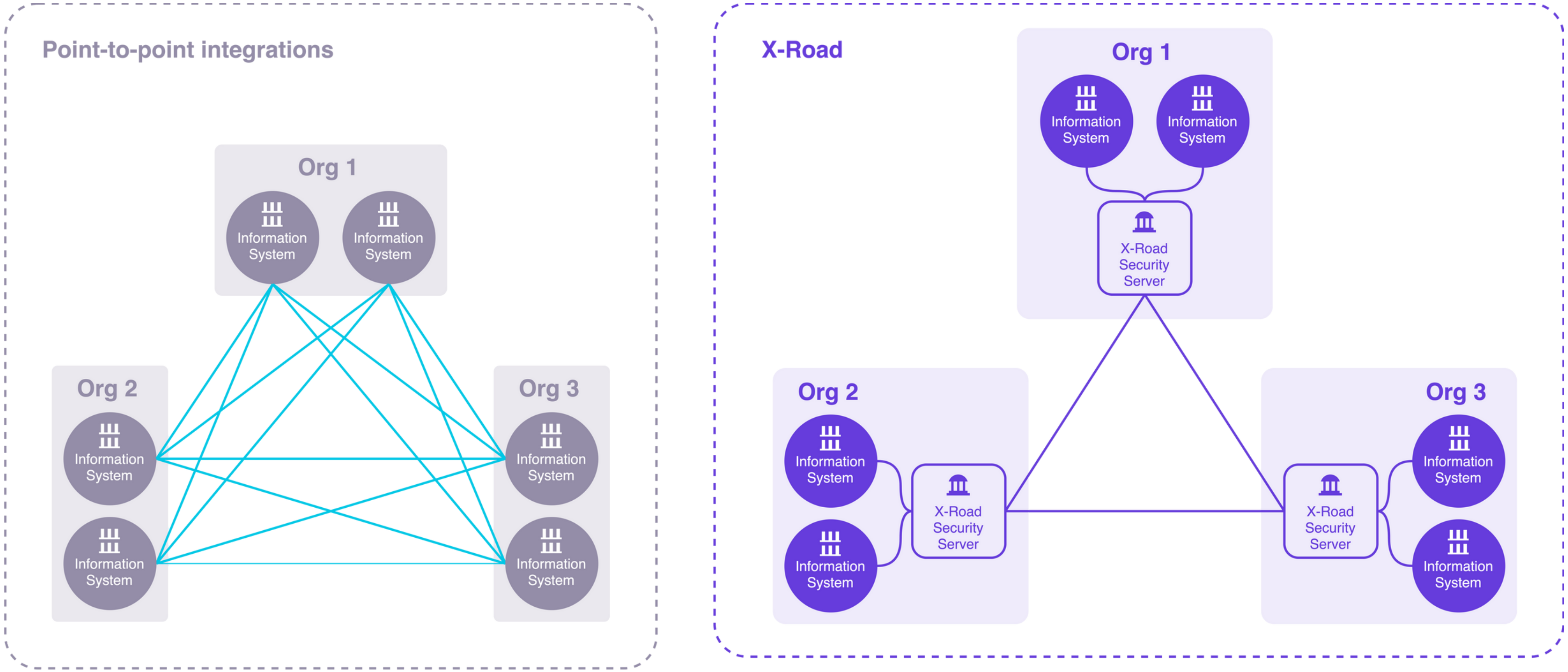
542M
END USERS
WORLDWIDE

COUNTRIES WITH X-ROAD ECOSYSTEMS

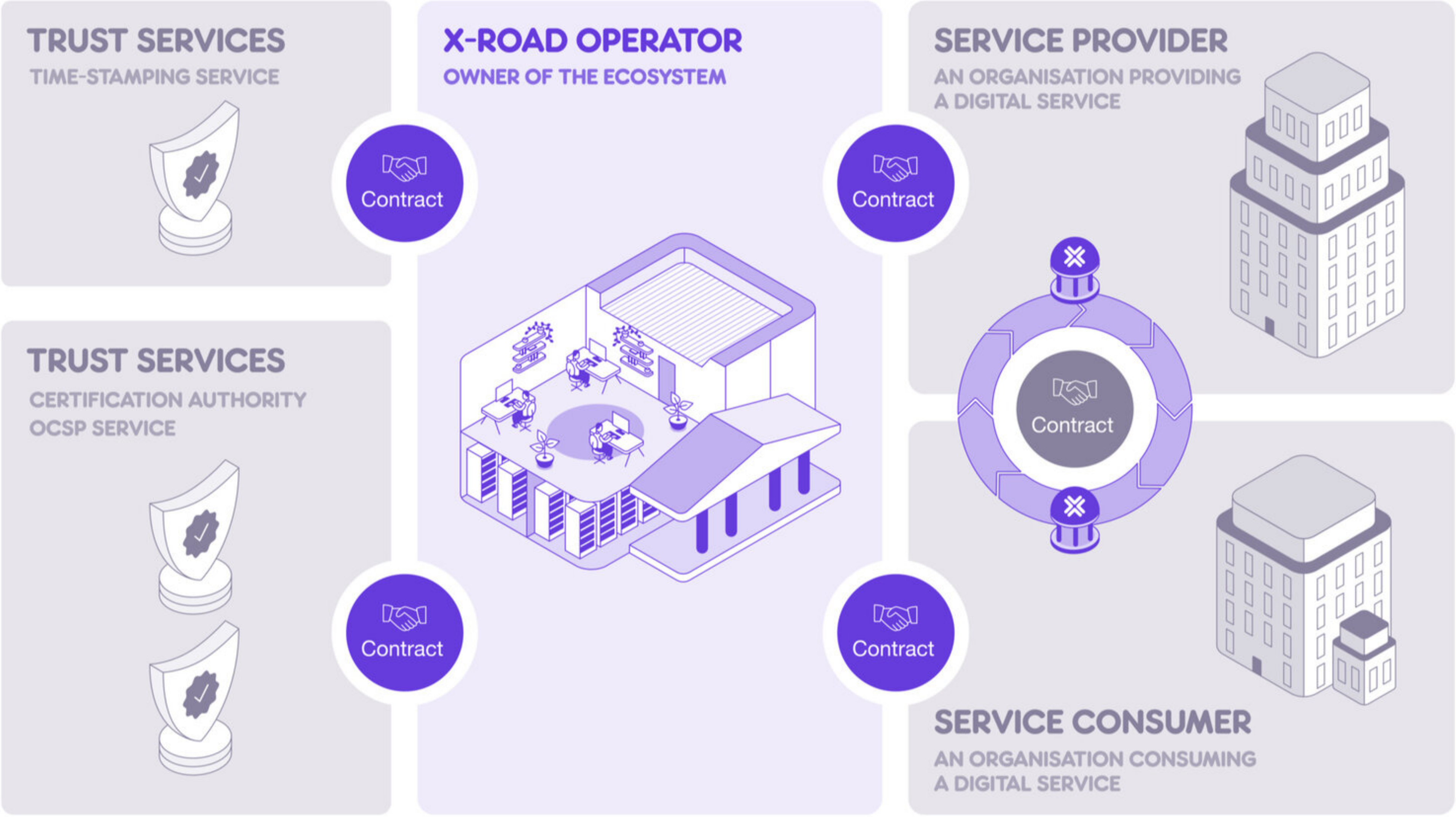



BUSINESS REGISTRY
TELECOM COMPANIES
TRANSPORT SERVICES
ELECTRONIC INVOICES
MUNICIPALITIES
VEHICLE REGISTRY
STATISTICS
POPULATION REGISTRY
HEALTHCARE SERVICES
SOCIAL SERVICES
LIBRARIES
BANKS
MINISTRIES
STUDENT REGISTRY
E-AUTHORIZATIONS
TAX ADMINSTRATION
ENERGY CONSUMPTION DATA
REGISTRY OF ECOSYSTEM MEMBERS
IDENTIFYING X-ROAD MEMBER ORGANISATIONS AND TIME-STAMPING OF MESSAGES
PUBLIC INTERNET
SERVICE CATALOGUE
REPORTING AND MONITORING OF THE ECOSYSTEM

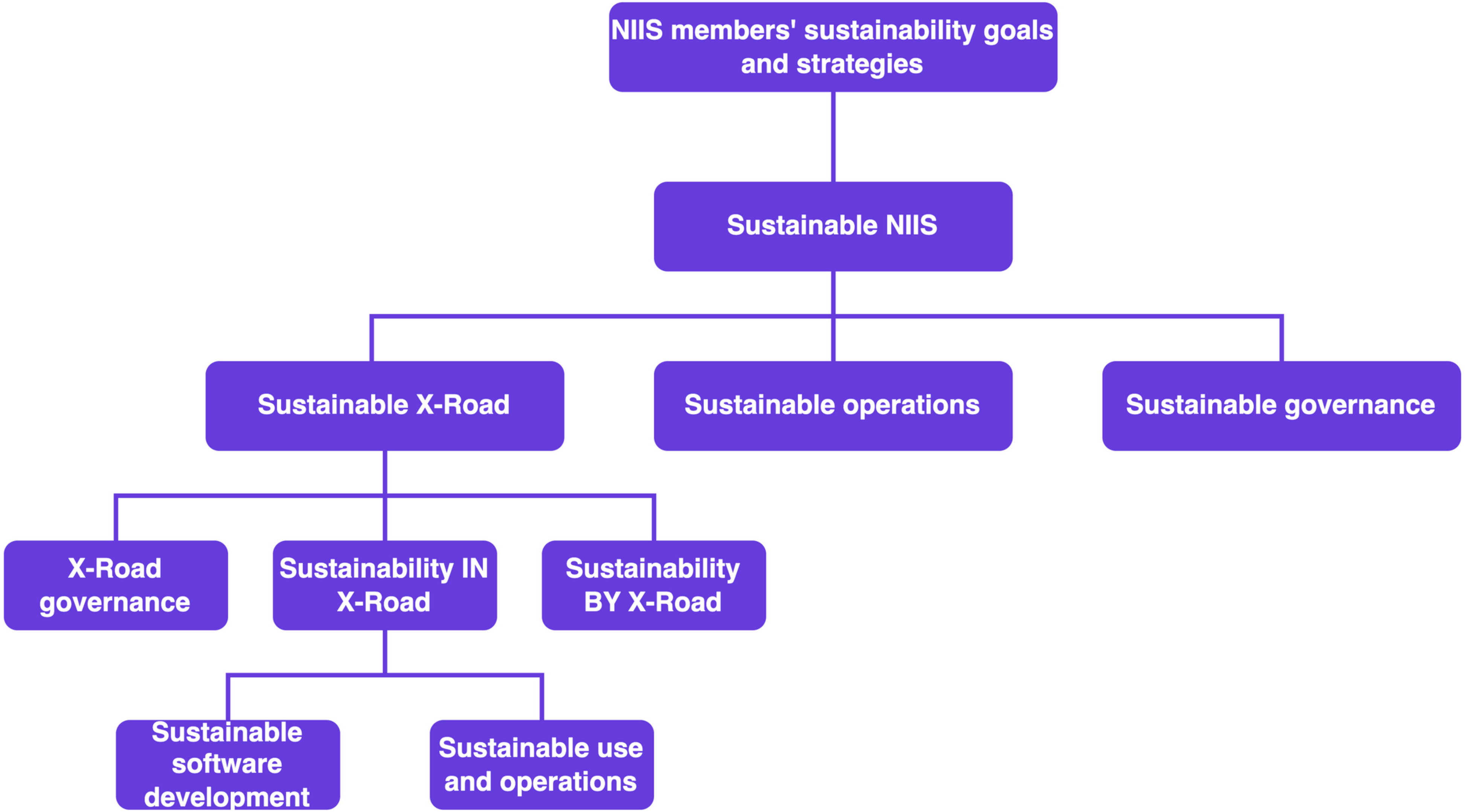
X-ROAD VS POINT-TO-POINT



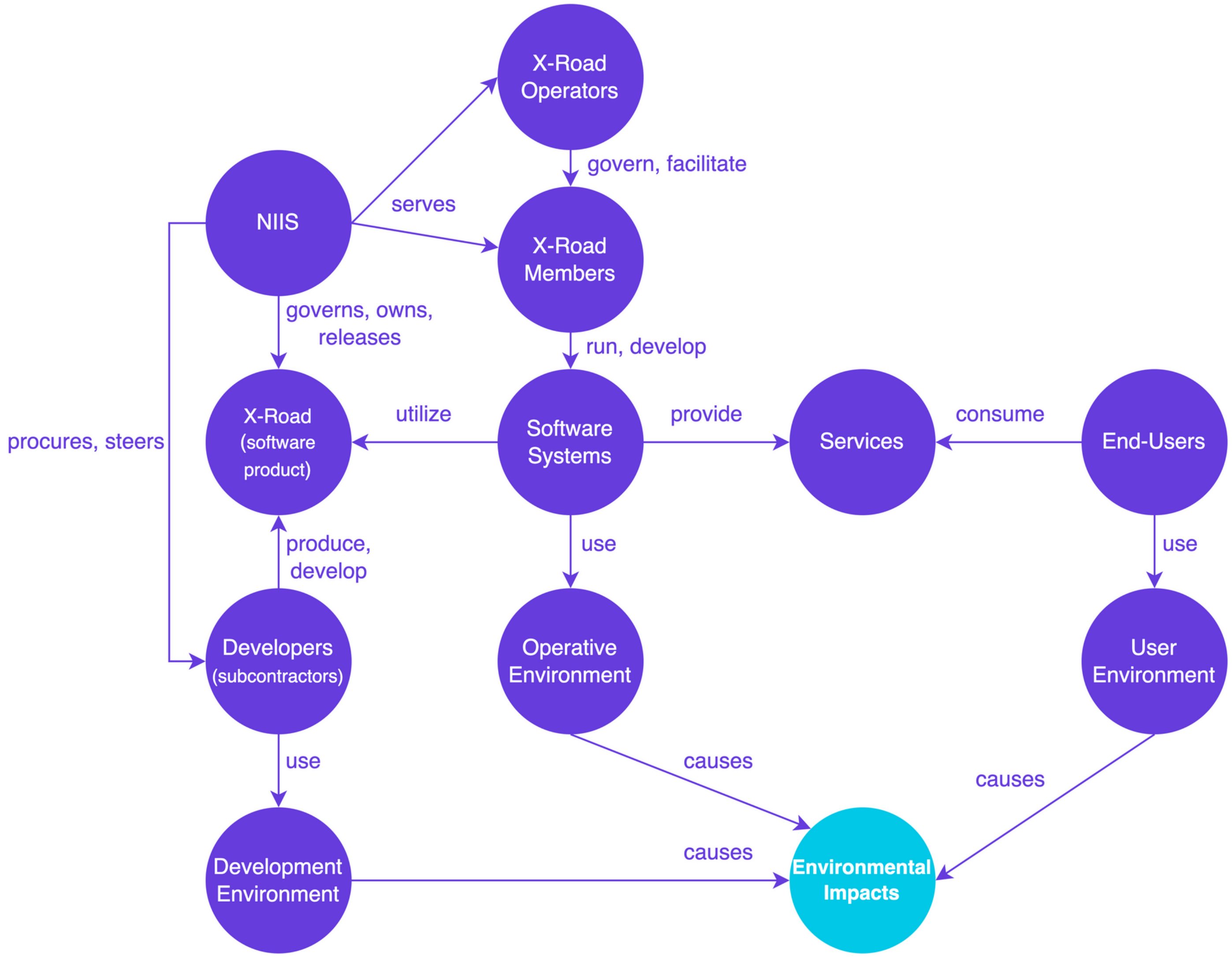
X-ROAD ECOSYSTEM



NIIS SUSTAINABILITY



X-ROAD SUSTAINABILITY - KEY CONCEPTS



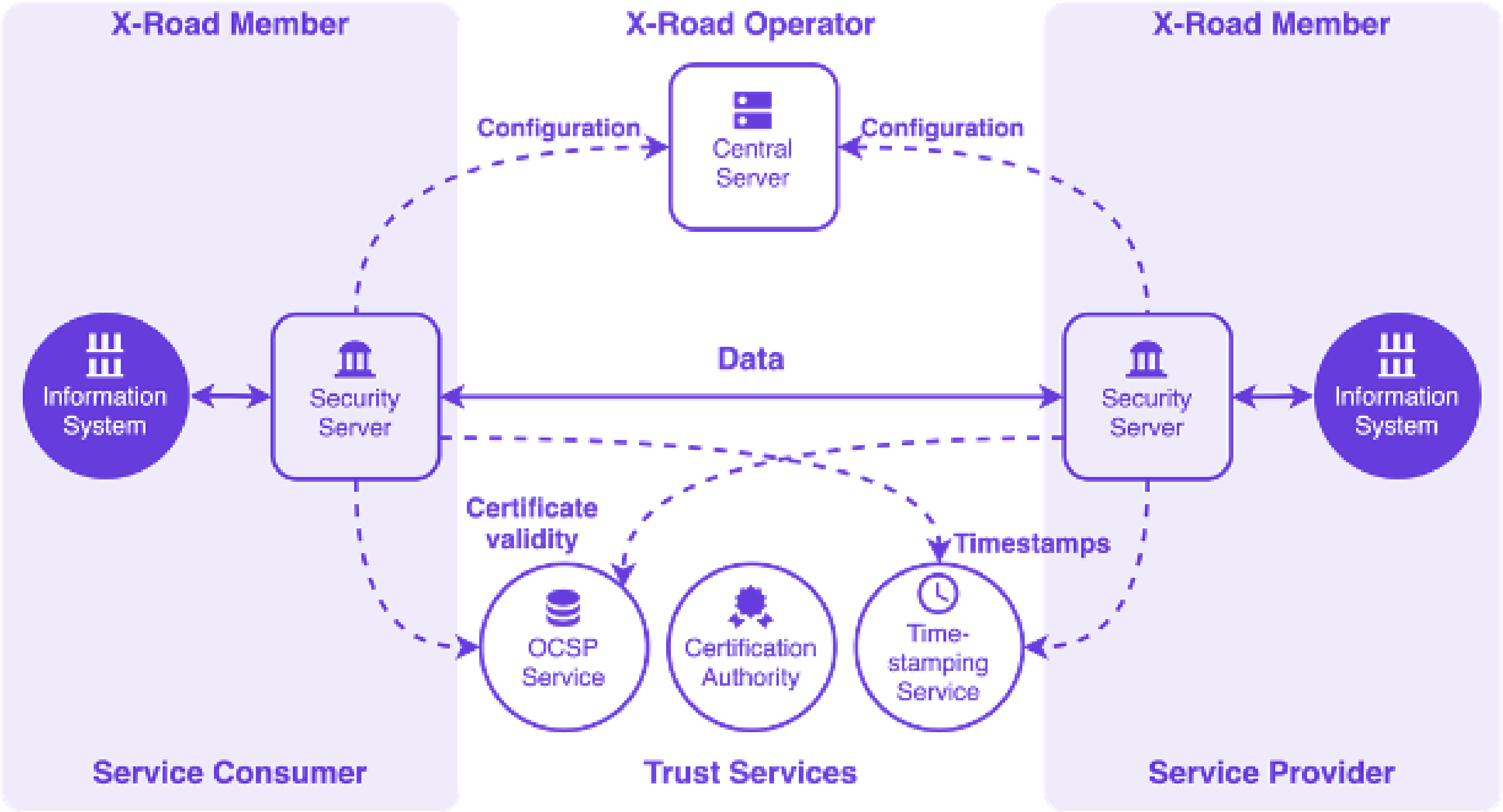
THE STUDY

- To better understand the direct and tangible environmental impacts of the use of X-Road software, NIIS commissioned a study to assess the current emissions profile across X-Road's operations and services.

- In 2021, the study was performed by Gofore and the Stockholm Environment Institute (SEI) in close collaboration with NIIS and the X-Road Governing Authorities in Estonia and Finland.
  - Project report.
  - X-Road Emissions Calculator.

- The study was divided in three phases:
  1. Determining 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 use cases.
  3. Defining recommendations for improving the sustainability of X-Road.

DEFINING THE EMISSIONS BOUNDARY



DEFINING THE EMISSIONS BOUNDARY

- The key function of X-Road is to provide secure data exchange between X-Road members over the public internet.
- Since the Security Server is the key component which is required to process data and enable secure data exchange, it was recognized as the main source of emissions.
- Central Server was not considered in the footprint calculations as its impact is quite minor.
- Information systems and certification authorities that provide trust services were also not included in the footprint calculations mainly because X-Road utilizes them as services while having no direct impact.
- The analysis of the life cycle of different components used by infrastructures that allow X-Road's operations was not a part of the study.

MAIN SOURCES OF CARBON EMISSIONS

Three main sources of carbon emissions were identified:

1. Security Server infrastructure (CPU + RAM)
2. Data transfer
3. Data storage

THE MODEL (1)

- The model was developed using existing research data, best practices, and operational data collected from Estonian and Finnish X-Road ecosystems.
- First, a model to understand the electricity burden of operating one X-Road Security Server was developed.
- Once the electricity consumption of one Security Server was determined, the results were multiplied with the total number of Security Servers in an entire X-Road ecosystem.

ASSUMPTIONS - INFRASTRUCTURE

- The data is from the year 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 Finland.
- Percentage of read/write commands are taken as the same as CPU utilization %.

ASSUMPTIONS - TRANSACTION

- Energy consumption factor for data transfer: 0.0075 kWh/GBs.

  Source: https://onlinelibrary.wiley.com/doi/pdf/10.1111/jiec.12630

ASSUMPTIONS - STORAGE

- All data is stored in HDDs.
- Every Security Server has 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.

THE MODEL (2)

- Another factor to consider is the energy consumption of the supporting infrastructure, e.g., cooling, lighting, etc.
- This is widely considered in the industry through a factor known as the power use effectiveness (PUE).
- PUE describes the amount of energy used by the IT devices compared to the amount used by the supporting infrastructure (in this project a PUE of 1.58 was used).
- Therefore, the total energy consumption of a Security Server is calculated as a product of total electricity consumption and PUE.

THE MODEL (3)

- Finally, the results were converted into an estimation of released emissions by multiplying them by an 'emission factor' for grid electricity.
- The emission factor describes the emissions for each unit of electricity and considers all the different sources of electricity generation within a country or region.

”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.”

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

THE CALCULATOR (1)

1. Emissions by Security Server infrastructure				
Assumptions The main physical infrastructure that enables secure data exchange through X-Road is the Security Server. Security Server contains a processor and RAM as the main energy consuming components. Servers repeat a weekly pattern of data processing. Infrastructure of a Security Server with processor with 4-8 cores is selected for calculations. For simplifications, the model Fujitsu, Server PRIMARY RX1330 M4 in which CPU model: Intel Xeon E-2288G is used as a reference. More information about processor power consumption can be found here RAM of 4-16 GB is recommended for Security Server. Storage space RAM calculations are based on reference values: DDR3 RAM at 1333 MHz.				
Parameters	**Value**	**Unit**	**Parameter explanation**	**Reference values**
Number of Security Servers in public cloud	100	#	Number of Security Servers in public cloud	
Number of Security Servers on premises	100	#	Total number of Security Servers registred in an X-Road instance and evaluated environment	Estonia 173 Finland 290
Emission factor	0,13622	kgCO2e/kWh	The Electricity emission factor that refers to the CO2 equivalent emissions per unit of electricity consumed. Input '0' when using renewable electricity. Emission factors for 2019 can be found here	**Values from 2019** Finland 0,13622 Estonia 0,72328
Processor multiplier	2	#	Multiplier to adjust the energy consumption difference between the average processor selected for this calculator (consisting of 8 cores) and average processor used in your instance. If your processor has half the number of cores (e.g., 4) please input the value of '0.5' if twice the number of cores (e.g., 16) please input the value of '2', if thrice the number of cores (e.g., 24), please input the value of '3' and so on.	Finland 2 Estonia 1
Average CPU utilization	5 %		Average CPU utilization of an average Security Server	Estonia 12-13% Finland 3-5%
Energy consumption in public cloud compared to on-premises	**12 %**		Energy consumption in a public cloud compared to on-premises	12 %
PUE	**1,58**		PUE is the power use effectiveness which is the ratio of total amount of energy used by a computer data center facility to the energy delivered to computing equipment. PUE references: Google, Microsoft Amazon	**Average: 1,58** Google 1,12 Microsoft 1,12 Amazon 1,45
Calculations and intermediate results				
Energy consumption by an average Processor in a week (on premises)	**6326,88**	Wh	The calculation includes the energy consumption of one processor that runs 24/7 based on our reference model and the CPU utilization input	
Energy consumption by the RAM in a week (on premises)	**1145,84**	Wh	The calculation includes the energy consumption of one RAM connected with the processor that runs 24/7 based on our reference model and the CPU utilization input	
Total energy consumption by one Security Servers for one year (on premises)	613,96	kWh	Considering number of weeks to be 52 and the PUE is included as well	
Total emissions by an average Security Server for one year (on premises)	83,63	kgCO2e	These are the emissions if one average Security Server is operated for one year on premises	
Total emissions by an average Security Server for one year (on public cloud)	10,04	kgCO2e	These are the emissions if one average Security Server is operated for one year in the public cloud	
Security Server Infrastructure total				

Emissions calculation of an X-Road instance

This sheet serves to perform CO2 equivalent calculations for a whole X-Road instance. The calculation revolves around numerous assumptions which are stated in the report. Parameter explanations are given in adjacent columns for every single input value. Reference values are also given for each parameter in case a user is not sure about some specific parameter. The whole calculations here are a bit basic, but give a good holistic picture of the emissions of X-Road's operations.

Legend for cell colours

- Input data required from the user
- Predefined input data and assumptions, based on the example of Estonia and Finland (2020)
- Results

2. Emissions by data exchange transactions supported by a Security Server				
Assumptions An average value for electricity consumed for data transfer over a fixed line is used. 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 public internet.				
Parameters	**Value**	**Units**	**Parameter explanation**	**Reference values**
Amount of data exchanged	15000	GB	Amount of data pushed over an X-Road instance in a year	Estonia 33000
Data transfer energy consumption	**0,0075**	kWh/GB	This refers to the electricity consumed when a GB of data is exchanged using internet.	
Emission factor	**0,13622**	kgCO2e/kWh	The Electricity emission factor that refers to the CO2 equivalent emissions per unit of electricity consumed.	
Data exchange total				
Estimated total emissions by data transactions of an X-Road instance for one year	15,32475	kgCO2e		

THE CALCULATOR (2)

3. Emissions by data storage of a message log

Assumptions

The carbon emissions of the message log database that stores the data only for 30 days is insignificant compared to the file archives where data is stored for years. The energy consumption for storing data for 30 days is included in Security Server calculations. The must common practice for storing file archives is on Hard disk drives (HDD). Carbon footprint calculation methodology calculates data storage in HDDs and the resulting emissions.
For calculation simplifications the reference model could be Seagate® BarraCuda® 3.5-inch HDD.

Parameters	Value	Units	Parameter explanation	Reference values
Number of HDDs	290	#	The total number of Hard disk drives (HDDs) utilized in an X-Road instance per year. It may be assumed that every member of the X-Road or every Security Server has one HDD.	Estonia 173
Amount of data stored	5000	GBs	Size of the archive files stored in an X-Road instance in a year. If the requirement is that the whole message has to be logged, then the estimation can be the same as amount of data exchanged. If the requirement is for logging only metadata then the stored data is estimated to be 32-51% of the amount of data exchanged.	
Calculations and intermediate results				
Emission factor	**0,13622**	kgCO2e/kWh	The Electricity emission factor that refers to the CO2 equivalent emissions per unit of electricity consumed.	**Values from 2019** Finland 0,13622 Estonia 0,72328
Idle hours of HDD in a year	**4380**	h	It is assumed that HDD are operating non-stop in a year. Half of their time is consumed in Idle mode and the other half in sleep mode	
Sleep mode hours of HDD in a year	**4380**	h		
Total energy consumption by one HDD in one year	12	kWh		
Data storage total				
Estimated total emissions by data storage of an X-Road instance for one year	476	kgCO2e		

Summary of results

Security Server	Estimated total emissions by Security Servers of an X-Road instance for one year	9367	kgCO2e
Data transaction	Estimated total emissions by data transactions of an X-Road instance for one year	15	kgCO2e
Data storage	Estimated total emissions by data storage of an X-Road instance for one year	476	kgCO2e
Total emissions		**9858**	kgCO2e

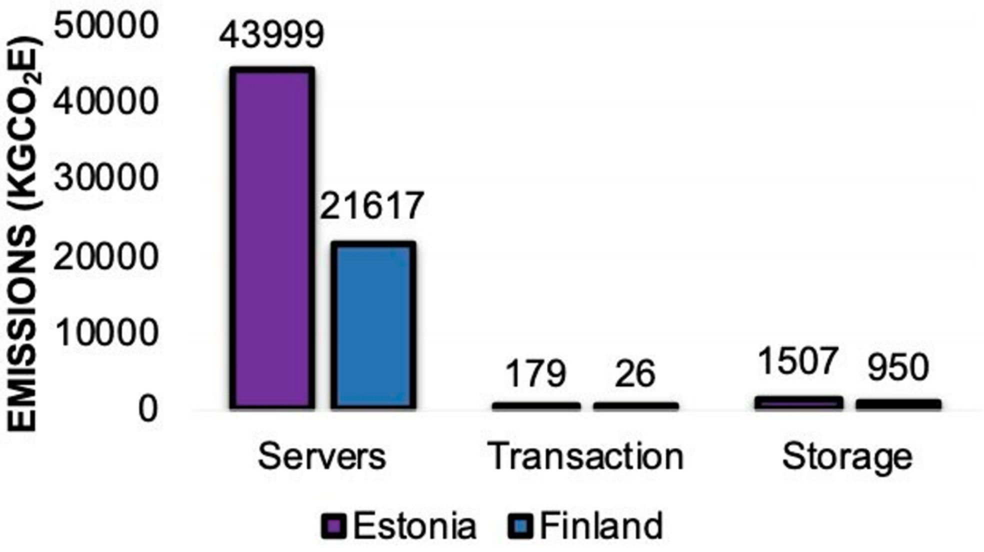
Visualization

Comparison

100 Security Servers, 5000 GBs of data storage and 15000 GBs of data transfer using X-Road translates to emissions equivalent to 9 roundtrips for a flight travelling from Tallinn to Lisbon

Reference journey planner assumes 0.158 kg CO2 / km emissions of a plane and 3312 km between Tallinn and Lisbon

CARBON FOOTPRINT RESULTS (1)



CARBON FOOTPRINT RESULTS (2)

- Around 96 % of total emissions are related to the operations of X-Road Security Servers.
- Data transmission and storage provide marginal contributions to the total carbon footprint (around 1 % and 3 %, respectively).
- The annual carbon footprint for Estonia and Finland was approximated as 45,685 KgCO2e and 22,593 KgCO2e, respectively.

45,685 KgCO2e translates to a diesel train travelling 106 000 kilometers which roughly equals to 68 roundtrips from Tallinn to Tapa.

RECOMMENDATIONS

- Flexibility to disable certain functionalities (e.g., message logging, timestamping), subject to potential performance and security requirements.
- Use an energy tracking application to enable emissions modelling of X-Road servers in real time.
- X-Road governing authorities can provide clear information and support emissions reduction strategies (e.g., permission to use cloud services, reduce message logging etc.).
- Where the option exists, infrastructure should be powered using renewable electricity
- Use of power efficient devices.
- X-Road members to implement X-Road services efficiently and in an optimized way (maximize server utilization, efficient equipment, using cloud if permitted etc.).

SOME FACTORS THAT AFFECT THE CARBON FOOTPRINT OF A SOFTWARE PRODUCT

- programming language
- architecture
- design patterns
- use of threads
- caching
- use of external libraries
- development practices.

CHANGES TO THE X-ROAD PRODUCT

After the research conducted in 2021, some of the feature-related recommendations and additional enhancements have been implemented.

- Entirely turning off message logging has been enabled.
- Different message logging-related alternatives have been documented better.
- A local PostgreSQL server isn’t installed anymore when a remote database is used.
- Better support for running the Security Server on the cloud .

CHANGES TO THE X-ROAD DEVELOPMENT PROCESS AND PRACTICES

- A new online training, Sustainability in Software Development, has been published by NIIS.
- Servers in development and test environments are automatically shut down when not needed.
- Development and test environments run on a public cloud.
- Development and test environments use the cloud's excess capacity (spot instances).
- CI/CD builds have been optimised.

NEXT STEPS

- Continue implementing changes based on the recommendations provided by the study and common best practices.
- In 2023, another research project was conducted in collaboration with the University of Helsinki with the following scope:
  X-Road software development process environmental impacts evaluation and improvement opportunities discovery.
  X-Road environmental handprint evaluation.
  X-Road carbon footprint measurement in actual operative environments compared to the X-Road Emissions Calculator estimations.
- In 2024, the research collaboration with the University of Helsinki continues with the following scope:
  X-Road technical sustainability.
  Environmental sustainability of X-Road ecosystems.
  Sustainability by X-Road through Sustainable Development Goals (SDGs).
- Apply the principles of green software engineering to the X-Road development process.
- Start (automatically) measuring the environmental impact of the X-Road software as a part of the software development cycle.
  Potential tools: GreenFrame.io, Green Metrics Tool

X-ROAD® 8

Are you ready to explore data spaces?

x-road.global/
spaceship