Big data-analys för energieffektivisering av städer

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E2B2

Förord

E2B2s vision är en resurs- och energieffektiv byggd miljö.

Bebyggelsesektorn svarar för cirka en tredjedel av Sveriges totala energianvändning och en effektivare energianvändning är en viktig del av utvecklingen av energisystemet. Hållbarhet, effektivitet och robusthet i bebyggelsen behöver stärkas och utvecklas. Lösningarna behöver samspela för att fungera och utnyttjas. Forskning, utveckling, innovation och kommersialisering spelar en avgörande roll.

I E2B2 arbetar forskare och andra aktörer tillsammans för att utveckla samhällets byggande och boende och effektivisera energianvändningen. Syftet med E2B2 är att ta fram ny kunskap, teknik, tjänster och metoder som bidrar till en hållbar energi- och resursanvändning i bebyggelsen.

E2B2 är ett forsknings- och innovationsprogram från Energimyndigheten där IQ Samhällsbyggnad är koordinator. Programmet startade 2013 och en andra programperiod pågår mellan 2018 och 2024. Projektet som beskrivs i den här rapporten har genomförts i programmet med hjälp av statligt stöd från Energimyndigheten.

Stockholm, 21 december 2022 (Reviderad 21 december 2024)

Rapporten redovisar projektets resultat och slutsatser. Publicering innebär inte att Energimyndigheten tar ställning till framförda slutsatser, resultat eller eventuella åsikter.

Sammanfattning

Projektets huvudsakliga syfte var att utveckla beslutsstödsverktyget Oden för att förbättra energieffektiviteten och **optimera energianvändningen i stadsmiljöer**. Projektet inriktade sig på att tillgodose de unika behoven inom konsortiet, inklusive Stockholms stads miljöförvaltning, Familjebostäder, Stockholm Stadsus AB och L&T, för att möjliggöra en hållbar stadsutveckling.

Projektets intressenter och partners har bekräftat behovet av en betydande förändring i hur **fastighetsenergidata** samlas in, struktureras, bearbetas och nås, för att frigöra enorma miljömässiga och ekonomiska vinster för energibolag, storskaliga fastighetsägare och bostadsrättsföreningar.

Projektet har dragit nytta av stora och komplexa datauppsättningar relaterade till den byggda miljön för att skapa en **nationell och harmoniserad datahub** för byggnadsenergidata, kopplat den till moderna **simuleringar** både på byggnadsnivå men viktigare på stadsdelsnivå, och skapat beslutsstödsverktyg för projektets partners och tillkommande intressenter

I denna riktning mobiliserades ett bredare nationellt konsortium av tre stora svenska städer, tillsammans med deras medföljande energibolag, fastighetsägare och akademi för att bilda ett konsortium för NUE Data Lab som kommer att ansöka om att bli ett kompetenscenter med Energimyndigheten 2026. Fram till dess kommer tjänsterna som skapats från detta projekt, inklusive Oden och OdenLife, att fortsätta att skapa värde för Stockholms stad, ElectriCITY Stockholm och har också nyligen fått uppmärksamhet från den europeiska kontinenten.

Summary

The primary objective of the project was to develop the decision-support tool Oden to enhance energy efficiency and **optimize energy usage in urban environments**. The project focused on the unique needs of project partners, including Stockholm City Environmental Administration, Familjebostäder, Stockholm Stadshus AB, and L&T, while promoting sustainable urban development.

The project stakeholders and partners have confirmed the need for a substantial shift in how **building energy data** is collected, structured, processed, and accessed, in order to unlock massive **environmental and financial gains** for energy utilities, large-scale building owners, and homeowner associations.

The project has drawn upon large and complex data sets relating to the built environment, to create a **national and harmonized data hub** of building energy data, coupled it with state-of-the-art **building simulations** on both a **building scale**, but more importantly on a **district scale**, and provided proof-of-concept decision support tools to the projects stakeholders and beyond.

In this direction, a wider **national consortium** of three large Swedish cities, with their accompanying energy utilities, building owners, and academia mobilised to form a consortium for NUE Data Lab that will apply to become a competence centre with the Energy Agency 2026. Until then, the **services** created from this project including Oden and OdenLife will continue to create value for the City of Stockholm, ElectriCITY Stockholm, and have also recently been garnering attention from the European continent.

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1 Introduction and background

1.1 Background

Energy efficiency in the existing built environment is one of the most important strategies for local governments for reaching their local climate targets. However, the existing data available is insufficient, making it very difficult to determine where and how the best investments can be made. Fortunately, there are already tremendous amounts of data available in cities that can be used to help municipalities and building companies to answer the following question: "Which buildings, with what characteristics, should be retrofitted with what measures to achieve our goals with the lowest societal investment cost?" During the first phase of the project, KTH’s research group UrbanT, together with City of Stockholm, L&T, and the consortium partners, have developed processes, agreements, methods and an alpha version of a decision support tool called "Oden" to help answer these questions. In this phase, Oden was developed into a prototype decision-support tool for key relevant stakeholders.

1.2 Aim and objectives

The project's aims and objectives can be summarised as follows:

1. Mapping the consortium's needs and objectives for the further development of the decision support tool Oden. Oden will primarily be built for three stakeholder groups: Stockholm City's Environmental Administration as a basis for climate and energy planning, Familjebostäder and Stockholm Stads as a basis for efficiency targets, and L&T for mapping the market for energy services.

2. Further development of methods and calculation models to expand the inclusion of various property types and measures that can be used for large-scale analysis.

3. Creation of the visualization system Oden Light, or "Energy Map," which provides aggregated energy mapping and information for public consumption and dissemination, similar to Stockholm's solar map. Stakeholders include urban planners, property owners, energy service companies, housing cooperatives, students, and public users.

4. Development of a national database and methods for evaluating the measured effects of completed efficiency projects.

5. Identification of possible business models that, in collaboration with energy companies, can enable long-term building efficiency projects in other cities.

6. A report with recommendations to Boverket on identified quality issues for future energy declarations, offering insights on how to enhance the system's effectiveness and reliability.

1.3 Scope and limitations

The primary aim of the project was to develop an advanced decision support tool, Oden, for enhancing energy efficiency and optimizing energy usage in urban environments. The project focused on addressing the unique needs of various stakeholder groups, including Stockholm City's Environmental Administration (sv. Miljöforvaltningen), Familjebostäder, Stockholm Stadshus, and L&T, while fostering sustainable urban development and facilitating the implementation of innovative energy solutions.

The project had certain limitations that needed to be considered while interpreting its results and outcomes:

Data availability and quality: The project relied on data from various sources, and the quality and completeness of this data have impacted the accuracy of the developed models and analysis in areas outside of Stockholm where data coverage was weaker.

Stakeholder engagement: While the project aimed to address the needs of a diverse group of stakeholders, it may not have been able to fully satisfy the unique requirements and expectations of each individual stakeholder.

Scalability: Although the project explored the potential for scaling up its results and solutions, the actual implementation of these solutions in other cities and regions is limited by data, regulation and business models.

2 Implementation

The project, executed primarily during the unprecedented pandemic period in Stockholm, was led by the KTH Royal Institute of Technology, in close collaboration with the City of Stockholm, Familjebostäder, L&T, Svenska Bostäder, Stockholm Exergi, Sweco, ElectriCITY Stockholm, and other relevant stakeholders. The project aimed to develop innovative and sustainable solutions for energy efficiency and optimization within the urban environment.

The project was organised around five distinct work packages, each focusing on a specific area of research and development (Figure 1). These work packages included: WP1 Stakeholder Analysis, WP2 Methods and Calculations, WP3 Visualization, WP4 Scaling up the Results, and WP5 Project Management. Each work package contributed to the overall success of the project, providing a comprehensive approach to achieving the desired outcomes.

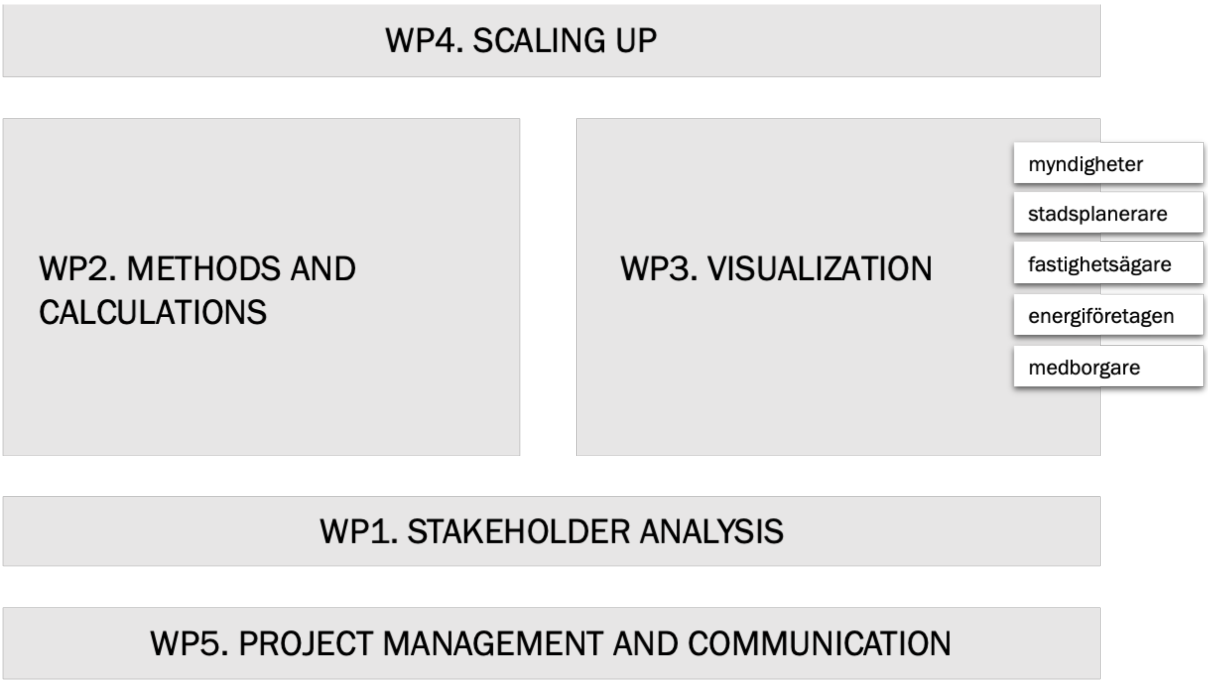


Figure 1. Work package breakdown

2.1 Summary by work packages

2.1.1 WP1. Stakeholder Analysis

The stakeholder analysis work package involved a thorough examination of the various stakeholders involved in the project, including property owners, energy companies, government agencies, and urban planners. This analysis enabled the project team to better understand the unique needs, priorities, and perspectives of each stakeholder group, informing the development of tailored solutions and facilitating effective communication and collaboration throughout the project.

In the fall of 2019, a needs analysis was conducted regarding tools for data-driven energy planning. The process was carried out to clarify how stakeholders currently use data as decision support, what needs and challenges they see related to this type of tool, and how they would like the development to proceed in the future. The needs analysis is a critical basis for determining the direction of further tool development.

The analysis highlights significant potential benefits of shared tools for data-driven energy planning. It also shows that property-related stakeholders, energy companies, and public actors often have different requirements for a data tool.

An important conclusion from the interview part of the project confirmed major obstacles related to the willingness to share data, the development of business models for data sharing, and the fact that data quality, measurement, and follow-up still require much development to be ready for implementing new tools.

Based on the conclusions of this report and the three in-depth user case studies analyzed during the November 2019 workshop, it is clear that housing associations, municipalities, and district managers would directly benefit from such a tool, referred to as *Oden*, developed during the project's earlier phase.

2.1.2 WP2. Methods and Calculations

This work package focused on the development of advanced methods and calculation models that incorporated multiple property types and measures for large-scale analysis. The models were informed by national data warehouses from Boverket, Lantmäteriet Building and Property Registers, geological database, as well as Stockholm's city museum database with cultural protection, and 3D building models. These data sources were harmonised using the industry-standard tool FME, enabling complex integrations of datasets that are not naturally related to each other. This work package also saw the addition of new property types and the development of calculations and valuation models for primary energy and emissions.

2.1.3 WP3. Visualisation

The visualisation work package produced a dynamic and interactive visualisation system, "Oden Light" or "Energy Map", which provides aggregated energy mapping and information for public consumption and dissemination. The system is publicly accessible and has been enriched with a CO2 map and a culture map. A dashboard for use by municipalities, EKR (sv: Energiklimatrådgivningen), city planning offices, and large property owners has been utilised to help stakeholders identify areas of their portfolio that require attention and action.

2.1.4 WP4. Scaling up the Results

This work package aimed to explore the potential for scaling up the project's results and applying the developed methods and solutions to other cities and regions. The project team collaborated with Ellevio, Stockholm Exergi, Vattenfall, and E.ON to discuss the possibility of building a national competence center for the development and implementation of similar services. The work package also identified various business models that could facilitate the entry of new players into the energy market.

2.1.5 WP5. Project Management

The project management work package oversaw the coordination and administration of the project, ensuring that all tasks and milestones were completed on time and within the established budget. This work package was responsible for facilitating communication among stakeholders, monitoring project progress, and addressing any challenges or obstacles that arose during the project's execution.

In conclusion, this groundbreaking project, carried out during a challenging global pandemic, has demonstrated the value of close collaboration between academic institutions, government agencies, and industry partners in developing innovative and sustainable solutions for urban energy efficiency and optimization. The project's outcomes have the potential to significantly impact the energy sector and contribute to the creation of more sustainable and efficient urban environments.

2.2 Results

Project objectives and outcomes

Objective 1: Further developed methods and calculation models with several property types and measures that can be used for large-scale analysis.

Outcome: The calculation models have been developed through a national data warehouse from Boverket, Lantmäteriet, Property Register, Geological databases, Cultural databases, 3D models, which have been harmonized in the industry standard tool FME, which enables complex integrations of datasets that are not naturally related to each other. New property types have been added, including energy-efficient multi-family homes and offices, calculations and valuation models for primary energy and emissions have also been developed. Furthermore, a layer of effect calculations and the effects on the electricity grid have been developed to help the consortium and the electricity grid company Ellevio to oversee the power demand at a granular level.

Objective 2: A visualization system, "Oden Light" or "Energy Map", which provides aggregated energy mapping and information for public consumption and dissemination.

Outcome: The Energy Map is publicly available with some public layers and some locked layers that require login. It has been enriched with a CO2 map and a culture map. A dashboard for use by the municipality, EKR, city planning offices and large property owners has been used to help them identify parts of their holdings that they need to work with.

Objective 3: A national database and methods for evaluating the measured effects of completed efficiency projects.

Outcome: The project has, based on measured data, identified when properties have carried out measures and obtained new energy signatures, and partly based on energy declarations - as the project now has received energy declarations that have been repeated twice for the same property. This has been able to provide indications of the efficiency rate in parts of the stock and show differences between cities, public utilities, private and housing cooperatives. The new energy declarations are also marked with implemented measures and Oden is adapted to integrate these measures as point interventions at a specific date.

Regarding data on completed efficiency projects, the project has not received a large set of historically completed measures. Several property owners have explained that they do not have structured documentation for this that they are comfortable sharing. Partly, it is not always clear in the data to read what is an efficiency measure and what is a standard renovation. However, Svenska Bostäder has submitted measures for their properties, but even there, there are gaps. Systematic work is required here, both in the declarations and by property owners who have worked more with their documentation.

Objective 4: Possible business models that, together with energy companies, can enable long-term building efficiency projects in other cities.

> **Outcome:** The basis for this business model was discussed with Ellevio, Stockholm Exergi, Vattenfall, and E.ON, who together are ready to build a national competence center to develop this type of service. Several other business models have also been identified for new players in the energy market.

Objective 5: Documentation on quality aspects that can be used by Boverket for future energy declaration systems.

> Here, the project has published articles on how Boverket and other countries can significantly improve their energy declarations and how they need to work in a more structured way in the management of the variables in the declarations, how the data is stored, and how they need to work with making new variables compatible with old variables so that the declarations become somewhat comparable over time.

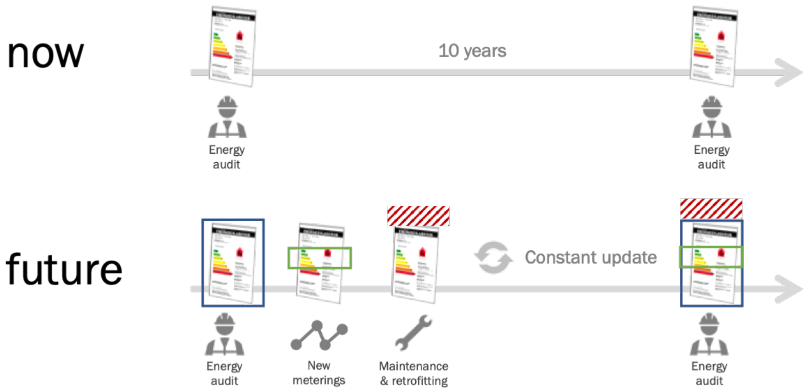


Figure 14. Proposed change of paradigm for generation of energy declarations (EPCs).

As suggested in Figure 14, energy declarations (EPCs) should evolve from a static document collected manually once-a-decade (being totally disconnected from its earlier and subsequent versions) into an up-to-date live versioned document that is constantly updated from automatic measurements, any certified energy interventions, etc.

3

3.1 Needs analysis - interviews & workshop with Sweco

The results from interviewing municipalities, energy suppliers, grid owners, building owners, and property managers and joint workshops with them were the following.

3.1.1 How is data used today?

Data is being used to track established energy goals, such as how much energy a geographic area can use within a specific time frame or how much energy a property can use per square metre per year. Historical information can provide insight into which existing properties need improved energy performance through renovation or to impose lower energy usage requirements in a planned residential area. For public organisations, it is of particular interest to use data to understand how future needs may look. The stakeholders also discuss how data is used by property companies to improve understanding of energy systems in buildings, for more efficient property management, and to provide feedback to customers. Finally, the stakeholders touch on how energy companies are using data to advise customers and predict future needs.

3.1.2 Future Needs

The stakeholders argued that the different types of data needed for different purposes in optimising resource usage in cities, including not just energy but also water and waste. Both historical and real-time data are necessary, and it must be aggregated effectively and made accessible to everyone while also being of good quality. AI is required to make sense of the real-time data. Coordination between different stakeholders can be difficult, but robust historical data and prognoses are necessary for companies like Vattenfall to create pricing signals to steer consumption. Automating the data collection process is desired, but it can be challenging to ensure the accuracy of the data. Ultimately, the focus should be on having high-quality real-time data to build smart systems.

3.1.3 Regulation

Stakeholders in the energy market face regulatory challenges, including the need for stable regulations and data privacy laws. The market needs a national approach to differentiate tariffs for small customers, and legislation to depersonalise data is necessary. The lack of a regulatory framework presents challenges, such as limited sharing of energy with neighbours and the need for more information to optimise energy flows. Data collection and aggregation are hindered by a lack of standardisation for communication systems and complex integration of data from various sources. While stakeholders may be willing to share data, there is no clear party to aggregate and manage the data, making it difficult to optimise the energy market.

3.1.4 Future Specific Needs

Stakeholders in the energy industry need better coordination with municipalities in planning processes and improved data for forecasting future energy needs. Organizations are not currently equipped for this type of thinking, and stakeholders need a more aggregate function for understanding future energy needs. There is a need for better data to address current network capacity limitations and to forecast future energy needs, which could help reduce the need for building more power plants and reduce the impact on the environment. There is also a need for tools to help understand how areas are developing, what systems they should be connected to, and whether they can be supplied with enough energy. Stakeholders face challenges in terms of resistance to new technology and the need for more coordinated planning across different entities.

3.1.5 Needs for New Metrics to Change the Industry

The stakeholders require new types of data to improve energy efficiency and reduce energy consumption. They need a baseline to compare data against and want to model energy needs from the beginning. They seek more national example data to compare with their own and would like energy providers to supply them with a certain level of data quality for comparison. To achieve their energy goals, they need to follow up on the performance of buildings and establish penalties for not meeting energy requirements. It is also important to understand how the needs for existing and new buildings will evolve in the future to plan capacity expansion. The stakeholders suggest that municipalities take on the responsibility for following up on energy requirements.

3.1.6 The Need for New Decision Support

The interviewed stakeholders have identified several areas where decision support is needed. They aim to build more energy-integrated mobility hubs, which requires more information and decision support. Good decision support is crucial for prioritising efforts and finding solutions that work for the whole society, not just individual buildings. The stakeholders need to understand how to prioritise aspects of building and energy systems, and data is key to achieving this. They require simple and visual tools for decision-makers to make informed decisions. Knowledge is also identified as a major barrier, as decision-makers do not have enough information to make well-informed decisions. The stakeholders stress the importance of open data and good examples of how open data has contributed to positive development. They need all types of energy usage data at high resolution to improve the decision-making process. There is a need for more accessible information for property owners, who may not understand the environmental impact and costs associated with energy systems. Data is needed to show the benefits of certain solutions, and the stakeholders recognize the need to prioritise infrastructure efforts, given the age of much of the existing infrastructure. Finally, data is identified as a necessary tool for net operators, who need clear benefits to be interested in using it.

3.1.7 The Need for New Data Collaborations

The interviewed stakeholders highlight the need for collaboration between different actors in the energy and building sectors. They point out the risks of organisations being content with their current situation and not realising the bigger problems until they come together to share information. The life cycle perspective of buildings also presents challenges for communication between different stages, which requires the use of tools like BIM. Despite existing platforms, the stakeholders note that collaboration around a system perspective is inadequate due to competing agendas. They emphasise the importance of making data accessible to the right people and promoting data-driven innovation through shared tools. Additionally, they stress the need for dialogue with building occupants to increase their understanding of how their energy use impacts the overall system.

3.1.8 The Barriers of Cost of Competences

The interviewed stakeholders highlight that there are several challenges related to costs and competences when it comes to developing and utilising tools for data-driven decision-making. Firstly, there is often a lack of funding and resources in municipalities to develop these tools, and there is also a shortage of necessary competences. Secondly, there has been a lot of personnel turnover in public organisations, and many have been sold off, resulting in a loss of in-house knowledge. Furthermore, the stakeholders note that there is a general lack of knowledge about energy efficiency and related topics, and visualisations can help disseminate this knowledge. However, there are concerns about whether the available knowledge is sufficient for decision-makers to make informed decisions based on visualisations. Finally, the stakeholders highlight that the biggest threat today is a lack of knowledge among the public, and more data is needed to increase understanding and awareness of these issues.

3.1.9 Use cases

The summary of all use cases identified through the Needs analysis is presented in Figure 2.

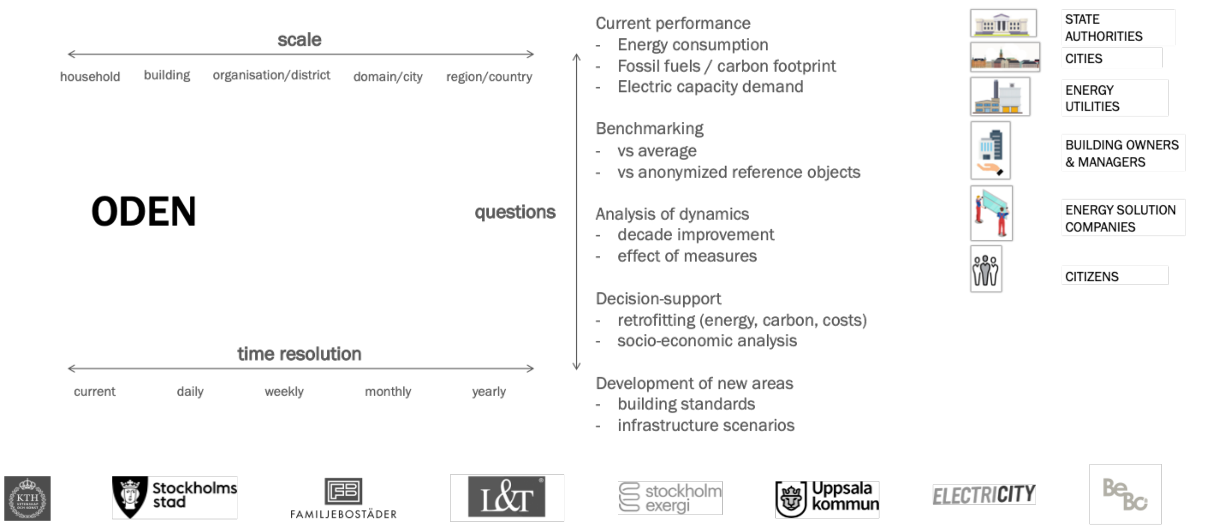


Figure 2. Oden's use cases

Further in the workshops, three cases were in focus for the data-transition: a rural town, a growing urban district, and a housing association.

3.1.9.1 Case 1 - The Rural Town

In the case of a rural small town with a population of around 30,000, the focus is on attracting residents and businesses while continuing to grow. The town aims to have 60,000 inhabitants by 2030, which requires the construction of housing, infrastructure, electrical grid, water, and digital infrastructure. The municipality owns much of the land, and the challenge is to create an attractive city while avoiding an increase in energy and power demand during the expansion. To achieve this, the stakeholders want to use tools to compare themselves with other similar municipalities and identify what makes them attractive. They also want to understand the needs and motivations of people who want to leave the cities and move to rural areas. The town requires assistance from consultants and energy offices of neighbouring municipalities to find suitable solutions.

3.1.9.2 Case 2 - The Growing Urban District

For an area in a growing city that wants to help with the energy problem while focusing on profitability, data-driven tools will be used to find the profitability in solutions and provide decision support, as well as investment analysis and performance estimation. To achieve this, they need to build new infrastructure, local production, energy and power distribution, and load management measures. Collaboration is essential, and an efficient pricing mechanism should be implemented. Only electric vehicles will be allowed to take advantage of V2G technology. However, the financing, ownership, and business model of the project are uncertain, and it is unclear who the responsible parties are. Therefore, they need knowledgeable contractors and green loans, as well as open control systems and infrastructure for all data. Centralized management is necessary to coordinate and manage the various systems in parallel. There is a risk that this solution will address their challenges while causing energy poverty issues. The legal issues should also be considered, and the responsible parties should be identified. To create engagement, they should share experiences and get inspired.

3.1.9.3 Case 3 - The BRF

The interviewed stakeholders are a homeowner association (BRF) that needs convincing information to make investment decisions. They want green loans, low energy consumption, and to avoid short-term thinking. They need help to calculate future projections in terms of today's money, convert kWh to currency, CO2 to environmental impact. They need a second opinion from an independent party. Questions that arise are how to know what is best, how to decide with available information, how to follow up on performance, and how to compare with others. It is important to show the correlation between energy and money, show that others' investments have been beneficial, understand economic opportunities, and display climate benefits in a simple way. They also need knowledge to critically review suppliers, and incentives such as social proof, choice of craftsmen, and recommendations. A reliable benchmarking actor is also required to provide an annual report. Additionally, they would benefit from access to data provided by other actors, such as municipal companies, in an anonymized manner.

3.2 Methods and tools

3.2.1 Data infrastructure development

The project has reengineered the data integration process created earlier in Big Data Phase 1 project with aim to setup a more universal Extract-Transform-Load (ETL) process that could be re-used for the national application with lower efforts on connecting additional datasets from local urban energy data providers (e.g. energy utilities, property owners, etc). Single building was chosen as the highest level of granularity (level of detail) meaning the detailed datasets on particular sensors or households was avoided in the further process.

The overview of the integrated data sources is provided in Figure 3. FME data integration software was used to generate the national database established in SQLite DBMS[1] with different datasets being joined through geographic proximity and identification strings (e.g. address, property name, post number etc) similarity. The obtained data lake was then used for creation of various data products tailored for different types of applications. At the end, three data blends proved to be of particular interest for further development - CityPlanner, CityModeller and PrettyMap.

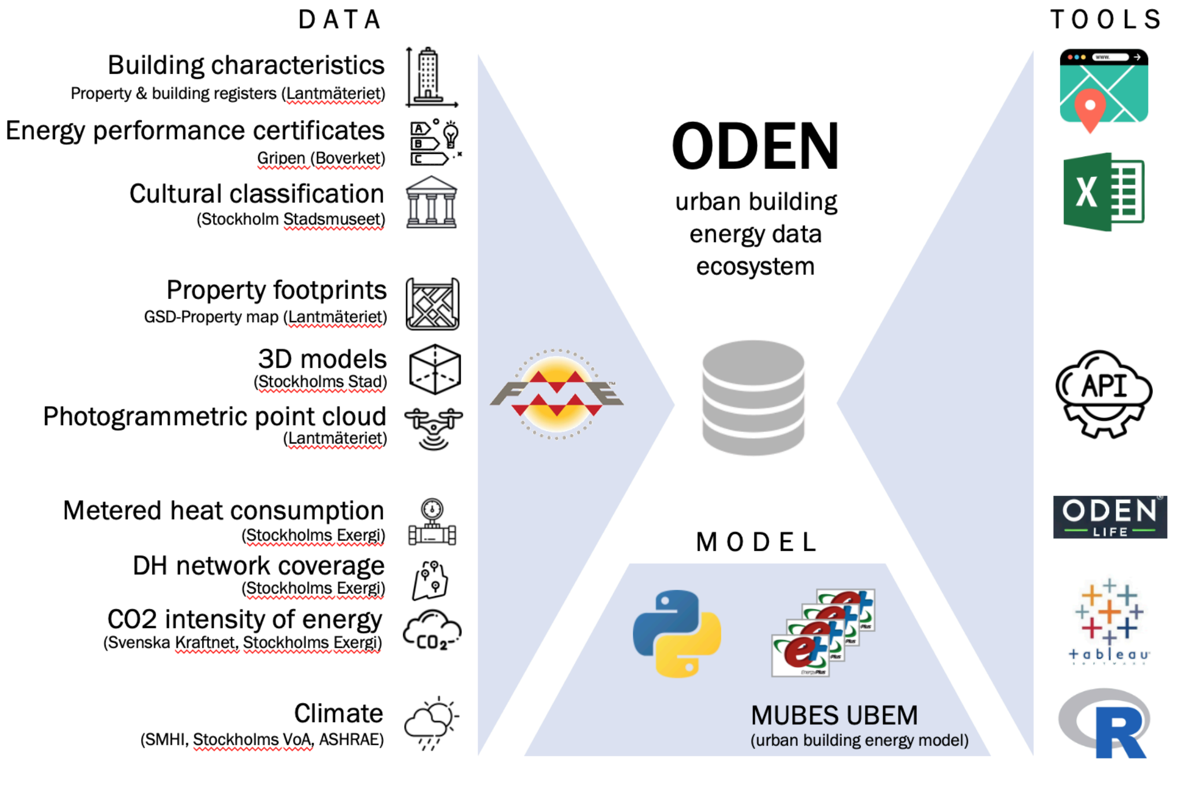


Figure 3. Overview of the ODEN urban energy data ecosystem.

3.2.1.1 *CityPlanner*

The CityPlanner data product (Figure 4) has emerged as a base product for research & development purposes, aiming for the universality (keeping most of value-rich fields of the input datasets), high modularity (keeping all non-geometric properties for entities of different nature in separate csv files)

[1] Database management system

and integrability (all buildings, properties and declarations are connectable through the keys on building level). The development of CityPlanner was largely informed by the co-design sessions with energy planners from Stockholm and Uppsala, resulting in static reports[2] or interactive dashboards (e.g. Figure 5).

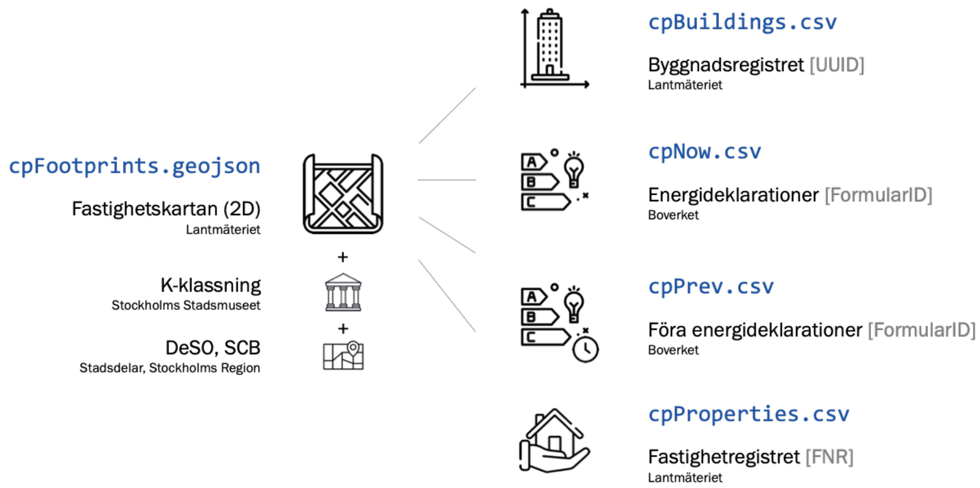


Figure 4. The structure of the CityPlanner data product in the case of Stockholm.

[2] E.g. https://urbant.org/stockholm-heat-energy-demand/

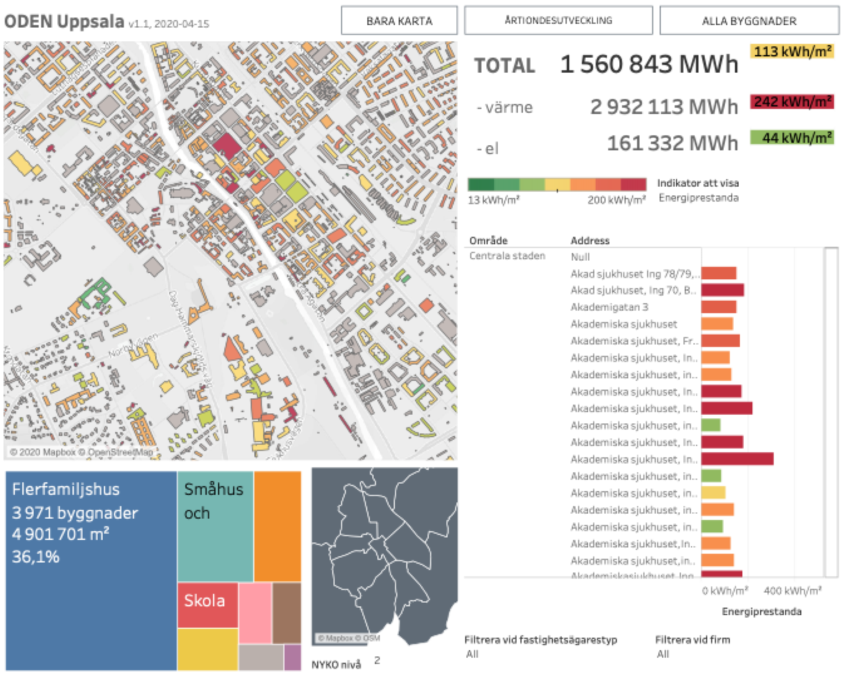


Figure 5. The urban energy dashboard in the case of Uppsala.

Given the specificity of EPC (energy performance certificates, sv. energideklarationer) data source, a number of additional design choices had to be made. At the moment of the project start, the 2nd wave of declarations has started, allowing for decade comparisons in case of buildings with 2 EPCs (Figure 6). After a number of experiments with data schemas (way of organising) for EPC data, the 'actual' schema was chosen as the default one (Figure 7). On one hand, it secures the consistency of the data, allowing only for one 'actual' EPC per building. On the other hand, it allowed us to preserve the older declarations in a convenient way to enable the longitudinal studies.

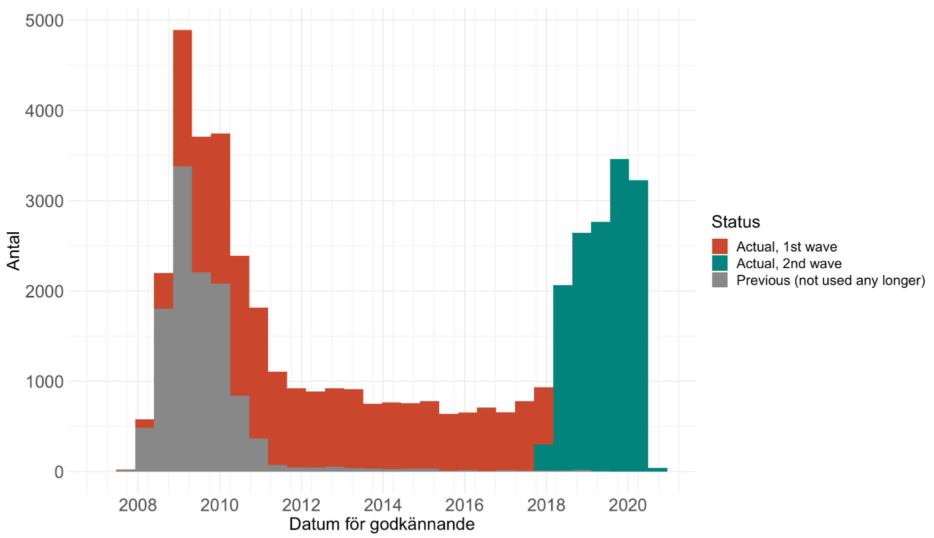


Figure 6. 'Waves' of energy declarations.

Schema name	Description (2 tables are used for WAVES and ACTUAL)	Has at least one EPC in the latest	Has exactly one EPC in the latest	Secured time validity for the latest	Recommendation
FULL	All Boverket exports combined together - Duplicates from export overlaps for are dropped in favour of later export - Energy values for <2.4 are converted	-	-	-	**Should be kept as a primary source, but avoided for any practical use**
TIDY	FULL with removed 'edit' duplicates & additional data cleaning - All EPCs for the same property that occur in the same buffer time* are removed - Additional cleaning corrections for particular EPCs	-	+	-	**Well-suited for longitudinal studies with more then 2 snapshots in statistical and single object analysis**
WAVES	TIDY with fixed time split into 2 tables by waves W1 (wave 1) 2007-2017 — W2 (wave 2) 2018-...	-	±	+	**Well-suited for two-wave longitudinal studies**
ACTUAL	TIDY with flexible time split into 2 tables prioritising the completeness of the Now table Prev (Latest EPC that was reported at least BT=1 year before Now) — Now (Most recent EPCs ignoring their age)	+	+	±	**Well-suited for 'snapshot' reporting of the current state statistics & single object analysis**

Figure 7. The possible data schemas for EPCs.

Secondly, as EPC data structure is continuously evolving on the data provider (Boverket) side, a number of automatic conversions was introduced, allowing for maximum comparability between EPCs submitted by the auditors in different years. Particularly, a split of consumed heat by the needs (heating & domestic hot water) was provided for older EPCs. Another important re-calculation made was for the specific primary energy (PET) and, subsequently, energy classes, bringing them to the same meaning despite different times of reporting, thus allowing to analyse the building portfolios for the whole municipality or property company in a more consistent manner.

3.2.1.2 PrettyMap

While the purpose of CityPlanner data product was to provide a universal data schema that could be used across applications for municipalities, they also requested higher level visualizations to provide to residents, one of which was called PrettyMap and that has been extensively used in meetings by citizens as well as practitioners.

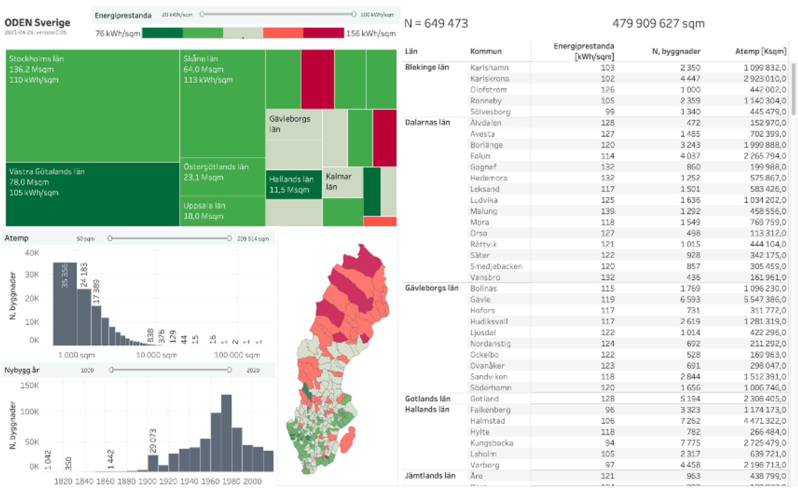


Figure 6. Oden's national coverage of over 10 independent data sets.

Figure 7. One of PrettyMaps layers for the Stockholm region

3.2.1.3 Decision support for public policy

The project was called on by the City Hall of Stockholm to provide criticial decision-support for Stockholm's politician's with regards to the policy requirements of large-scale heating (District Heating) or local small-scale heating (e.g. heat pumps) and their implications. The results clearly showed the benefits and disadvantages of the different choices in new construction as well as the resulting differences in method of quantification. The project ensured to not pick sides and provide results with all system boundaries to allow the politician's to make their own decisions and see the different outcomes.

The report discusses two building types, namely lamella and point block buildings, with different heating and energy recovery systems. The lamella is a freestanding, elongated building structure with several stairwells, while a point block is a freestanding building with a central staircase around which apartments are placed. The report compares the energy efficiency of these two building types. Four heating and energy recovery system combinations were analyzed for each building type. These systems are district heating with mechanical ventilation and heat recovery (FTX), district heating with FTX and exhaust air heat pump, geothermal heating with FTX, and geothermal heating with FTX and exhaust air heat pump.

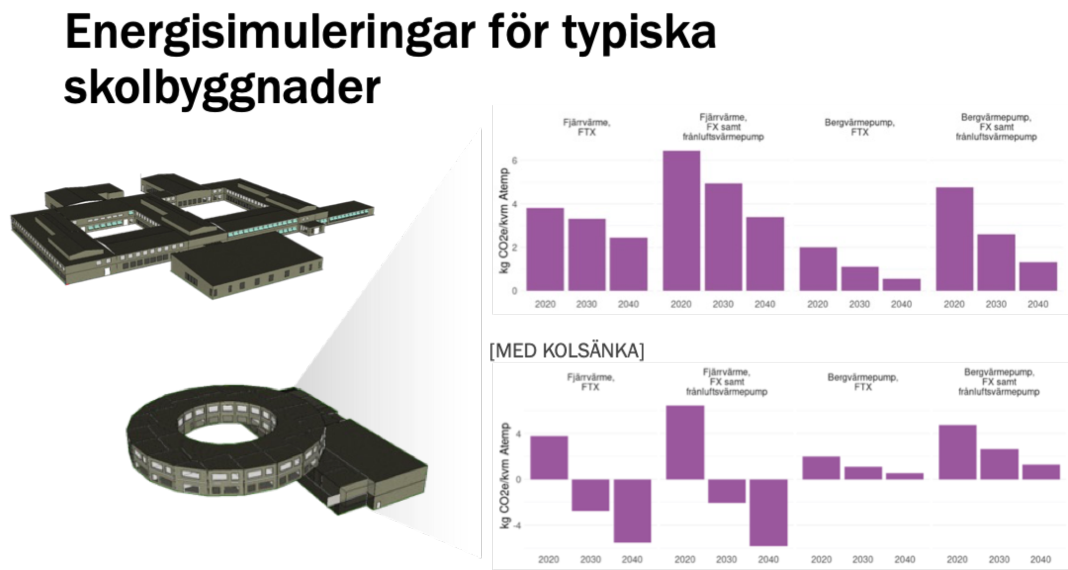
The report presents the concept of geothermal heating, which extracts stored solar energy from boreholes in the bedrock, and explains how this renewable energy source is used to heat buildings. FTX, on the other hand, is a mechanical ventilation system that distributes air with fans and recovers heat from the outgoing ventilation air, which is then returned to the building's heating system. Exhaust air heat pumps are used to recover heat from the outgoing ventilation air, which is then supplied to the building's heating system and hot water production.

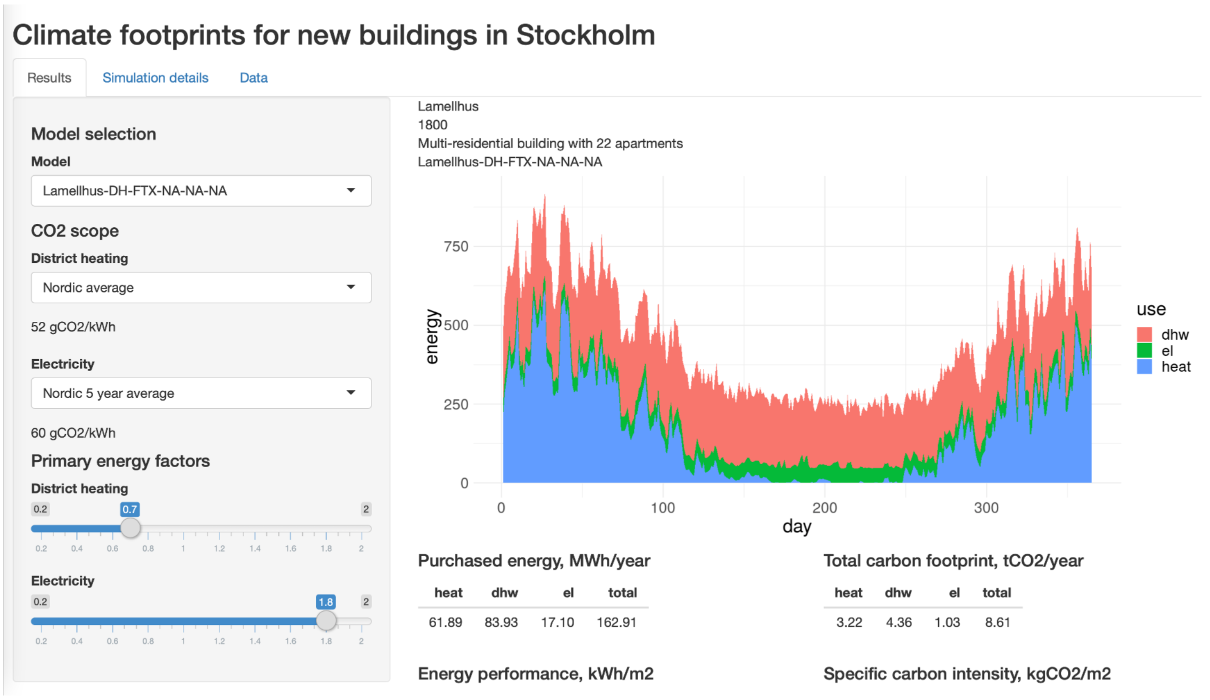
The report notes that there are several ways to calculate the climate impact of electricity consumption. The report presents the concept of the accounting method, which describes the climate impact of a certain energy usage. The report explains that in Sweden, national electric mix is used for reporting in international calculation protocols, but Stockholm city has chosen to use Nordic electric production for its climate calculations. The report notes that Stockholm aims to be fossil-free by 2040 but may not achieve this goal in the heating sector. The report presents scenarios for the Nordic electricity system in 2030 and 2040, which reduce nuclear power to a third and double wind power, while the remaining electricity production is mainly from waste incineration and peat.

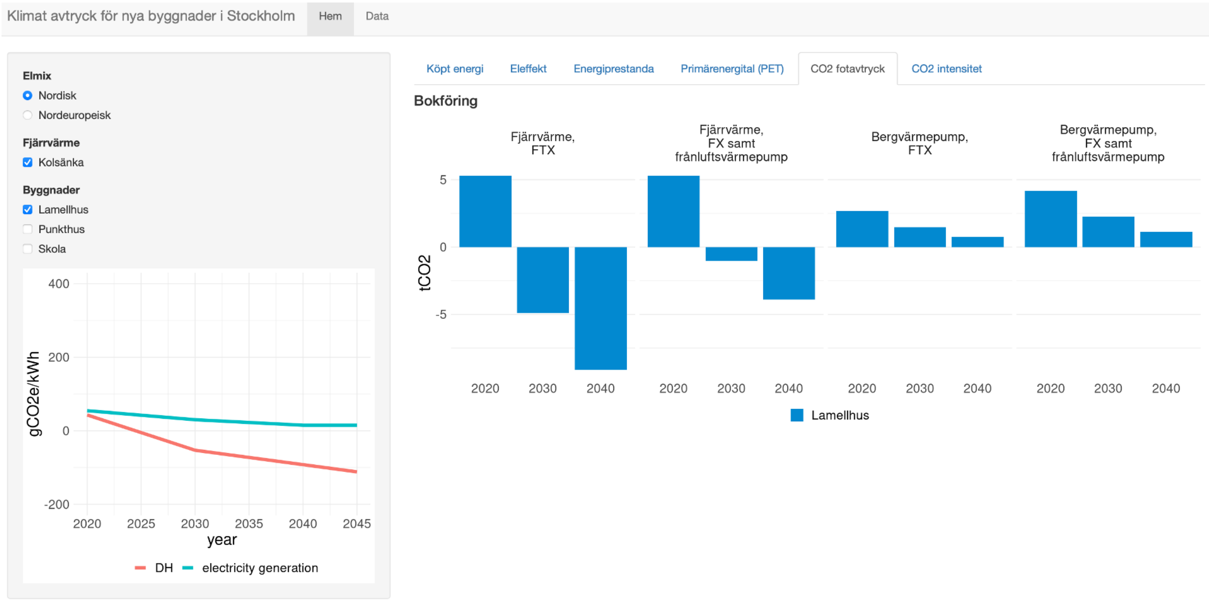
The report presents the emissions factors used in climate calculations for the two building types with the different heating and energy recovery systems. The report notes that there are uncertainties in the emission factors due to changes in technology and policy. The report presents the emissions factors for district heating with Nordic electric mix, district heating with North European electric mix, Nordic electric mix, and North European electric mix for the year 2020, 2030, and 2040. The report highlights that the choice of electric mix affects the emissions of district heating as electricity is used in district heating production.

The report concludes that the choice of calculation method affects the calculation results, and no method can be considered entirely accurate. The report emphasizes that factors other than climate impact should be considered, such as societal benefits of waste incineration and energy recovery from waste.

3.2.2 Storskalig energieffektivisering







3.2.2.1 *Decision support for public policy*

In conclusion, Oden also provided answers to the following question: the stringent energy requirements in eco-districts like the Stockholm Royal Seaport - what has been the their actual corresponding energy performance, what types of building owners have been able to meet those goals, and what type of building owners have failed.

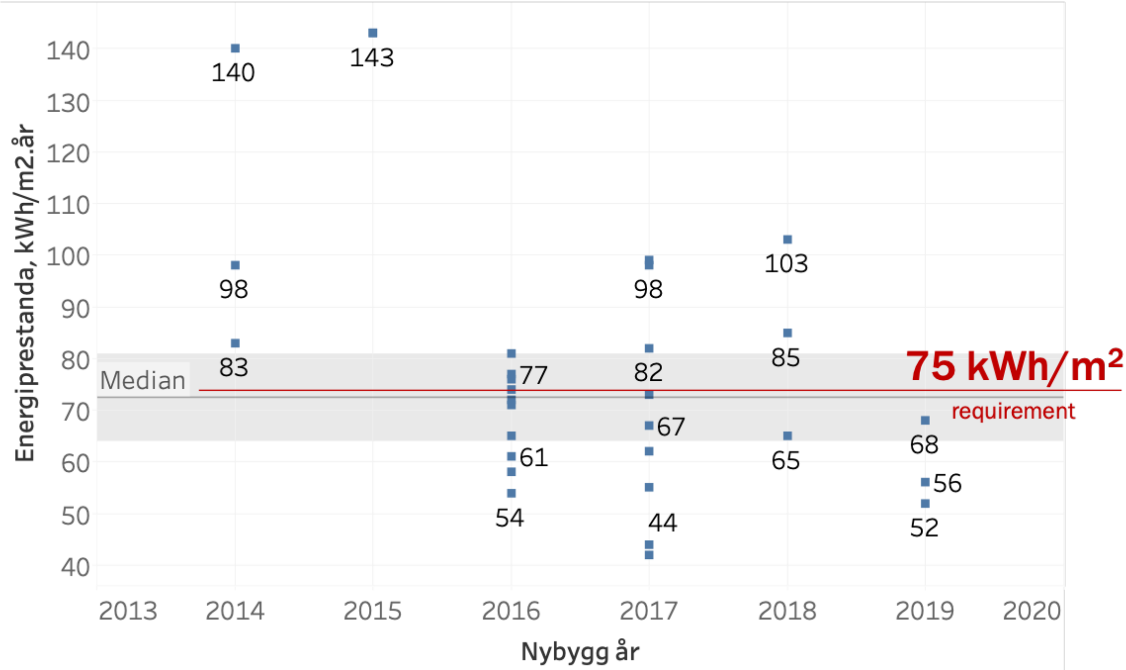
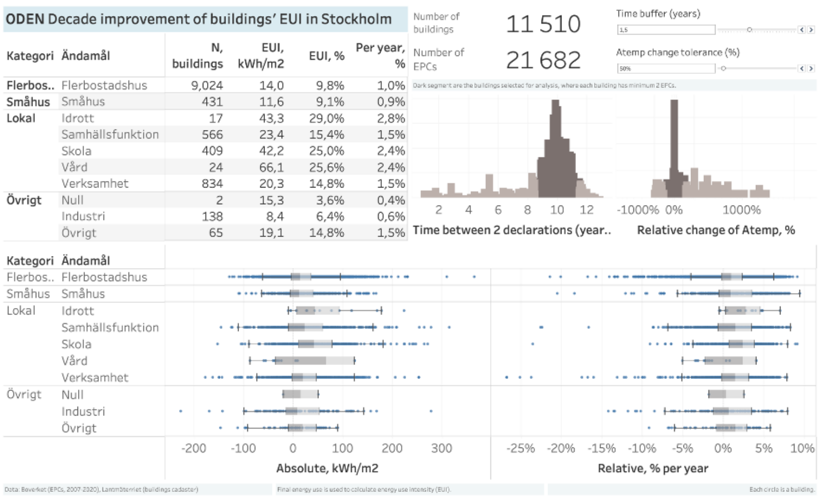


Figure 8. Efficiency of city requirements to new buildings in Stockholm Royal Seaport

3.2.2.2 Energy efficiency

One analysis was also to identify the rate of energy efficiency in Sweden. With the help of a 10-year dynamic the project was able to identify the rate of efficiency renovations in e.g. Stockholms vs Uppsala



ODEN Decade improvement of buildings' EUI in Stockholm

Kategori	Ändamål	N, buildings	EUI, kWh/m2	EUI, %	Per year, %
Flerbos..	Flerbostadshus	9,024	14,0	9,8%	1,0%
Småhus	Småhus	431	11,6	9,1%	0,9%
Lokal	Idrott	17	43,3	29,0%	2,8%
	Samhällsfunktion	566	23,4	15,4%	1,5%
	Skola	409	42,2	25,0%	2,4%
	Vård	24	66,1	25,6%	2,4%
	Verksamhet	834	20,3	14,8%	1,5%
Övrigt	Null	2	15,3	3,6%	0,4%
	Industri	138	8,4	6,4%	0,6%
	Övrigt	65	19,1	14,8%	1,5%

Figure 9. Annual rate of energy efficiency for various buildings types in Stockholm

3.2.3 Building Portfolio Management Tool - Svenska Bostäder

The new building portfolio management service, based on Oden and developed in collaboration with Svenska Bostäder, will enable the energy manager to create more data-driven and structured maintenance plans, allowing for small incremental changes across their building portfolio. This approach is expected to help Svenska Bostäder improve the efficiency of their building operations, reduce maintenance costs, and prolong the lifespan of their assets, ultimately benefiting both the building portfolio owner and its tenants. By leveraging data-driven insights, Svenska Bostäder can make more informed decisions and prioritize resources to address maintenance needs and optimize building performance.

3.2.4 OdenLife / Spara - The BRF First Aid

A specific effort has been made on the particular group of buildings that are home owner associations (BRFs). To begin with, they have been deeply analyzed in terms of their jobs, pains, and gains as members of the board with some responsibility for their building's energy performance.

Based on this, and the results from the sister project MUBES, a novel method to create digital twins for all BRFs has been created but not concluded within the scope of this project, but with a continuation project with EKR Stockholm and ElectriCITY's energy community in Hammarby Sjöstad which both aims to support energy communities and all BRFs that ought to take action to decrease their unproportionately high energy losses. The OdenLife concept is aimed towards the board of directors of BRFs whom are given access to their estimated current energy performance. From there, they are guided towards a number of pre-computed retrofitting measures, and are then put in touch with their local energy and climate advisors to support them with their decisions. To further help facilitate those decisions, they are also invited to a digital energy community - a social network with buildings that have similar circumstances that they do, to help getting the social proof, and asking other BRFs that have performed similar measures on advice on their experience with regards to suppliers and potential complaints of residents. The concept is also supported by behavioral research at KTH to further increase the probability that the BRFs understand what to do, and feel more inclined towards making decisions.

In addition to a graphical user interface, KTH is exploring how to draw on ChatGPT to introduce an avatar in the shape of "Spara" to help collect data and respond to basic questions.

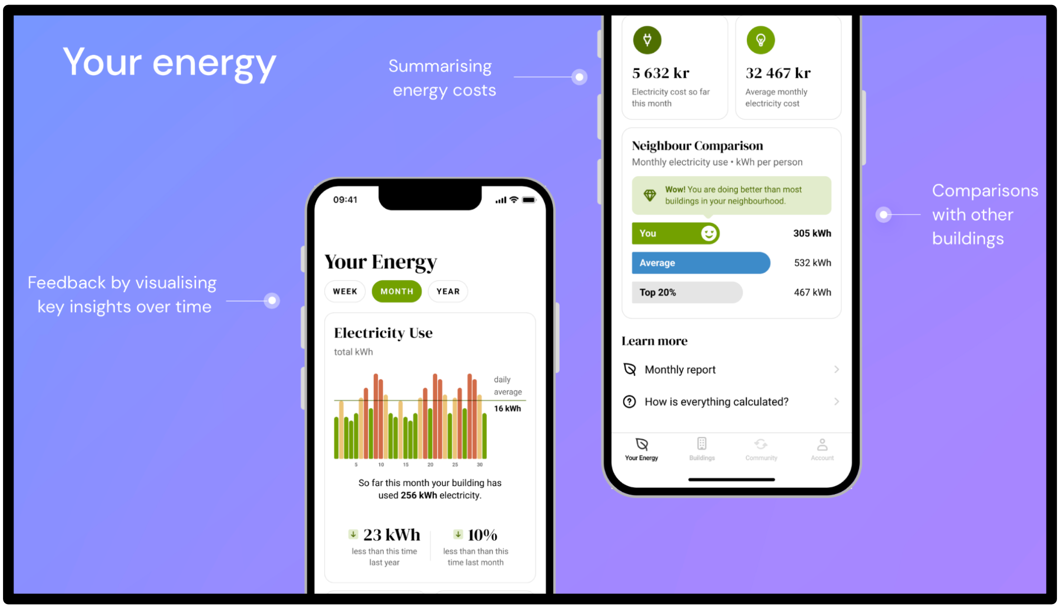


Figure 10. Annual rate of energy efficiency for various buildings types in Stockholm

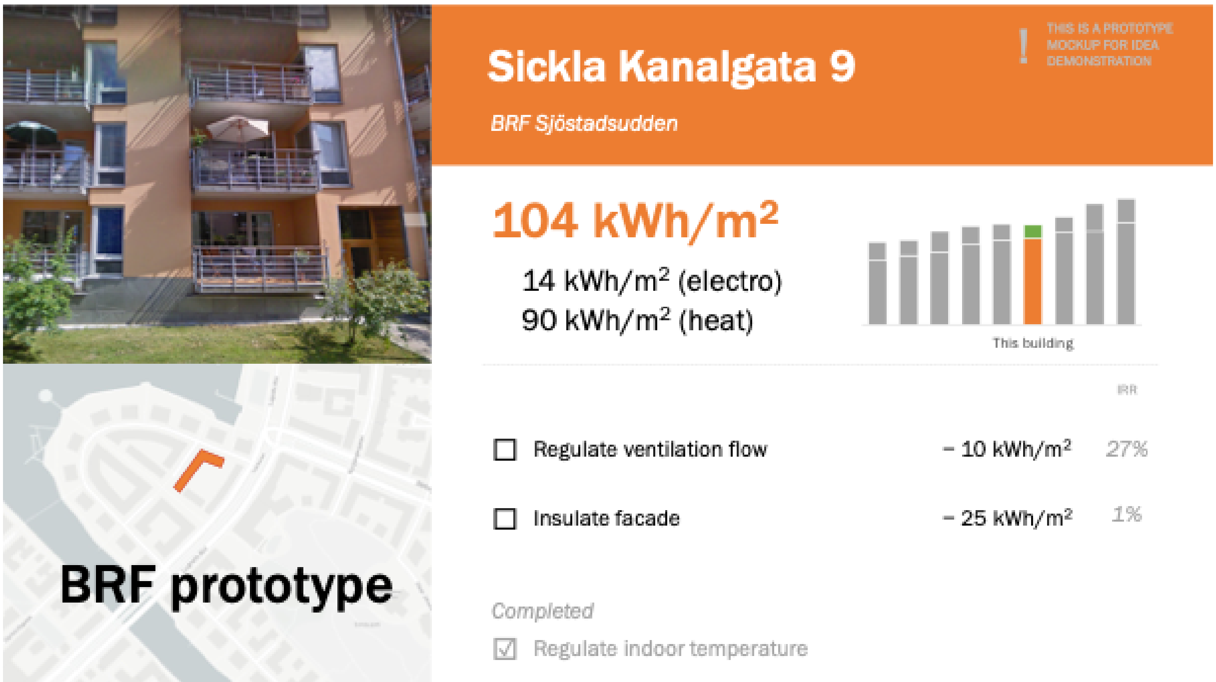


Figure 11. Annual rate of energy efficiency for various buildings types in Stockholm

3.3 Growing demand for energy-related services

The need for data-driven energy services is rapidly growing among local governments, utilities, and building companies. With the increasing demand for energy-efficient buildings and sustainable urban environments, there is a significant need for accurate and timely data to support decision-making processes. Sweden, being at the forefront of green energy and sustainable practices, needs to build more infrastructure, competence, and capacity to meet these needs. This includes investing in high-performance computing, cybersecurity, energy system analysis, industrial economics, smart urban metabolism, urban building energy modelling, interaction design, governance of urban transitions, and behavioural economics. By building up these capabilities and establishing a network of experts in these fields, Sweden can effectively respond to the increasing demand for data-driven energy services and continue to lead the way in sustainable development.

4 Discussion

By overcoming a number of major obstacles the project and the project partners have made a contribution to the built environment that cannot be understated. The project has essentially bridged the gap between raw data and energy efficiency investment by providing very reliable metrics. While work remains, the proof-of-concept has opened up new opportunities with municipalities, large portfolio managers, and homeowner associations. From an international perspective, the results are advancing the emerging field of Urban Building Energy Modeling.

There are a number of challenges with the technology that accompany it. The first challenge is the fact that the energy simulations need to be calibrated with real data, and in Swedish context this is managed thanks to the availability of rich utility and building owner data. But internationally, this is a substantial limitation unless energy utilities adopt the energy-data-as-a-service model where they are able to sell their data or create their own services on top of their data.

4.1 Results in relation to a sustainable urban development

The needs analysis articulates the value chains, the benefits and risks for all stakeholders. In general all actors in the energy system benefit from the existence of national energy system data labs that manage the storage, structures, logic, and computations on these massive data sets, for a greater good. Given the factors that all actors have large benefits to gain from a better management of urban building energy data, this entire field will likely be very different within ten years, strongly for the benefit of sustainable urban development.

4.2 Project design and lessons learned

The project design was challenge-driven, where the stakeholders set the challenges, and the other packages revolved around finding solutions to those challenges. The process was collaborative and iterative in nature which has led to numerous improvements and even completely new services, compare to the concepts that were envisioned when applying for the project.

The project design was very person-dependent and fragile. Despite the exciting development work in the project, the very niche competences required made it extremely hard to find, attract, and keep talents that could push this long-term agenda forward. In the future, the few people active in this space in Sweden, should strive to coordinate, to be able to provide mobility of talents amongst them.

4.3 Project design and lessons learned

There is additional R&D and business development needed to create a well-functioning services, in line with E2B2's program goals

As presented earlier in this report, the following services are currently being refined together with their end-users: OdenLife / Spara for homeowner associations, Oden for building portfolio managers, Oden City for Municipalities, Hosting and running Oden off of KTH's supercomputer Dardel, Advancing national networks towards data harmonization, Setting up a national competence center / governmental data lab.

5 Conclusions

The project has drawn upon large and complex data sets relating to the built environment, to create a national and harmonized data hub of building energy data, coupled it with state-of-the-art building simulations on both a building scale, but more importantly on a district scale, and provided proof-of-concept decision support tools to the projects stakeholders and beyond.

The stakeholders and partners have confirmed the need for a substantial shift in how building energy data is collected, structured, processed, and accessed, in order to unlock massive environmental and financial gains for energy utilities, large-scale building owners, and homeowner associations.

In this direction, a wider national consortium of three large Swedish cities, with their accompanying energy utilities, building owners, and academia mobilized to form a consortium for NUE Data Lab that will apply to become a competence center with the Energy Agency 2026. Until then, the services created from this project including Oden and OdenLife will continue to create value for the City of Stockholm, ElectriCITY Stockholm, and have also recently been garnering attention from the European continent.

None of this would have been possible without the E2B2 programme's directed mission to support energy efficiency in the built environment.

6 List of publications

6.1 Papers in peer-reviewed journals

- Eriksson, P.; Johansson, T. Towards Differentiated Energy Renovation Strategies for Heritage-Designated Multifamily Building Stocks. Heritage 2021, 4, 4. https://doi.org/10.3390/heritage4040238
- Wu, P.-Y.; Mjörnell, K.; Mangold, M.; Sandels, C.; Johansson, T. A Data-Driven Approach to Assess the Risk of Encountering Hazardous Materials in the Building Stock Based on Environmental Inventories. Sustainability 2021, 13, 7836. https://doi.org/10.3390/su13147836
- Pasichnyi, O., Levihn, F., Shahrokni, H., Wallin, J., Kordas, O., 2019. Data-driven strategic planning of building energy retrofitting: The case of Stockholm. Journal of Cleaner Production 233, 546–560. https://doi:10.1016/j.jclepro.2019.05.373
- Pasichnyi, O., Wallin, J., Kordas, O., 2019. Data-driven building archetypes for urban building energy modelling. Energy 181, 360–377. https://doi:10.1016/j.energy.2019.04.197
- Pasichnyi, O., Wallin, J., Levihn, F., Shahrokni, H., Kordas, O., 2019. Energy performance certificates — New opportunities for data-enabled urban energy policy instruments? Energy Policy 127, 486–499. https://doi:10.1016/j.enpol.2018.11.051

6.2 Conference proceedings

- Pasichnyi O., Shahrokni H., Kordas O., Oden — urban building energy model and dashboard for Swedish cities, EMP-E Conference 2019 "Modelling the implementation of a clean planet for all strategy - output from the Energy Modelling Platform for Europe (EMP-E)", October 8-9, 2019, Brussels.

6.3 PhD thesis

- PhD in Industrial Ecology, KTH Royal Institute of Technology. Advancing urban analytics for energy transitions : Data-driven strategic planning for citywide building retrofitting. https://urn.kb.se/resolve?urn=urn:nbn:se:kth:diva-285928

6.4 MSc thesis

- Kafashtehrani, Maryam. Life Cycle Perspective on School Buildings' Energy Retrofitting. Degree project in Environmental Engineering and Sustainable Infrastructure, 2022, http://urn.kb.se/resolve?urn=urn:nbn:se:kth:diva-319552

6.5 Reports

- Stockholms Stad (eds), 2021. Storskalig vs småskalig värme- och elproduktion, 53 pages.

6.6 Web tools

- Public energy efficiency map (PrettyMap) for Stockholm and Uppsala (building level) and Sweden (DeSO level)
  - https://oden.urbant.org
- Climate footprints for new buildings in Stockholm
  - https://pasichnyi.shinyapps.io/climate-footprints/
  - https://pasichnyi.shinyapps.io/models_summary/

Runt 35 procent av all energi i Sverige används i bebyggelsen. I forskningsprogrammet E2B2 arbetar forskare och samhällsaktörer tillsammans för att ta fram kunskap och metoder för att effektivisera energianvändningen och utveckla byggandet och boendet i samhället. I den här rapporten kan du läsa om ett av projekten som ingår i programmet.

E2B2 är Energimyndighetens program där IQ Samhällsbyggnad är koordinator. Läs mer på www.E2B2.se.