EGDC Case study – City of Stockholm Apartment Heat Optimisation Solution

March 2026

Case Study Methodology

EUROPEAN GREEN DIGITAL COALITION

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1 Introduction

The European Green Digital Coalition (EGDC) is an initiative of companies, supported by the European Commission and the European Parliament, based on the request of the EU Council, which aims to harness the enabling emission-reducing potential of digital solutions on all other sectors.

The main aim of the EGDC is to maximise the sustainability benefits of digitalisation within the ICT sector, while supporting sustainability goals of other key sectors such as energy, transport, agriculture, and construction. The Coalition recognises the need for science-based methods to estimate the reduction and avoidance of greenhouse gas (GHG) emissions by specific ICT solutions across sectors. This will accelerate the sustainability and circular transitions of these sectors while contributing to an innovative, inclusive, and resilient society.

To support the EGDC, a set of case study calculators are developed to provide a practical example of calculating the net carbon impact of a green digital solution in line with the European Green Digital Coalition (EGDC) methodology. This work aims to support the members of the EGDC with Action 2 of the EGDC Declaration.

This case study methodology accompanies the '*City of Stockholm – Apartment Heat Optimisation*' case study calculator and provides further details, additional context and transparency around the case study calculator to ensure the outcomes of the case study are interpreted and used correctly.

Disclaimer for European Parliament Pilot Project – European Green Digital Coalition (EGDC) Case Studies

The following disclaimer is intended to provide clarity and context for the case studies prepared as part of the EP Pilot Project, which have showcased the net carbon impact of specific digital solutions using the EGDC ICT Methodology developed during the project:

1. Purpose of the Case Studies:
The case studies served multiple purposes, including:

- **Development of the Methodology:** They contributed to the development of the EGDC ICT Methodology. These case studies were conducted concurrently with the methodology's creation and served as a valuable testing ground for its initial formulation.
- **Application Examples:** They provided practical examples of how the methodology can be applied to real-life use cases. These case studies were essential in demonstrating the practicality and effectiveness of the methodology when applied to concrete situations.
- **Identification of Improvement Areas:** By conducting these case studies, we aimed to highlight parts of the calculation in need of improvement. They shed light on the challenges and limitations inherent in using available data and indicated the necessary steps to move towards best practices in assessing net carbon impacts.

2. Data Quality as a Key Determinant:
It is imperative to emphasise that data quality is a fundamental determinant of the quality and reliability of the case studies. The accuracy and completeness of the data used significantly influence the outcomes and findings of these case studies.
It is essential to acknowledge that the data available for each case study may differ in terms of accuracy, granularity, and coverage. As a result, the case studies may not necessarily represent the best practice application of the EGDC ICT Methodology. Instead, they reflect the application of the methodology at various stages of data availability.

3. Liability for Errors/Omissions:
While reasonable steps have been taken to ensure that the information contained within the case studies is correct, the EGDC gives no warranty and makes no representation as to its accuracy. We accept no liability for any errors or omissions that may be present in the case studies, methodology, or related information. Users and readers are advised to exercise their judgment and seek further clarification if needed, as the information provided may evolve over time and depend on external factors beyond our control.

4. Appropriate Use of the Case Study Calculators:
The case study calculators are intended for educational and informational purposes. They rely on certain assumptions and input data to generate results.
The results of the calculators are specific to the implementation of the ICT solution and may not be representative for other implementation contexts.
As such, it is imperative for users to refrain from directly extrapolating these results to ICT solutions or implementation contexts that may seem conceptually similar.
Instead, users are advised to use the calculators as a means to understand the practical application of the EGDC ICT Methodology, thereby equipping themselves with the knowledge required to develop customised calculators specifically tailored to their unique ICT solutions and implementation circumstances.

In conclusion, these case studies provide valuable insights into the calculation of the net carbon impact of digital solutions through the practical application of the EGDC ICT Methodology. However, it is vital to exercise caution when interpreting the results, considering the variances in data quality and the evolving nature of the methodology. The findings are indicative of the methodology's potential and its room for refinement as we work towards more accurate and comprehensive assessments of net carbon impacts.

2 Results

ICT Solution and assessment overview
Stockholmshem, one of Sweden's largest municipal housing companies, launched a large-scale project to optimise heating in 21,678 of its 29,000 apartments. This involved installing over 21,678 temperature sensors connected to an AI-based control system to reduce energy consumption and improve indoor climate comfort. The solution was implemented gradually between 2021 and 2024. This case study is an ex-post assessment carried out on Stockholmshem's 21,678 residential apartments in Stockholm, Sweden comparing data for a period of 1 year in 2021 and 2024.

Quantified impacts	
Assessment period:	1 year
Net carbon impact range:	-276 to –545 tCO2e
Net carbon impact:	-389.12 tCO2e
Net impact per sqm:	-0.3 kgCO2e/year

Organisational contribution
Stockholmshem is responsible for deploying the solution. This aligns with A-level classification as defined by ITU-T L.1480 (contribution of implementing the integrated solution or the innovation of the solution).

Other identified impacts
Reduction in energy use leads to significant cost savings. If all cost savings are invested into typical business carbon-intensive activities, it is estimated that this increase in emissions could result in a ~16% reduction of the total net impact. However, Stockholmshem has confirmed that any cost savings achieved through the solution will be reinvested into additional energy efficiency initiatives across its residential buildings. The solution also enables more stable indoor temperatures which reduces the use of energy at peak times and avoids the use of fossil fuel powered "peaker" plants. However, this has not been quantified due to insufficient data.

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3 Methodology

Name of solution	
Assessment Objective	The purpose of this assessment is to quantify the avoided emissions from Stockholmshem's Apartment Heat Optimisation project by comparing the energy consumption within Stockholmshem's apartment buildings before and after implementing the solution. The output of the assessment will demonstrate the solution's impact on energy consumption and CO_2 emissions reductions. The assessment will focus on a single implementation context: 21,678 apartment buildings located in Stockholm, Sweden with a total floor area of 1,474,751 m^2. An ex-post assessment will be conducted, drawing on operational data from before and after solution deployment to establish a robust comparison.
Solution Description	With the apartment heat optimisation solution, the energy needed for the heating system in residential buildings is based on a simulated model considering the outdoor temperature and apartment temperatures instead of only the current outdoor temperature. The solution measures the indoor building temperature and humidity using sensors and combines this with individual settings for each property using AI to predict demand and optimise the energy use. The avoided emissions mechanism is achieved by reducing energy consumption for district heating, thereby lowering the CO_2 emissions associated with generation. The AI also allows for short periods of slightly cooler indoor temperatures when predicting that the indoor or outdoor temperature is expected to

<table>
<tr><td></td><td>rise. This enables more stable indoor temperatures which reduces the use of energy at peak times and avoids the use of fossil fuel powered "peaker" plants.</td></tr>
<tr><td>Solution Boundary</td><td>The solution is made up of the following components used in residential apartments.

Digital components:
• Gateway enabling interoperability and data management.
• IoT sensors monitoring temperature, humidity & pressure' differentiation
• Cloud processing and storage
• Real-time AI/ML optimisation controlling energy consumption
Non digital components:
• Previously installed heating systems, including boilers and radiators

These components work together to enable automated, data-driven control of the ventilation system within the office building.</td></tr>
<tr><td colspan="2">Components of the solution:


Cloud storage (Azure cloud)

30 IOTSU sensors
26 - temperature & humidity
4- differential pressure

Access Point for LoRa technology</td></tr>
<tr><td>Functional Unit</td><td>per square meter per year</td></tr>
<tr><td>Calculation Boundary</td><td>The calculation represents a one-year period using data collected in 2021 before the solution was implemented and 2024 when the solution had been fully implemented across all apartments.

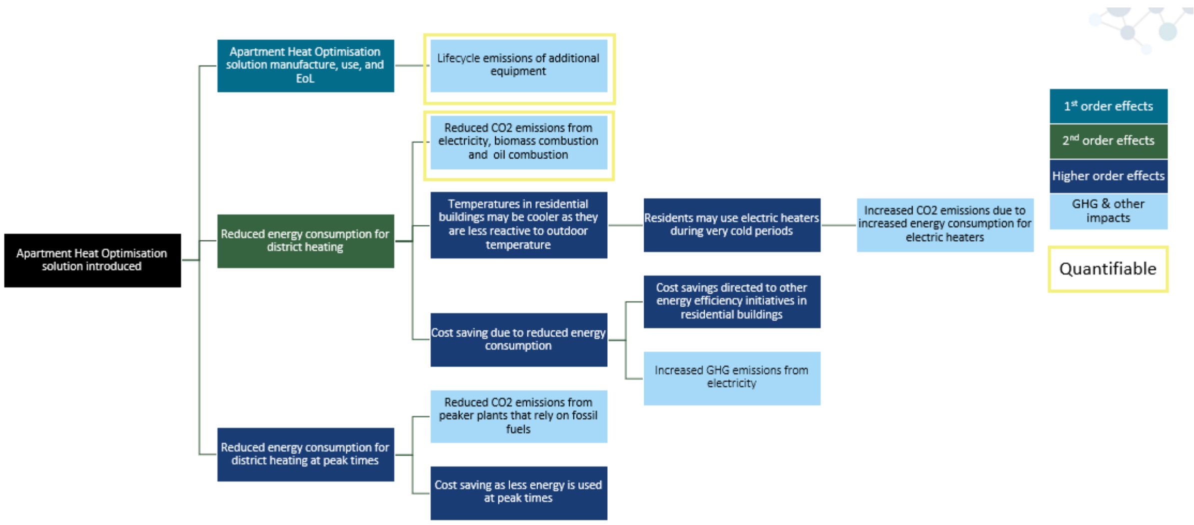
The geographic boundary of the solution is limited to Stockholm, Sweden, where the residential apartment buildings are located.</td></tr>
</table>

Reference scenario	In the reference scenario, the energy needed for the heating systems in Stockholmshem's residential apartment buildings in Stockholm, Sweden is based on the outdoor air temperature regardless of the temperature inside the apartment. This baseline is supported by secondary literature which states that "in Swedish residential buildings connected to district heating (80% of multifamily buildings), the heating power is adjusted on the building level by controlling the supply temperature to the radiator system based on the outdoor temperature" (Building and Environment, 2022). Stockholmshem's Energy Monitoring Program collected one year of primary data on energy consumption in residential apartment buildings prior to the solution implementation in 2021. All energy consumption data is normalised with regard to the normal outdoor temperature.
Description of 1st order effects	The first-order effects of the Apartment Heat Optimisation solution are related to the direct environmental impacts arising from the deployment and operation of the system's components. These include the embodied emissions, use-phase emissions, and end-of-life emissions of the hardware, as well as the emissions from cloud computing resources. Three categories of components are considered for this solution: **1) Cloud Storage and processing** • Emissions have been estimated using secondary data, average costs for a similar solution per year, and Extended input output (EIO) emission factors which are industry average emission factors. **2) Sensors (IoT – temperature & humidity, 1 per apartment)** • Only embodied and end-of-life emissions are considered since the sensors are battery-powered. **3) Access Point (Gateway for LoRa Technology)**

	• Emissions include use-phase electricity consumption, embodied emissions from production, and end-of-life treatment.
Description of 2nd order effects	The 2nd order effects of the solution is the decrease in energy consumption for district heating that occurs when the apartment heat optimisation solution is implemented. With the apartment heat optimisation solution, the energy needed for the heating system in residential buildings is based on a simulated model considering outdoor temperature and apartment temperatures instead of only the outdoor temperature. The solution measures the indoor building temperature and humidity using sensors and combines this with individual settings for each property using AI to predict demand and optimise the energy use. This optimisation reduces energy consumption and therefore reduces the associated CO_2 emissions from district heating generation. Data on annual energy consumption was collected from 21,678 apartment buildings. The solution was implemented gradually from 2021 to 2024. Data from both before the solution was implemented in 2021 and after the solution had been fully implemented in 2024 was used to calculate the reduction in energy consumption. During this time, buildings without heat optimisation also saw a reduction in energy use due to other energy saving measures such as improved insulation, therefore a control is used to isolate the impact that can be attributed to the solution. All energy consumption data is normalised for outdoor temperatures, as heating demand varies significantly with weather conditions.

Description of higher order effects	The reduction in unnecessary energy consumption leads to significant cost savings for Stockholmshem. This could have several benefits, including investing in additional energy efficiency initiatives across its residential buildings. Another important impact of the solution is that the AI also allows for short periods of slightly cooler indoor temperatures when predicting that the indoor or outdoor temperature is expected to rise. Therefore, the solution enables more stable indoor temperatures which reduces the use of energy at peak times and avoids the use of fossil fuel powered "peaker" plants. This effect was not quantified due to insufficient data but could be reconsidered in the future if more data becomes available.

Mapping of 2nd order and higher order effects



Assessing the impact of higher order effects

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Higher order effect	Description	Magnitude	Likelihood
Increased use of electric heaters during very cold periods	As buildings are less reactive to outdoor temperatures, tenants may use electric heaters during very cold periods, leading to increased electricity consumption.	**Medium:** if this behaviour was adopted across all apartments, the increase in electricity consumption could be substantial.	**Low:** the solution allows for a very small and temporary reduction in indoor temperature, with the expectation that tenants will not notice it at all.
Reduced energy consumption at peak times	Reducing energy consumption at peak times could reduce demand for fossil fuel powered peaker plants, lowering the carbon intensity of district heating.	**High:** depending on the number of apartments, this could have significant benefits for emission reductions.	**High:** the solution explicitly aims to reduce energy consumption at peak times.

Higher Order Effect	Quantitative Assessment	Magnitude	Likelihood	Mitigation
Cost savings due to reduced energy consumption	**Energy Savings kWh/year:** 8,258,606 kWh **Cost of district heating in Sweden (SEK/kWh) - Link**: 0.98 SEK/kWh **Cost of district heating in Sweden ($/kWh):** $0.10 $/kWh (exchange rate 18th March 2026) **Cost of energy saved per year ($/kWh):** $825,860.60 **EIO Factor OPEN CEDA (Tenant occupied housing, Sweden) - Link**: 0.068 kgCO2e/$ **Estimated emissions impact:** 56.16 tCO2e/year	**High:** 14% of total carbon savings enabled by solution.	**High:** unless cost savings are ring fenced for specific activities	Stockholmshem has confirmed that any cost savings achieved through the solution will be reinvested into additional energy efficiency initiatives across its residential buildings.

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Description of calculation	**1st Order Effects** The solution emissions are calculated by summing the annualised embodied emissions, annual use-phase emissions, and annualised end-of-life emissions of all hardware, as well as emissions related to the use of data transfer and storage via cloud services. Emissions from the cloud platform have been estimated based on secondary research and assumptions as no primary data was provided by Stockholmshem. The emissions associated with the AI model have not been calculated as no primary data was provided, and this was deemed to be immaterial. Use-phase emissions for the IoT Gateway have been calculated from the annual electricity consumption of each device multiplied by the relevant emission factor for the electricity grid. No use-phase emissions have been considered for sensors, as they are battery-powered. Embodied emissions account for the contributions from materials used in device components, divided by the expected lifetime of the device. End-of-life emissions are calculated by multiplying the weight of the device or sensor by the relevant waste emission factor and dividing it by the device's lifetime. The rate of recycling vs landfill is assumed to be in line with the 2023 EU Average of 30.8% recycling to 69.2% landfill based on European Environment Agency data. Total first-order emissions are obtained by summing up the contributions from all devices and the cloud platform, including embodied, use-phase, and end-of-life emissions. **2nd Order Effects** The second-order effects represent the emissions avoided due to reduced energy consumption in apartments after implementing the heat optimisation solution. They are calculated as the difference between the baseline annual electricity emissions before the solution and the annual electricity emissions after the solution is in place.

	Buildings without heat optimisation also saw a reduction in energy use due to other energy efficiency measures such as improved insulation. Therefore, a control was to distinguish and accurately attribute the effects specifically to the heat optimisation solution. The control is subtracted from the change in emissions between the reference and solution scenario. To ensure a fair comparison between test and control groups, two categories of buildings were excluded from the analysis. Newly developed buildings (less than 5–8 years since completion) were excluded, as their energy consumption profiles are atypical due to early-stage operational effects and system optimisation, and because these buildings use different sensor technologies. These buildings were removed from the control scenario as no newly developed buildings were included in the test scenario. Properties with sold district-heating distribution systems were also excluded from both scenarios, as changes in ownership of distribution infrastructure mean that measured district-heating consumption no longer includes distribution losses, making energy use non-comparable with other properties. **Net Carbon Impact** The net carbon impact is calculated by subtracting the first-order emissions generated by the solution itself from the second-order effects. This ensures that the environmental benefit accounts for the emissions embedded in the solution components and cloud usage, providing a more accurate measure of the net reduction in greenhouse gas emissions.
Net Carbon Saving Impact of the Solution	1st order effect (emissions from solution components): 7.3 tCO2e/year 2nd order effect (avoided emissions from reduced energy use): -396.4 tCO2e/year Total net carbon saving impact: -389.1 tCO2e/year **Other Savings from reference scenario:**

	% Energy savings through use of the solution: 4.2% CO2 emissions reduction per square meter per year: -0.3 kgCO2e/m²/year
Uncertainty and sensitivity analysis	**Total carbon savings enabled (tCO_2e):** Calculated Net Avoided Emissions: -148.4 Lower uncertainty range: -275.7 Higher uncertainty range: -544.8 **Uncertainty & Sensitivity Analysis:** Energy consumption is the main driver of uncertainty. In the ranges assessed, electricity-related emissions (2nd order effects) vary from 278.5 tCO_2e to 564.3 tCO_2e. The sensitivity analysis indicates that the net carbon impact is most sensitive to this input (~5%) meaning that the quality of the data used will significantly impact the reliability of the results. The data quality of this input ranges from good to very good. The uncertainty analysis indicates that the activity data and emission factors used for the cloud storage emissions are of low quality which impacts the reliability of the results. Emissions range from 1.7 tCO2e to 13.9 tCO2e. However, the sensitivity analysis shows low sensitivity of (<1%), meaning that this does not have a significant impact on the net carbon impact of the solution. The remaining first order effects for Sensors and Gateways have low uncertainty and sensitivity (<1%) meaning that this will have minimal impact on the results of the net carbon impact calculator. It should be noted that the analysis performed is not a quantitative uncertainty analysis. By providing a more granular view of data quality, which builds on the data quality assessment, this analysis highlights areas of uncertainty within the calculation using a qualitative assessment framework. It can however be used to feed into a quantitative uncertainty analysis using guidance from the Greenhouse Gas Protocol on Quantitative

	Inventory Uncertainty: https://ghgprotocol.org/sites/default/files/2022-12/Quantitative%20Uncertainty%20Guidance.pdf
Assumptions	**Bill of Materials and Component Weights** • The weights of individual components have been assumed based on available specifications for comparable products. • Where exact data was not available, the Bill of Materials (BOM) was estimated, and missing values were calculated by deducting known component weights from the total product weight (e.g., chassis, plastics). • All sources and technical references used for these assumptions are stored within the calculator and can be consulted if needed. **Performance and Efficiency** • Power supply efficiency has been assumed at 82%, reflecting average performance of commercial power supplies. **Lifetime of Devices** • When the lifetime was specified in the product sheet, that value was used. • When lifetime information was not available, an assumption was made based on comparable devices, with all references and justification available in the calculator. **Estimation Methodology** • For missing weight data, values were back-calculated by deducting known components from the total product weight. • For cables, a rough estimation has been applied in the absence of detailed specifications. • All assumptions regarding hardware components and BOM are based on secondary data sources available in the calculator. **Operational Assumptions** • Energy consumption was provided as kWh/m2/year so this has been multipled by the total apartment area in m2 to caculate the total energy consumption. **Emissions** • For the cloud solution, emissions data is based on secondary data and research as primary data was not provided.

	• It is assumed that the district heating emissions factor used from Stockholm Exergi's 2024 Annual Report accounts for full lifecycle CO2e/kWh.
Data sources	**Data provided by Stockholmshem:** • Raw data on the energy consumption before and after the solution was implemented. • Data used to normalise energy use – EnergiIndex – which is a summary of the total effect caused by temperature, solar radiation, cloudiness and wind power. • Data sheets for the solution components – ERS Lite LoRaWAN Wireless Sensor and MultiTech Conduit AP – Access Point for LoRa Technology. • Emissions intensity for the district heating energy consumption via Stockholm Exergi. **Other data sources:** • All secondary data sources used during calculations of the 1st order effects have been linked within the calculator
Input adjustments and key considerations for usage of results	**List of things to consider if using results in other use cases:** • Country (for the electricity grid) • Location, city • Building type • Area of the apartment buildings (m2) • Energy consumption • Data period and year • Control data
'Do no significant harm' criteria	Do not foresee any negative impacts on any of the EU Taxonomy's environmental nor social objectives and strongly supports objective 1. Climate change mitigation. The Apartment Heat Optimisation solution is scalable, while also having the potential to improve quality of life and human comfort.

Key areas for improvement	1. The primary area for improvement lies in the assessment of first-order effects, as the analysis relied heavily on secondary research, assumptions, and estimates due to the limited availability of primary data. This reliance introduces greater uncertainty into the calculated impact and highlights the need for more robust, directly sourced data in future assessments. 2. Analysis of higher order effects could also be improved by providing actual costs as the quantitative element of this is currently assessed using EIO factors.