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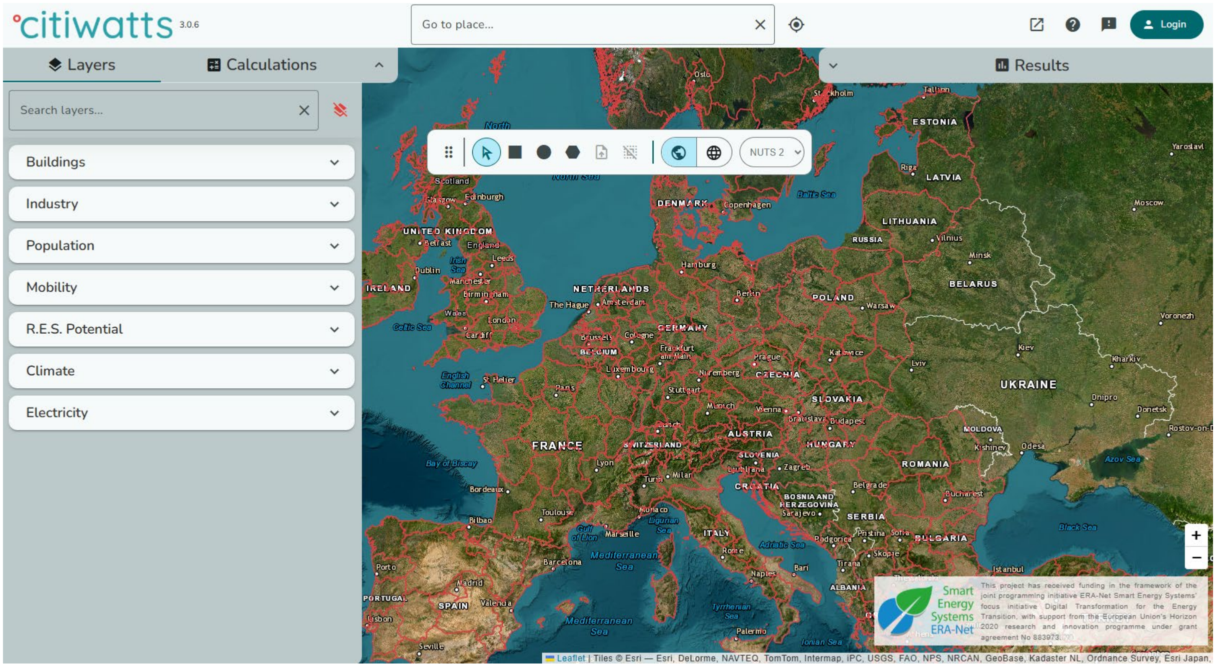
Final report from 14 November 2025

Open Geographic Information System for Energy Transition – OPENGIS4ET



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Summary

OpenGIS4ET successfully delivered Citiwatts 3.0, a comprehensive open-source energy planning platform that advances the green transition across heating, cooling, mobility, and sector coupling domains. Building on the H2020 Hotmaps foundation, the project reached TRL-8 by providing default data for all EU27 nations, UK, Norway and Switzerland at national and local levels, enabling energy planners and public authorities to efficiently analyze, model, and map solutions to meet their energy demands.

The platform features a robust DevSecOps development framework with continuous security analysis through SonarQube integration, responsive design compatibility across desktop and mobile devices, and comprehensive two-factor authentication through Keycloak services. A secure public API enables external system integration, while advanced session management allows users to maintain multiple calculation results per module, transforming the tool from single use to a comprehensive analysis workspace.

Three sophisticated calculation modules were developed and validated through real-world case studies: The EV-Mobility tool provides Vehicle Kilometer Travelled mapping with charging behavior modeling across four scenarios (home, workplace, points of interest, and home office charging), coupled with photovoltaic production potential analysis. The District Heating and Cooling tool addresses temperature-level optimization with economic feasibility assessment. The Sector Coupling tool integrates electrical, heating, and transport systems through connection with EnergyPLAN, enabling comprehensive flexibility analysis for multi-sector energy planning.

The project exceeded dissemination targets with 1,457 person-hour equivalents through summer schools (250 participants), webinar series, and training events across partner countries. Case studies in Denmark, Austria, Switzerland, and Germany confirmed the platform's effectiveness in diverse regulatory and technical contexts. Export capabilities including PDF reports, ZIP packages, and Excel format compatibility extended practical utility for integration into existing planning workflows.

The platform's success enabled major spin-off projects including OpenMod4Africa (extending energy planning capabilities to 500 million citizens across West and East Africa), CoolLIFE (sustainable cooling solutions), SAPHEA, and the OFPP project (microgrid resilience planning). Academic integration at University of Applied Sciences Western Switzerland and TU Wien ensures ongoing educational impact, while comprehensive wiki documentation and training materials support continued adoption beyond the project timeline.

Zusammenfassung

OpenGIS4ET hat erfolgreich Citiwatts 3.0 veröffentlicht, eine umfassende Open-Source-Plattform für die Energieplanung, die die grüne Wende in den Bereichen Heizung, Kühlung, Mobilität und Sektorkopplung vorantreibt. Aufbauend auf der H2020-Hotmaps-Grundlage erreichte das Projekt TRL-8, indem es Standarddaten für alle EU27-Länder, das Vereinigte Königreich, Norwegen und die Schweiz auf nationaler und lokaler Ebene bereitstellte, sodass Energieplaner und Behörden Lösungen zur Deckung ihres Energiebedarfs effizient analysieren, modellieren und kartieren können.

Die Plattform verfügt über ein robustes DevSecOps-Entwicklungsframework mit kontinuierlichem Security Analyse durch SonarQube-Integration, responsive Design, das mit Desktop- und Mobilgeräten kompatibel ist, und umfassender Zwei-Faktor-Authentifizierung durch Keycloak-Dienste. Eine sichere öffentliche API ermöglicht die Integration externer Systeme, während das fortschrittliche Session Management es Benutzern ermöglicht, mehrere Berechnungsergebnisse pro Modul zu speichern, wodurch das Tool von einem einfachen Werkzeug zu einem umfassenden Analyse-Arbeitsbereich wird.

Drei hochentwickelte Berechnungsmodule wurden entwickelt und anhand von Fallstudien aus der Praxis geprüft: Das EV-Mobility-Tool bietet eine Kartierung der zurückgelegten Fahrzeugkilometer mit einer Modellierung des Ladeverhaltens in vier Szenarien (Zuhause, Arbeitsplatz, Points of Interest und

Homeoffice-Laden) in Verbindung mit einer Analyse des Photovoltaik-Produktionspotenzials. Das Fernwärme- und Fernkälte-Tool befasst sich mit der Optimierung des Temperaturniveaus und der Bewertung der wirtschaftlichen Machbarkeit. Das Sektorkopplungs-Tool integriert Strom-, Heizungs- und Verkehrssysteme durch die Verbindung mit EnergyPLAN und ermöglicht so eine umfassende Flexibilitätsanalyse für die multisektorale Energieplanung.

Das Projekt übertraf die angestrebten Verbreitungszahlen mit 1.457 Personenstunden pro Jahr durch Sommerschulen (250 Teilnehmer), Webinare und Schulungsveranstaltungen in den Partnerländern. Fallstudien in Dänemark, Österreich, der Schweiz und Deutschland bestätigten die Wirksamkeit der Plattform in unterschiedlichen regulatorischen und technischen Kontexten. Exportfunktionen wie PDF-Berichte, ZIP-Pakete und Excel-Kompatibilität erweiterten den praktischen Nutzen für die Integration in bestehende Planungsabläufe.

Der Erfolg der Plattform ermöglichte wichtige Folgeprojekte wie OpenMod4Africa (Ausweitung der Energieplanungsmöglichkeiten auf 500 Millionen Bürger in West- und Ostafrika), CoolLIFE (nachhaltige Kühlungslösungen), SAPHEA und das OFPP-Projekt (Planung der Widerstandsfähigkeit von Mikronetzen). Die akademische Integration an der Fachhochschule Westschweiz und der TU Wien gewährleistet eine nachhaltige Wirkung im Bildungsbereich, während umfassende Wiki-Dokumentationen und Schulungsmaterialien die weitere Anwendung über den Projektzeitraum hinaus unterstützen.

Résumé

OpenGIS4ET a livré avec succès Citiwatts 3.0, une plateforme open source de planification énergétique qui fait progresser la transition verte dans les domaines du chauffage, du refroidissement, de la mobilité et du couplage sectoriel. S'appuyant sur les fondations du projet H2020 Hotmaps, le projet a atteint le TRL 8 en fournissant des données pour l'ensemble des 27 nations de l'UE, le Royaume-Uni et la Suisse aux niveaux national et local, permettant aux planificateurs énergétiques et aux autorités publiques d'analyser, de modéliser et de cartographier efficacement les solutions pour répondre à leurs besoins énergétiques.

La plateforme s’appuie sur un cadre de développement DevSecOps robuste avec une analyse continue de la sécurité via l'intégration de SonarQube, une conception responsive sur ordinateurs de bureau et appareils mobiles, et une authentification à deux facteurs complète via les services Keycloak. Une API publique sécurisée permet l'intégration de systèmes externes, tandis qu'une gestion avancée des sessions permet aux utilisateurs de conserver plusieurs résultats de « calculation module », transformant l'outil en un espace de travail d'analyse complet.

Trois « calculation module » ont été développés et validés à travers des études de cas réelles : L'outil EV-Mobility fournit une cartographie des kilomètres parcourus par les véhicules avec modélisation des comportements de recharge selon quatre scénarios (domicile, lieu de travail, points d'intérêt et télétravail), couplée à une analyse du potentiel de production photovoltaïque. L'outil de chauffage et de refroidissement urbain traite l'optimisation des niveaux de température avec évaluation de la faisabilité économique. L'outil de couplage sectoriel intègre les systèmes électriques, de chauffage et de transport via la connexion avec EnergyPLAN, permettant une analyse complète de la flexibilité pour la planification énergétique multisectorielle.

Le projet a dépassé les objectifs de dissémination avec 1 457 équivalents-heures-personnes à travers des écoles d'été (250 participants), des séries de webinaires et des événements de formation dans les pays partenaires. Des études de cas au Danemark, en Autriche, en Suisse et en Allemagne ont confirmé l'efficacité de la plateforme dans des contextes réglementaires et techniques divers. Les capacités d'exportation incluant des rapports PDF, des packages ZIP et une compatibilité au format Excel ont étendu l'utilité pratique pour l'intégration dans les flux de travail de planification existants.

Le succès de la plateforme a permis la réalisation de projets dérivés incluant OpenMod4Africa (extension des capacités de planification énergétique à 500 millions de citoyens en Afrique de l'Ouest et de l'Est), CoolLIFE (solutions de refroidissement durables), SAPHEA, et le projet OFPP (planification de la

résilience des microréseaux). L'intégration académique à la Haute École Spécialisée de Suisse Occidentale et à TU Wien assure un impact éducatif continu, tandis que la documentation wiki complète et les supports de formation soutiennent l'adoption continue au-delà de la durée du projet.

Main findings («Take-Home Messages»)

Open-Source Energy Planning Platform Achieves Market Readiness

Citiwatts 3.0 successfully reached TRL-8, providing Swiss and European energy planners with a free, scientifically grounded tool featuring default datasets for EU27, UK, Norway and Switzerland. The platform's open API and responsive design enable seamless integration into existing workflows, directly supporting Switzerland's energy strategy 2050 by democratizing access to sophisticated energy planning capabilities.

Integrated Mobility-PV Analysis Supports Electric Vehicle Infrastructure Planning

The EV-Mobility calculation module provides unprecedented spatial and temporal analysis of electric vehicle charging demand coupled with photovoltaic production potential. This enables Swiss municipalities and energy planners to optimize charging infrastructure deployment and renewable energy integration, directly addressing key challenges in Switzerland's transport sector decarbonization.

Advanced Session Management Transforms Energy Planning Workflow

The implementation of multi-result session management converts the platform from a single-use calculator to a comprehensive analysis workspace, enabling iterative scenario testing and hypothesis validation. This capability significantly improves decision-making quality through comparison of multiple energy strategies.

International Collaboration Extends Swiss Innovation to Global Scale

The project's success catalyzed major international initiatives including OpenMod4Africa (500 million citizens), demonstrating how Swiss-led open-source innovation in energy planning can achieve global impact. Academic integration at HES-SO and projects such as CoolLIFE, SAPHEA, OFPP and OM4A ensure sustained knowledge transfer and continued platform development, supporting sustainable energy transition.

Contents

List of abbreviations

2FA – Two-Factor Authentication
AC – Alternating Current
API – Application Programming Interface
CM – Calculation Module
DAST – Dynamic Application Security Testing
DC – Direct Current
DevOps – Development Operations
DevSecOps – Development Security Operations
DHC – District Heating and Cooling
EPFL – École Polytechnique Fédérale de Lausanne
EU27 – European Union 27 member states
EV – Electric Vehicle
FAIR – Findable, Accessible, Interoperable, Reusable
GDPR – General Data Protection Regulation
GIS – Geographic Information System
HES-SO – University of Applied Sciences Western Switzerland (Haute école spécialisée de Suisse occidentale)
HTTPS – HyperText Transfer Protocol Secure
KEA – Klimaschutz- und Energieagentur (Climate Protection and Energy Agency)
KEM – Klima- und Energie-Modellregion (Climate and Energy Model Region)
LAU – Local Administrative Units
NCPs – National Contact Points
nFADP – New Federal Act on Data Protection
NUTS – Nomenclature of Territorial Units for Statistics
OFPP – Office Fédéral de la Protection de la Population
POI – Points of Interest
PV – Photovoltaic
RES – Renewable Energy Sources
SAFe5 – Scaled Agile Framework
SAST – Static Application Security Testing
SCA – Software Composition Analysis
SCCER – Swiss Competence Center for Energy Research
SECO – State Secretariat for Economic Affairs (Switzerland)
SFOE – Swiss Federal Office of Energy (Bundesamt für Energie)
SNSF – Swiss National Science Foundation
TRL – Technology Readiness Level
UX – User Experience
V2G – Vehicle-to-Grid
VKT – Vehicle Kilometer Travelled
WP – Work Package

1 Introduction

1.1 Project Context

The OpenGIS4ET project builds upon the H2020 Hotmaps platform, an open-source Geographic Information System (GIS) toolbox developed to support heating and cooling demand mapping and planning across the European Union. The Hotmaps platform established a foundation for integrating scientific partners through advanced calculation modules implementation.

OpenGIS4ET extends this foundation by developing citiwatts.eu, a comprehensive energy planning platform that addresses geospatial analysis of renewable energy potential, grid management support, electric mobility charging demand modeling, and sector coupling analysis. The project employs open-source tools for heating and cooling mapping while enabling seamless integration with external systems through standardized APIs.

Launched in 2022 under Joint Call 2020, the project aimed to advance the platform from Technology Readiness Level (TRL) 7 to TRL-8 by 2025, focusing on secure development practices, GDPR compliance, and responsive user experience design across heating, cooling, electric vehicle infrastructure, and sector coupling domains.

1.2 Project objectives

OpenGIS4ET aimed to create a Europe-wide platform for energy planning at local, regional, and national levels, providing free and open-source online tools with downloadable default datasets.

The platform addresses three critical energy planning needs: heat and cooling demand analysis at hectare resolution, identification of potential district heating and cooling areas with associated grid cost estimates, and scenario-based geographical distribution of electric vehicle charging demand coupled with photovoltaic production potential.

1.2.1. Gap in Available Tools

While numerous digital tools exist for energy planning—ranging from GIS platforms (ArcGIS, QGIS, GrassGIS) to specialized energy system analysis tools (EnergyPlus, Thermos, EnergyPRO) and comprehensive city planning tools (City Energy Analyst, CityOpt, ICLEI Clearpath)—most are either proprietary or lack comprehensive default datasets. Citiwatts distinguishes itself by providing complete default data coverage for EU27, UK, Norway, and Switzerland while simultaneously enabling easy integration of users' private data. The platform offers various analysis options from national (NUTS0) to hectare-level resolution.

1.2.2. Open Data and Source Approach

Developing comprehensive energy demand and resource inventories requires synthesizing data from diverse sources including ESPON, European Environment Agency, Ge2O, PVGIS, and Thermomap. While EU-wide data providers offer broad territorial coverage, gaps inevitably exist. The project addresses these gaps by collecting supplementary data from national statistics and establishing relationships with National Contact Points (NCPs) to support ongoing data collection efforts.

1.2.3. Technical Challenges

The project addressed three primary technical challenges. First, securing the open API required implementing a Keycloak-based authentication system that balances robust security for sensitive energy planning data with accessibility for authorized users across the EU. Second, integrating four new calculation modules—Electric Vehicle-Photovoltaic sector coupling, Electric Vehicle charging needs, District Cooling, and the EnergyPLAN sector coupling tool—demanded harmonization with existing platform architecture while ensuring compatibility with established data formats. Third, incorporating EnergyPLAN, a Windows-based application developed in Delphi by Aalborg University partners, required sophisticated architecture to enable advanced energy system flexibility simulation without disrupting established platform functionality.

1.2.4. EV-Mobility and Grid Infrastructure

The rapid growth of electric vehicle adoption, with sales exceeding 30% of new passenger vehicles in some EU countries by 2020, necessitates large-scale charging infrastructure deployment across residential, commercial, and industrial sites. Simultaneously, decentralized photovoltaic systems are expanding toward becoming major electricity sources in many EU countries. Coordinated deployment of these technologies through smart charging coupled with local PV production can significantly reduce electric grid infrastructure upgrade costs. Building on previous research from the OFEN Microgrid-DC [1] and SCCER FURIES [2] Digitalization projects, the platform enables analysis of scenarios and policies for smooth, coordinated EV and PV development while considering differences in national market landscapes.

1.2.5. District Heating and Cooling Networks

District Heating and Cooling (DHC) systems are essential for achieving carbon-neutral energy infrastructure by enabling utilization of renewable and efficient energy sources including industrial excess heat and geothermal energy. While numerous information sources and tools address DHC planning—such as Heat Roadmap Europe, City Energy Analyst, and Thermos—they either lack user customization options or present excessive complexity for rapid assessment. The Hotmaps calculation modules established initial capabilities; OpenGIS4ET extends these to address temperature-level optimization and economic feasibility assessment, enabling public authorities to quickly identify locations with DHC potential.

1.2.6. Sector Coupling and Flexibility

OpenGIS4ET introduces flexibility quantification and prediction capabilities not available in comparable platforms. Flexibility—defined as the ability to accelerate or delay energy injection or extraction relative to a reference profile—enables optimization of building operations and integration of decentralized electricity-based heat sources including heat pumps and electric boilers. The platform addresses demand-side management requirements identified in the prior Eranet IntegrCiTy project, providing tools to integrate flexibility analysis into appropriate planning phases.

1.2.7. Development Framework including security along the development process

The project implemented a DevSecOps approach, extending traditional DevOps with integrated security testing throughout the development lifecycle to reduce vulnerabilities, failures, and cyber risks. Prior research established technical feasibility: a master thesis demonstrated cloud deployment viability on DigitalOcean infrastructure while identifying base platform limitations, and a subsequent bachelor thesis validated Kubernetes-based containerization, confirming the technical foundation for dynamic container management. [@todo add ref]

1.3 Purpose of the project

OpenGIS4ET extends the H2020 Hotmaps platform (TRL-7) to achieve TRL-8 by developing enhanced calculation modules, implementing data sharing capabilities, and improving user experience. The platform enables public authorities to develop local, regional, and national strategies for heating, cooling, mobility, and sector coupling flexibility aligned with renewable energy source (RES) targets and CO_2 emission goals at national and European levels.

1.3.1. Strategic Objectives

The project pursues three interconnected strategic objectives. First, it accelerates renewable energy transition by providing an open-source, scientifically grounded digital tool with 50+ updated default datasets for EU27, UK, Norway, and Switzerland. The platform enables users to integrate proprietary data following privacy and security principles, with optional sharing to private or public user groups following integrity and completeness validation. Security is ensured through DevSecOps practices that mitigate vulnerabilities throughout the platform lifecycle. The tool links to existing applications, initiatives, and policy processes, building upon expert knowledge from multiple countries.

Second, the platform creates transnational business and investment opportunities by enabling easy application throughout the EU with adaptation to local situations. Multiple ready-to-use default datasets accelerate initial strategy definition for municipalities and energy planners.

Third, the project ensures social sustainability and coherence with broader digitalization efforts through standardized Application Programming Interfaces (APIs) that enable integration and interoperability with existing systems. This approach builds an ecosystem around an extended community of contributors and users.

1.3.2. Technical Implementation

The project addresses key technical challenges including data platform and API scalability through dynamic container management for European cloud deployment with GDPR compliance. Sector coupling analysis extends from hectare level to regional, national, and transnational strategy plans, defining optimized time horizons for municipal and energy planner needs.

The mobility calculation module simulates electric vehicle evolution mapped with photovoltaic production using machine learning algorithms. Different voltage scenarios enable what-if analysis, including DC-Grid and AC-Grid comparison validated on real DC-test infrastructure at EPFL PV-Lab.

For thermal grid systems, the platform addresses rapid and reliable identification of locations suitable for District Heating and Cooling exploitation by public authorities. This includes sensitivity analysis related to different temperature levels in grids and potential resources including industrial excess heat. While substantial research exists on technical and economic DHC potential, questions remain regarding temperature level influence across various resources.

1.3.3. Research Questions

The project investigates three fundamental research questions. First, which spatial resolution optimally supports middle to long-term deployment of targeted technologies? Specifically, can hectare-level default datasets effectively accommodate near-real-time building-level data for sector coupling, flexibility strategies, and EV charging analysis?

Second, which temporal resolution provides reliable long-term planning? What represents the optimal trade-off between computing time, resolution (spatial and temporal), result accuracy, and user expectations?

Third, how can local results be effectively scaled to regional and national levels, and to what extent do scaling methodologies preserve analytical validity?

1.3.4. Implementation Approach

The project develops innovative calculation modules for Electric Vehicle mobility associated with Photovoltaic energy sources to support mobility planners in optimizing EV infrastructure advancement. Integration of real-time flexibility data enables management of actual flexibility assets within defined areas, while enhanced tools identify areas with District Heating and Cooling exploitation potential for public authorities.

Beyond calculation module development, the project enhances visualization tool usability through iterative testing with end users. A microservice infrastructure improves platform performance and scalability, while a public API enables interoperability with external systems used by municipalities and energy agencies throughout Europe.

1.4 Project management

The project employed Scaled Agile Framework (SAFe5) in conjunction with DevOps application lifecycle management (ALM) tools to ensure efficient development. SAFe5 provided proven methodology prioritizing safety, reliability, and quality, while DevOps enabled robust tracking and monitoring of project progress across distributed teams.

DevSecOps methodology facilitated rapid adaptation to user needs and feedback through multiple security tests integrated throughout the development process. This approach enabled early identification and resolution of issues, ensuring the final platform implements security best practices while meeting user requirements.

1.4.1. Consortium Structure and Collaboration

The consortium established effective project management structures at project inception. Regular monthly online meetings, SAFe5 framework implementation, and formal consortium meetings (kickoff May 2022, first meeting March 2023, new partner's integration meeting November 2023) maintained coordination across partners. (c.f. Figure 1)

Collaboration within the consortium proved effective overall, though some deviations from the original plan occurred. On January 1, 2023, HES-SO assumed responsibility for CREM collaborators and research activities, including all OPENGIS4ET project commitments. This ownership transition required team adjustments and caused delays in completing certain tasks originally assigned to CREM, though ultimately strengthened the project through enhanced institutional support.

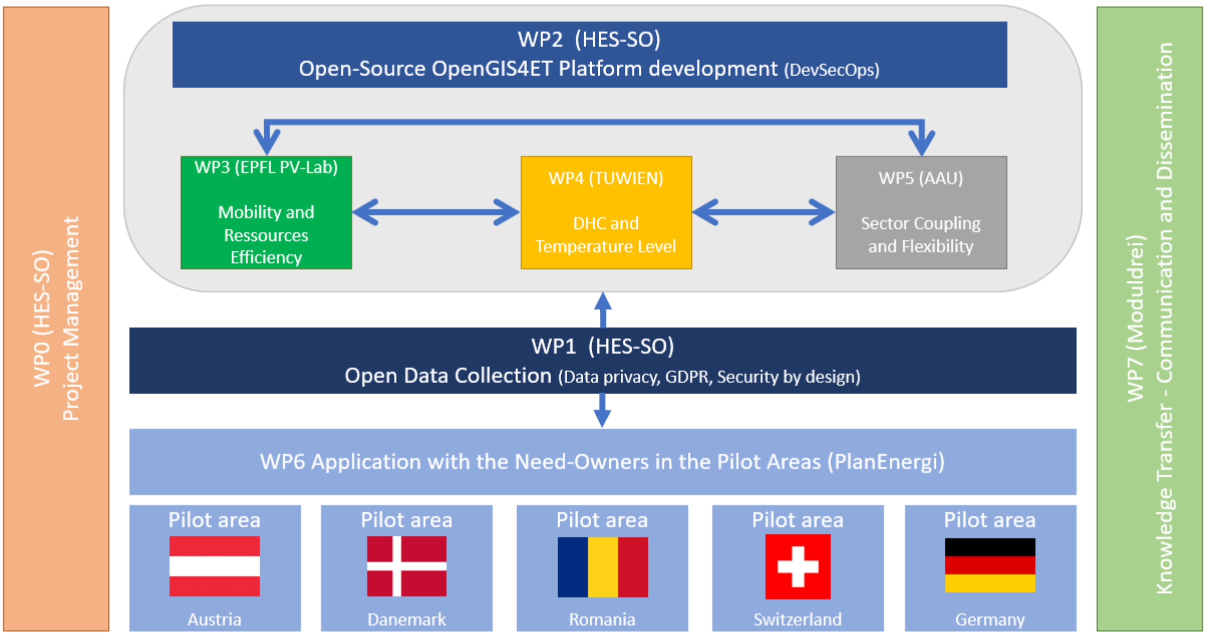


Figure 1 Work Packages Detail

1.4.2. Partnership Evolution

In Work Package 5, FlexShape left the consortium and were replaced by Aalborg University in 2023, necessitating task restructuring. While this transition caused initial delays, the partnership ultimately delivered more sophisticated sector coupling functionality than originally envisioned, with successful integration of the EnergyPLAN external tool providing advanced flexibility analysis capabilities.

1.4.3. Spin-off Project Enablement

The project's success enabled participation in major Horizon Europe initiatives including OpenMod4Africa, CoolLIFE, SAPHEA, and Act on Heat, with Citiwatts source code serving as the foundation (see Section 2.6 for details).

1.4.4. Branding Process

During development, trademark analysis revealed that "Hotmaps" was protected as a registered trademark for GIS-based services, precluding its use for commercialization. Simultaneously, user needs assessment identified branding and recognition as critical for building trust with public authorities and energy planning professionals. The consortium initiated a comprehensive branding process, consulting trademark experts to evaluate multiple alternatives. "citiwatts" was selected in early 2024 following legal review.

This extensive branding and name selection process, including multiple rounds of trademark consultation, delayed development of the corporate design package. However, by project completion, comprehensive corporate identity materials including website and communication materials were established.

2 Project Results

The OpenGIS4ET project delivered Citiwatts 3.0 as a production-ready platform serving 160 registered users through a secure Keycloak authentication system. Between December 2024 and November 2025, the platform recorded 2,088 visits generating 6,335 pageviews and 22,858 user interactions spanning map navigation, calculation module executions, and data queries. Platform analytics were implemented in December 2024 as part of GDPR and Swiss nFADP compliance, replacing Google Analytics tracking systems with privacy-focused Matomo, hosted on HES-SO infrastructure.

The platform provides comprehensive geographic coverage across EU27, UK, Norway, and Switzerland (c.f. Figure 2) through 47 default geospatial data layers organized across seven thematic categories encompassing buildings, industry, population, mobility, renewable energy potentials, climate data, and electricity data. Multiple spatial resolutions from hectare to national level (NUTS0-3, LAU) are available, enabling energy planning assessments for Europe citizens. Technical capabilities achieving TRL-8 include DevSecOps framework implementation, responsive design across desktop and mobile, Keycloak two-factor authentication, RESTful API enabling external system integration, and comprehensive data management.

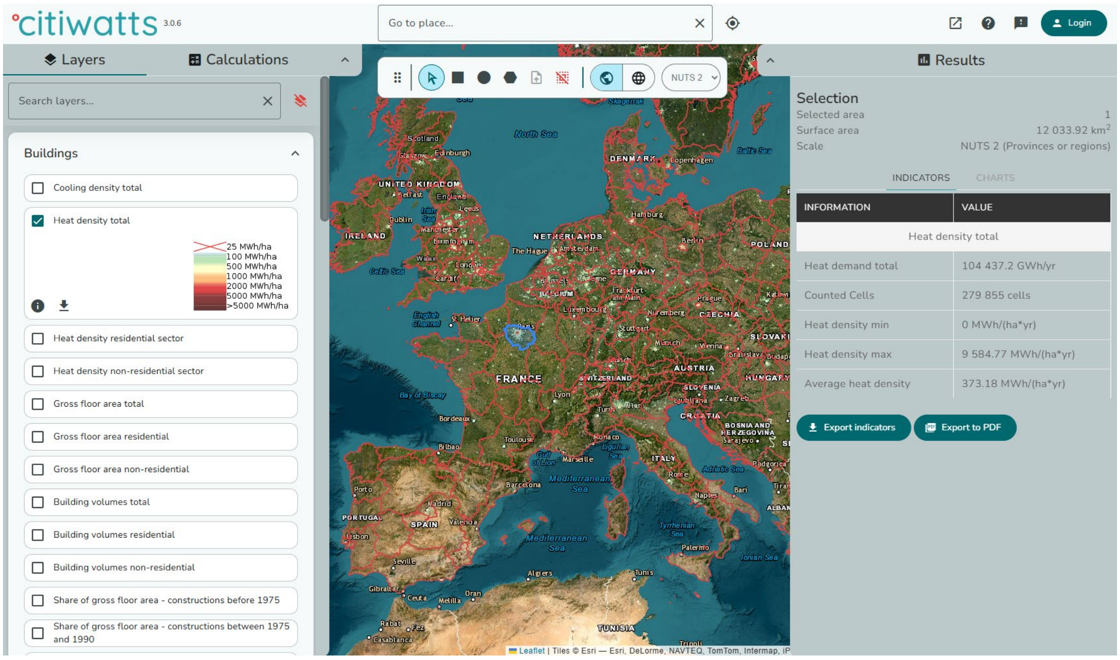


Figure 2 Citiwatts 3.0 main interface showing data for EU 27, Norway, UK and CH [24]

Platform validation occurred through comprehensive multi-module case studies, with the 89-page Sønderborg Municipality assessment (October 2025, pending peer review) providing systematic evaluation across all three major calculation modules for a Danish municipality of 74,000 inhabitants.

- The Heat Planning module analyzed 40.5 GWh total heat demand across three villages, identifying 28.21 GWh/year district heating potential at 70% connection rates and assessing €7.24 million infrastructure investment requirements with specific grid costs of 10.64 EUR/MWh.
- The EV-Mobility module modeled scenarios ranging from 18,723 to 37,900 electric vehicles with daily charging capacity requirements of 88,403 to 241,205 kWh/day, demonstrating 93% CO_2 reduction potential at full fleet electrification and identifying optimal spatial distribution for charging infrastructure deployment.
- The Sector Coupling module examined nine EnergyPLAN-based scenarios with renewable capacity varying from 14 MW to 165 MW wind plus 100 MW solar, analyzing peak electricity demand ranges of 40-200 MW and demonstrating how vehicle-to-grid participation could reduce both import and export peaks.

The results showed that platform performance relies more on locally tailored parameters than on universal defaults. Compared with Sønderborg's consultant-developed heat plan, the analysis confirmed that Denmark's non-profit district heating model can support viable networks at around 200 MWh/ha, rather than the 300 MWh/ha default often used in commercial European models. When Danish reference values from the KEA Baden-Württemberg methodology and national technology catalogs were applied, the platform's screening outputs closely matched consultant feasibility studies while remaining suitably conservative for investment decisions. Overall, this supports the platform's core principle: flexible, local parameter customization works better than fixed, one-size-fits-all assumptions.

Knowledge transfer reached 347 people through direct training: 250 participants in the SCCER Joint Activity Summer School 2024 and 97 students in courses at HES-SO (18) and TU Wien (79). In total, 1,457 person-hours of dissemination were delivered—121% of the 1,200-hour target—through webinars, on-site trainings, and focused workshops. Academic outputs included five peer-reviewed papers, more than ten international conference presentations, and three professional journal articles aimed at practitioners. A robust documentation suite—including an 89-page validation methodology, a technical wiki, tutorial videos, and interactive workshops—ensures continued platform adoption beyond the project's end.

The platform's proven effectiveness has triggered several major spin-off projects with global reach. OpenMod4Africa (SNSF–SECO, 2024–2027) adapts the methodology for energy planning across 15 African countries, serving more than 500 million people. CoolLIFE (EU LIFE, 2024–2028) develops urban cooling strategies for five European cities, while SAPHEA (SFOE, 2024–2027) advances analysis of solar-assisted heat pump integration. The OFPP project (SFOE, 2024) applies the platform to Swiss microgrid resilience planning for blackout scenarios.

Academic programs at HES-SO Valais-Wallis and TU Wien now teach the platform annually. Its open-source model—maintained through active GitHub repositories, documented APIs, an extensible module architecture, and adherence to FAIR principles—ensures continued innovation. Hosting and development have transitioned to a stable academic infrastructure jointly operated by TU Wien and HES-SO, securing long-term availability for the expanding European energy planning community.

2.1 User-Centered Development Process

Platform development followed a rigorous user needs assessment methodology to ensure tools addressed real planning challenges rather than theoretical requirements. Between June and August 2023, the consortium conducted structured expert interviews with energy planning professionals from 11 organizations across five countries (Austria, Denmark, Germany, Hungary, Switzerland, and Croatia). Interview partners included municipal energy planners (Sønderborg Municipality, Denmark; Frankfurt am Main, Germany), regional energy agencies (EA Steiermark, Austria; KEA Baden-Württemberg, Germany), cantonal energy services (SENE Neuchâtel, Switzerland), and climate-energy model regions (KEM Almenland and Weiz-Gleisdorf, Austria). These interviews revealed fundamental insights that shaped platform development priorities:

Critical Finding - The "Playground" vs. Prescriptive Tools Paradigm:

Planners consistently expressed that they needed hypothesis-testing capabilities rather than prescriptive solutions. As one municipal planner stated: "We won't perform studies ourselves but would like to 'ask better questions'" when engaging consultants and utilities. This insight fundamentally redirected development from automated assessment tools toward flexible scenario exploration capabilities.

Validity Over Volume

Interview partners emphasized that "validity of a given calculation is more important than the amount of calculations"—preferring simple, trustworthy tools over complex systems attempting to "solve everything" while risking accuracy. This principle guided the focus on three well-validated calculation modules rather than numerous experimental features.

Differential Detail Requirements

User needs analysis revealed that planners required different levels of detail for different energy sectors based on their existing knowledge. For thermal planning (especially district heating), higher detail was required as many authorities already had plans and needed tools for iteration. For emerging topics like EV charging infrastructure and electricity flexibility, less detailed screening tools were valued as any systematic analysis represented advancement beyond current practice. These findings were systematically categorized into 47 prioritized user needs spanning overall platform requirements, platform-level functionalities, and sector-specific calculation module features. User needs were integrated into agile development through regular SCRUM processes, with the prioritized list maintained and updated throughout the project based on testing feedback and evolving requirements.

2.2 Continuous Security during Platform Development

The project established a robust development framework using Scaled Agile Framework (SAFe5) with integrated security testing throughout the development lifecycle. Key security measures include continuous security analysis through SonarQube, Static Application Security Testing (SAST), Dynamic Application Security Testing (DAST), and Software Composition Analysis (SCA). Keycloak-based authentication with two-factor authentication (2FA) was implemented to ensure user privacy. Migration from Google Analytics to privacy-focused Matomo, hosted on HES-SO servers, ensures all user data is now stored locally within HES-SO infrastructure, achieving full GDPR and Swiss nFADP compliance.

Beyond security infrastructure, the platform achieved significant improvements in accessibility and usability. Citiwatts 3.0 now provides responsive design compatibility across desktop and mobile devices. Bachelor of Science theses validated the cloud deployment [3] and Kubernetes-based containerization [4], establishing the foundation for dynamic resource allocation and a scalable infrastructure.

To enable integration with existing municipal workflows, a secure public API was developed allowing municipalities and energy agencies to incorporate Citiwatts into their established planning processes.

Perhaps most significantly for end users, the platform evolved from a single-use calculator to a comprehensive analysis workspace through advanced session management capabilities. Users can now maintain multiple calculation results per module, save and manage results when logged in, and share layers with email-specific permissions. Export capabilities in multiple formats, including PDF reports with integrated charts, ZIP packages, and Excel-compatible data, enable integration into existing planning workflows.

2.3 New layers integration and Calculation Modules

The platform's analytical capabilities rest on a foundation of default data layers covering the entire EU27, UK, Norway and Switzerland. A total of 47 geospatial layers provide ready-to-use datasets re-organized across seven thematic categories: Buildings (including volumes, gross floor area, and building age classifications), Industry (industrial sites and excess heat potentials), Population (density and distribution), Mobility (fleet composition and commuting patterns), Renewable Energy Source Potentials (solar, wind, and geothermal resources), Climate (temperature, heating and cooling degree days), and Electricity (generation capacity and grid infrastructure). These default layers enable immediate analysis at hectare, LAU and NUTS resolution without requiring users to compile bottom-up datasets, substantially lowering barriers to initial energy planning assessments. Users can supplement or replace default layers with proprietary local data to increase precision for specific applications.

Building on this data foundation, the project proposes a total of 17 calculation modules enabling diverse analytical workflows. Three sophisticated modules received particular development focus, each validated through real-world case studies and deployed to production:

2.3.1. EV-Mobility Module

This calculation module provides spatial and temporal analysis of electric vehicle infrastructure needs:

- Vehicle Kilometer Travelled (VKT) mapping based on population distribution and city commuting ranges (c.f. Figure 3)
- Charging behavior modeling across four customizable scenarios: home, workplace, points of interest (POI), and home office charging
- Photovoltaic production potential analysis for solar-EV coupling
- Time-series generation showing charging demand variation throughout the day
- CO_2 emissions reduction assessment

Validated through case studies in Denmark and Switzerland, presented at multiple international conferences including Smart Energy Systems 2024 and Swiss Solar Congress 2024-2025.

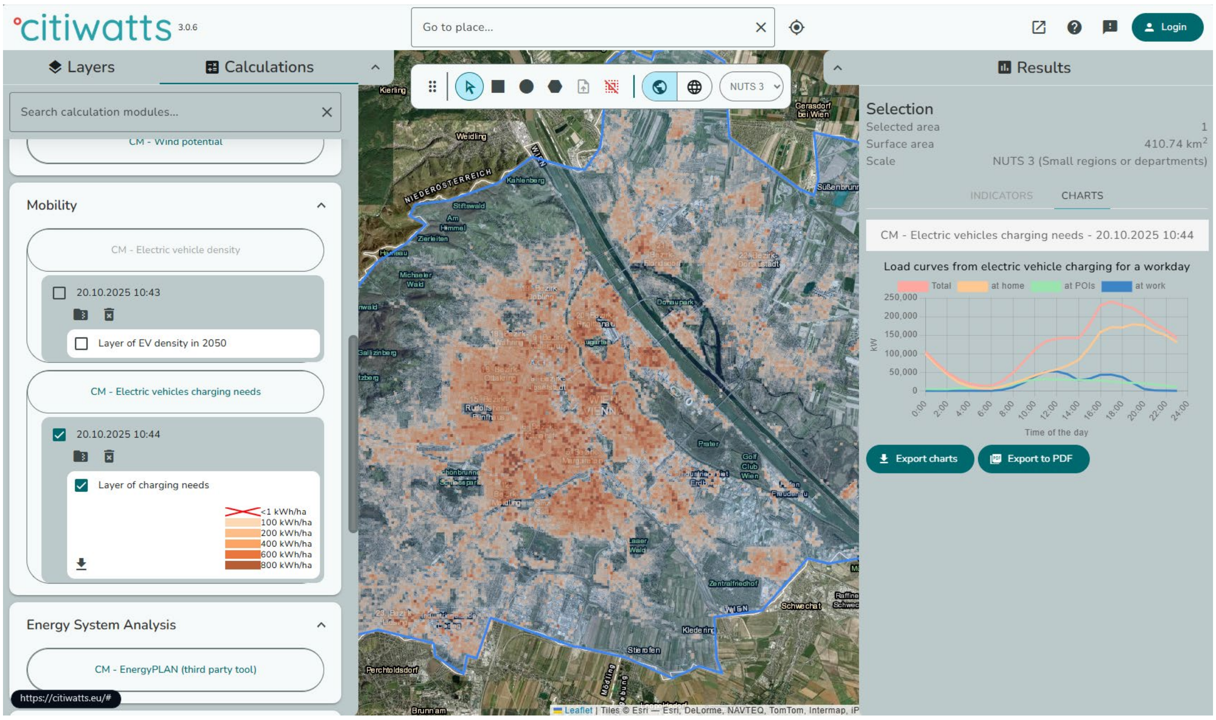


Figure 3 EV-Mobility calculation module showing the layer of charging needs mapping and charging behavior scenarios

2.3.2. District Heating and Cooling (DHC) Module

This calculation module (c.f. Figure 4) addresses thermal grid optimization with economic feasibility assessment:

- Temperature-level optimization for different heat sources (including industrial excess heat)
- Grid cost estimates at hectare resolution
- Economic indicators for district heating development

- Support for multiple temperature thresholds (>100°C, 50-100°C, <50°C)
- Water body identification as cooling sources using Corine Land Cover data

Validated through case studies in Austria and Germany, with research published at IAEE 2023 and IEWT 2023 conferences.

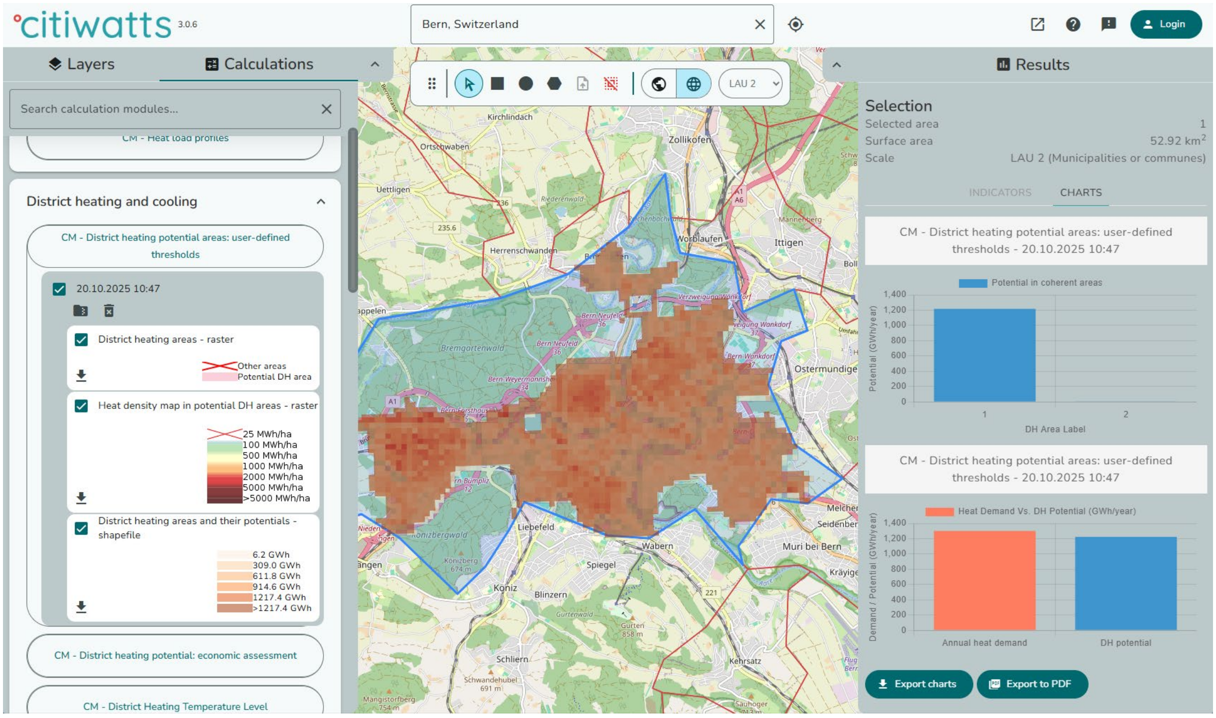


Figure 4 District Heating and Cooling Calculation Module

2.3.3. Sector Coupling Module

This calculation module integrates electrical, heating, and transport systems through integration with EnergyPLAN, an external energy system analysis tool developed and maintained by Aalborg University.

The platform embeds a modified version 16.3 of EnergyPLAN to provide:

- Comprehensive flexibility analysis across energy sectors
- Multi-sector energy planning capabilities
- Scenario-based assessment of system flexibility and resilience

EnergyPLAN is proprietary software developed by Aalborg University partners, available independently at energyplan.eu. The Citiwatts implementation represents a simplified version focused specifically on electricity-heating-transport sector coupling, enabling users to investigate flexibility options within the Citiwatts geospatial environment without requiring separate EnergyPLAN installation.

This module replaced originally planned tasks after the transition from FlexShape to Aalborg University as project partner, ultimately delivering more sophisticated functionality than initially envisioned through the partnership. (c.f. Figure 5)

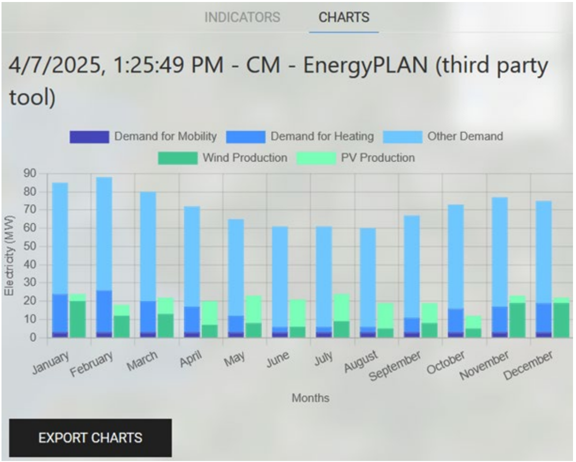


Figure 5 Chart generated by Calculation Module EnergyPLAN

2.4 User Experience & Adoption

The Sønderborg Municipality case study (Denmark, October 2025) provided real-world validation of all three major calculation modules by applying the platform to a municipality of 74,000 residents with established energy-planning practices. The study tested whether the platform could substitute or complement consultant-prepared analyses, comparing its outputs with existing municipal heat plans, utility assessments, and previous feasibility studies. This demonstrated both the platform's practical strengths and the importance of localizing key parameters to suit different regulatory and economic contexts.

2.4.1. Heat Planning Module - District Heating Potential Assessment

The DHC module was applied to screen potential district heating areas in Blans, Ullerup, and Avnbøl—three villages currently supplied by natural gas, representing typical Danish rural planning challenges. Analysis covered 40.5 GWh total heat demand with the following quantified outcomes:

- District heating potential identified: 28.21 GWh/year at 70% connection rate (representing economically viable expansion from existing networks)
- Grid construction cost estimation: €7.24 million total investment for distribution and service pipes
- Specific grid costs: 10.64 EUR/MWh (significantly lower than initial scenarios without Danish parameter adaptation)
- Levelized cost of heat comparison: District heating supply approximately 90 EUR/MWh versus individual heat supply options exceeding 100 EUR/MWh (individual air-source heat pumps, biomass boilers)

2.4.2. Critical Validation Finding - Parameter Localization Requirement:

Comparative analysis against Sønderborg's detailed municipal heat plan (2021-2024) revealed that international default parameters required substantial adjustment for Danish contexts. Specifically, Denmark's not-for-profit district heating business model supports economically viable networks at lower heat density thresholds (200 MWh/ha vs. 300 MWh/ha default) than commercial models typical in other European countries. When parameters were adapted to Danish reference values (drawing from KEA Baden-Württemberg methodology and Danish technology catalogs), citiwatts screening results aligned well with consultant-prepared feasibility studies, though remained appropriately more conservative for investment-grade decisions.

This finding validated the platform's design: providing flexible parameter customization rather than attempting universal defaults, enabling planners to adapt tools to diverse national regulatory and economic frameworks.

2.4.3. EV-Mobility Module - Charging Infrastructure Scenarios

The EV-Mobility module mapped charging demand across Sønderborg Municipality and Southern Denmark NUTS2 region (motorization rate: 497 cars/1,000 inhabitants), testing five scenarios varying EV penetration (49.4% to 100% of fleet) and charging behavior patterns:

- EV fleet projection 2040 (49.4% penetration): 18,723 electric vehicles requiring 88,403 kWh/day charging capacity
- EV fleet projection 2045 (100% penetration): 37,900 electric vehicles requiring 178,954 kWh/day (home-dominant charging) to 241,205 kWh/day (optimized workplace/POI charging)
- Smart charging impact: Load shifting from 18:00-22:00 afternoon/evening peaks to 02:00-06:00 night hours, enabling better integration with variable renewable production
- Workplace/POI charging scenarios: 40% workplace + 50% home-office + 20% POI charging shifted 30% of total demand to daytime hours, maximizing direct PV utilization potential
- CO_2 emission reductions: 46% reduction at 50% EV penetration, 93% reduction at 100% EV penetration compared to 100% fossil fuel fleet baseline

Module outputs provided spatial distribution of charging demand at hectare resolution, enabling infrastructure planners to identify optimal locations for public charging stations based on commuting patterns, population density, and points-of-interest concentration.

2.4.4. Sector Coupling Module - Energy System Flexibility Analysis

Nine EnergyPLAN-based scenarios systematically examined flexibility options through progressive electrification of heating (district heating heat pumps: 30-45 MWe; individual heat pumps: increasing from 0.01 to 0.08 TWh/year demand coverage) and transport (1,600 to 35,000 EVs) sectors:

- Base inflexible electricity demand: 0.37 TWh/year (residential, commercial, industrial excluding heating/transport)
- Renewable capacity scenarios: 14 MW to 165 MW wind power, 100 MW solar PV
- Peak electricity demand variation: From ~40 MW (limited electrification, low renewables) to ~200 MW (high electrification with 35,000 EVs, extensive heat pump deployment)
- Electricity import/export dynamics: Scenarios with 165 MW wind + 100 MW PV demonstrated significant export potential (reducing import dependency), while high electrification without renewable expansion (Scenario 7) eliminated exports entirely
- Vehicle-to-Grid potential: Scenario 9 (100% V2G participation with 35,000 EVs) reduced both import and export peaks compared to unidirectional charging, demonstrating battery storage potential

Analyses demonstrated how coordinated deployment of large-scale heat pumps in district heating, individual heat pumps replacing fossil fuel boilers, and flexible EV charging could mitigate renewable intermittency challenges while identifying infrastructure bottlenecks requiring grid reinforcement.

2.4.5. Platform Applicability Assessment for Danish Context

The comprehensive three-module validation led to clear conclusions about platform utility for Danish municipal energy planning:

Strengths identified:

- Rapid screening capability: District heating potential assessment completable in hours versus weeks for consultant studies
- Parameter flexibility enabling adaptation to Danish not-for-profit DH economics and technology catalog cost assumptions
- Scenario exploration supporting "hypothesis testing" approach valued by municipal planners

- Integration across heating, cooling, mobility, and sector coupling providing comprehensive energy system perspective unavailable in specialized single-sector tools

Limitations identified:

- Default parameters require substantial adaptation for Danish contexts (heating network economics, EV adoption trajectories differ from EU averages)
- Platform positioning appropriate for screening and scoping rather than investment-grade feasibility studies
- Limited added value for municipalities already completing detailed heat planning (2022-2024 mandatory process): "The potential of this application however is assessed to be low, as most municipalities have performed more specific and assumably more precise analyses"
- Greater utility for emerging planning domains (EV charging infrastructure, sector coupling flexibility) where municipalities lack established methodologies

2.4.6. Comparative Methodology Validation:

The case study explicitly compared Citiwatts results against three prior Sønderborg analyses: consultant-prepared detailed heat plan (2021), utility company grid expansion assessments (2022), and EU LIFE project COHEAT screening (2023). This triangulation approach, unprecedented in Citiwatts validation studies, demonstrated that appropriately parameterized screening analysis could substitute for expensive preliminary studies in planning workflows, while consultant engagement remained appropriate for final investment decisions.

The Sønderborg case study contributed 89 pages of detailed methodology documentation and quantified results to the public knowledge base, establishing replicable workflows for other Danish municipalities and demonstrating platform effectiveness for both mature planning domains (district heating) and emerging challenges (EV infrastructure, sector coupling).

2.5 Knowledge dissemination

The project achieved 1,457 person-hour equivalents across dissemination activities, exceeding the original target by 21% through a diversified approach combining academic integration, professional training, and scientific publication. A comprehensive list of publications and events can be found in Annex I. Special emphasis to Annex IV, which presents an accepted abstract for the ISEC2026, the 4th international Sustainable Energy Conference of 2026.

Academic integration formed a core component of knowledge transfer activities. TU Wien integrated the platform into curriculum courses reaching 79 students across 2024-2025 (3 hours plus exercises each), while Aalborg University engaged 18 bachelor and master students in energy planning applications (1 day plus exercises). The HES-SO Summer Schools 2025 validated Citiwatts 3.0 with 250 participants, providing intensive hands-on training while simultaneously serving as a large-scale platform stress test.

Beyond academic environments, the project conducted extensive professional training to reach practitioners directly. The eLearning/Webinar Series delivered English and German modules to 40 participants (12 hours each), offering flexible, modular training adaptable to professional schedules. A dedicated training event in Wiesbaden, Germany, brought together 30 participants from local authorities for intensive 1½-day workshops. ERA-Net SES Knowledge Community workshops facilitated cross-project learning, while targeted webinars reached 83 participants with mean engagement of 5 hours each.

This training and dissemination effort was complemented by substantial academic output. The project generated 5 peer-reviewed journal articles [14-17, 22-23] documenting methodological innovations and validation results, delivered over 10 conference presentations at international venues, and produced 3 professional publications [19-21] reaching practitioner audiences. A complete publication list is provided in Appendix I.
Validation through real-world applications confirmed these dissemination efforts translated into practical utility. Case studies in Denmark, Austria, Switzerland, and Germany demonstrated platform

effectiveness across diverse regulatory and technical contexts. These applications revealed critical insights: users require hypothesis-testing capabilities rather than prescriptive solutions; the "playground" concept supporting exploratory analysis proved more valuable than automated assessment tools; local data integration capabilities are essential for municipal adoption; and export functionality (PDF, Excel) enables seamless integration into existing planning workflows.

Final dissemination of the platform took place at the Smart and Sustainable Planning for Cities and Regions (SSPCR) 2025 Conference in Bolzano, which convened a large international audience of urban planning professionals and researchers.

2.6 Data Management and Compliance

Underlying all platform functionality and dissemination activities, rigorous data protection measures ensure compliance with European and Swiss regulations. Comprehensive security infrastructure includes HTTPS encryption for all data transmission, Keycloak authentication with two-factor authentication (2FA), and role-based access control limited to authorized personnel. Database access is restricted to the internal network, with automated account management deleting unverified accounts within 48 hours and inactive accounts after one year with user notification. User-controlled data deletion remains available via email request, ensuring individual data sovereignty.

Environmental considerations further informed platform development decisions. CO_2 impact assessment of project servers guided infrastructure optimization and containerization strategies, ensuring the platform's technical sustainability complements its commitment to supporting energy transition planning.

2.7 Spin-off Projects and Sustainability

The platform's demonstrated effectiveness and open-source architecture catalyzed major follow-on initiatives extending its impact globally.

- OpenMod4Africa, based on the open-source code of citiwatts, adapts the energy planning methodology to address the needs of 500 million citizens across West and East Africa, demonstrating the platform's transferability beyond European contexts.
- CoolLIFE develops sustainable cooling solutions for EU buildings,
- SAPHEA, with branding and module activation, functionality and use of the branding option of the platform, advances heating and cooling analysis capabilities, while the OFPP Project applies the technology to microgrid resilience planning for the Swiss Federal Office for Civil Protection, addressing electricity network resilience during blackout scenarios [2[]].
- The proposed AI4SWEng Horizon project envisions using the Citiwatts API with AI tools for automated geographic dataset generation, potentially reducing barriers to platform adoption.

Academic integration at HES-SO and TU Wien ensures ongoing educational impact and continued platform development beyond the project timeline, creating a sustainable ecosystem for platform maintenance, enhancement, and knowledge transfer to future generations of energy planners.

2.8 Project Management and adaptations

Achieving these outcomes required navigating significant organizational and strategic adaptations throughout the project lifecycle. The transition from CREM to HES-SO on January 1, 2023, required team adjustments but ultimately strengthened the project through enhanced institutional support. More substantially, the replacement of FlexShape with Aalborg University in WP5 necessitated fundamental task restructuring. While this mid-project partner change introduced delays, it ultimately delivered more sophisticated sector coupling functionality than originally envisioned, with successful EnergyPLAN integration providing advanced flexibility analysis capabilities.

Perhaps most importantly, the SAFe5 framework enabled responsive adaptation to user feedback throughout the development process. The critical pivot from prescriptive assessment tools to hypothesis-testing "playground" capabilities emerged from systematic user needs analysis (D6.1) and case study applications (D6.2), significantly enhancing practical utility. This agile approach—balancing structured project management with flexibility to incorporate evolving user requirements—proved essential to the project's success in delivering a tool that meets actual rather than assumed user needs.

3 Conclusions and outlook

The OpenGIS4ET project successfully achieved all its primary objectives, delivering Citiwatts 3.0 as a mature, production-ready open-source energy planning platform that has reached Technology Readiness Level 8 (TRL-8). The platform now serves as a comprehensive tool for universities, energy planners and public authorities across Europe, providing default data coverage for EU27, UK, Norway and Switzerland at unprecedented spatial resolution (hectare level).

3.1 Key Achievements:

The project exceeded its original scope in several important areas. The dissemination target of 100 participants in 1½-day events was transformed into a more effective approach reaching 1,457 person-hour equivalents through diverse formats including summer schools (250 participants), webinar series, on-site training events, and focused workshops. This adaptive strategy proved more successful in the post-pandemic environment where extensive webinar formats faced reduced interest.

The DevSecOps implementation from Security by design to dynamic application security testing (DAST) through Software Composition Analysis (SCA) and Static Application Security Testing (SAST) integration established a robust security framework that ensures ongoing code quality and vulnerability management. The platform's responsive design now enables seamless operation across desktop and mobile devices, while advanced session management capabilities transform user workflow from single calculations to comprehensive iterative analysis workspaces.

All three new calculation modules (EV-Mobility, District Heating and Cooling, and Sector Coupling) were successfully developed, validated, and integrated into production (see Section 2.2).

3.2 Platform Sustainability and Continued Development:

The platform's open-source architecture and comprehensive API ensure long-term sustainability and continued evolution. Integration into academic curricula at University of Applied Sciences Western Switzerland (HES-SO) and TU Wien guarantees ongoing educational impact and knowledge transfer to future generations of energy planners.

The successful launch of major spin-off or linked projects demonstrates the platform's versatility and scalability:

- OpenMod4Africa extends the energy planning methodology to African contexts, addressing energy needs of 500 million citizens
- CoolLIFE adapts the platform for sustainable cooling solutions across Europe
- SAPHEA branding for advanced heating and coding analyses
- The OFPP project applies the technology to microgrid resilience planning in Switzerland

3.3 Challenges Overcome

The project successfully navigated several significant challenges. The replacement of WP5 partner FlexShape with Aalborg University required task restructuring but ultimately delivered sophisticated flexibility tools. Trademark issues necessitated rebranding from Hotmaps to Citiwatts, resulting in a stronger, distinctive identity. The extension to August 2025 allowed completion of critical summer school activities that substantially enhanced validation and dissemination outcomes. The agile development approach proved essential in adapting to evolving user needs.

3.4 Future Outlook

The citiwatts platform is positioned for sustained growth and impact beyond the project timeline. Comprehensive documentation, training materials, and wiki resources support continued adoption by new user communities. The public API enables integration with existing tools and workflows used by municipalities and energy agencies across Europe.

Related projects (OpenMod4Africa, CoolLIFE, SAPHEA, OFPP) will continue platform enhancement and validation in diverse contexts. The academic integration ensures continuous knowledge transfer and potential for further research-driven improvements. The established consortium and user community provide foundation for future collaborative development and support.

3.5 Contribution to Swiss Energy Policy

For Switzerland specifically, the platform directly supports Energy Strategy 2050 implementation by providing municipalities and cantons with free, scientific tools for heating, cooling, and mobility planning. The platform's capabilities in scenario analysis, renewable energy integration assessment, and sector coupling evaluation align with Swiss federal objectives for decarbonization and energy transition. The successful OFPP project demonstrates practical application for Swiss energy security and resilience planning of the electricity network in case of blackout [5]. Linked with a master thesis “Optimisation de la taxation des émissions de CO2 des véhicules de tourisme à moteur thermique en Suisse à l’aide du machine learning” from Huy-Duc Nguyen, an abstract has been submitted and accepted to ISEC2026, which will contribute to help policy makers (see appendix 4). [5]

3.6 Final Assessment

The OpenGIS4ET project successfully transformed the H2020 Hotmaps foundation into a comprehensive, user-friendly, and scientifically robust energy planning ecosystem. Achievement of TRL-8 confirms the platform's readiness for widespread deployment and operational use. The combination of technical excellence, user-centered design, comprehensive training resources, and active community engagement positions Citiwatts as a valuable long-term resource for European and international energy transition planning.

4 References

[1] Ellert, C. (2021) DC microgrid with partial self-sufficiency enabling the smoothing of renewable generation peaks and highly variable consumption. https://www.hevs.ch/en/applied-research/research-institute-sustainable-energy/dc-microgrid/

[2] SCCER FURIES II – Future Swiss Electrical Infrastructure Project. https://www.epfl.ch/labs/ipese/ipese-research/ipese-urban_systems/sccer-furies-ii-future-swiss-electrical-infrastructure/

[3] Zuber, L. (2020). "Impacts of cloud-based infrastructure for the deployment of a microservice-based docker software architecture." Master's thesis.

[4] Mabillard, M.-E. (2025). "Containerization and Orchestration of the Citiwatts Architecture: Towards a Resilient and Sovereign Energy Platform". Bachelor's thesis.

[5] Binjos, A. (2025). "Integration of artificial intelligence for the exploration of energy transition solutions". Poster session. CIRED 2025 https://www.cired2025.org

[6] Nguyen, Huy Duc (2025). "Optimisation de la taxation des émissions de CO2 des véhicules de tourisme à moteur thermique en Suisse à l'aide du machine learning". Master's thesis. An abstract was submitted and accepted at the International Conference ISEC-2026 to disseminate these results (Appendix 4)

Online Resources

- Hotmaps. "The open-source heating/cooling mapping and planning toolbox." Available: https://www.hotmaps-project.eu/
- Project Homepage: https://project.citiwatts.eu/
- Citiwatts-toolbox: https://citiwatts.eu/
- Citiwatts-wiki: https://citiwatts.github.io/wiki/
- Case Study Reports (WP6): https://citiwatts.github.io/wiki/case-study-reports/
- Learning Center (WP7):eLearning materials incl. webinar recordings, presentations and exercises https://citiwatts.github.io/wiki/learning-toolchain-approach/#elearning-center-webinars-and-training-materials

Appendix

Appendix I - Publications & Events list

Appendix II - Detailed Data Management Plan

Appendix III – Energy Impact Estimate

Appendix IV – ISEC-2026 Optimization of CO2 Emissions taxation in Switzerland using machine learning

Appendix I – Publications & Events list

Dissemination

National and International conferences

- **10th International Conference on Smart Energy Systems**
  - 10-11 September 2023 in Aalborg (Denmark), "From PV to EV: Mapping the Potential for Electric Vehicle Charging with Solar Energy in Europe" oral presentation by Noémie Jeannin; a paper will be submitted for the proceedings.

- **13. Internationale Energiewirtschaftstagung an der TU Wien**
  - 15-17 February 2023 in Vienna, Presentation of the concept developed for DC CM

- **31st Young Energy Economists and Engineers an der TU Wien**
  - 11-12 May 2023 in Vienna, Draft paper, and presentation

- **SFOE e-mobility roadmap event**
  - EPFL – presentation at the SFOE e-mobility roadmap event (9.12.2022, online)

- **PVinMotion Conference 2024**
  - 06.03.2024, Neuchâtel, Presentation of EPFL work

- **Solar and Storage Zurich**
  - 17-18.09.2024, EPFL presentation of work and poster (WP3 result)

- **SESAAU2024 – the 11th edition of the Smart Energy Systems Conference**
  - Aalborg, DK, 10-11.09.2024. Presenting and discussing scientific findings and industrial experiences related to the subject of Smart Energy Systems based on renewable energy.

- **DevOps Days Geneva**
  - 2022, HES-SO presentation of Scale Agile Framework SAFe5 used to manage distributed Scrum teams and coordinate the OpenGIS4ET project.

- **IAEE 2023 Conference**
  - "Modeling the technical and economic feasibility of district cooling networks under scenarios of increasing cooling demand" by TU Wien (Aadit Malla)

- **IEWT 2023 Conference**
  - Same topic presentation on district cooling networks

- **Swiss Solar Congress 2024**
  - Poster presentation on Swiss mobility case study

- **Smart Energy System Conference 2024**
  - Aalborg, European case study presentation using mobility CMs

- **Swiss Solar Congress 2025**
  - Poster presentation on mobility CMs

- **CIRED 2025**
  - Full-paper Swiss case ‘Résilience des réseaux électriques en cas de blackout’
  - Full-paper citiwatts.eu data privacy manaagemetn and DevSecOps approach
  - Full-paper LLM used to interact with GIS citiwatts.eu platform

- **Final Project Presentation at the SSPCR conference Bolzano 2026**

Training Events and Workshops:

- **ERA-Net SES Knowledge Community**
  - Peer-to-Peer (P2P) Session Consumer and Citizen Involvement (CaCI), June 26, 2023
  - Presentation at JPP ERA-Net SES Knowledge Community Working Groups

- **Target Group Webinars (2023)**
  - Series targeting German forum for energy planning research, student groups, local authorities
  - Total reach: 83 participants, mean engagement 5 hours/participant

- **eLearning/Webinar Series (2025)**
  - English: 5+1 modules, thematically listed. Presentation, demonstration and application (in guided exercises) of all major developments of the platform. 1-3 hours/webinar. Approx. 20 participants, 12 hours total.
  - DACH/German: 5+1 modules, thematically listed. Presentation, demonstration and application (in guided exercises) of all major developments of the platform. 1-3 hours/webinar. Approx. 20 participants, 12 hours total.

- **Academic Integration**
  - Class at TU Vienna (2024): Primarily heat and cold planning toolchains. 44 participants, 3 hours + exercises.
  - Class at TU Vienna (2025): Primarily heat and cold planning toolchains. 35 participants, 3 hours + exercises.
  - Class at Aalborg University (2025): Targeted to bachelor and master students in energy planning, focusing on the application of tools for energy system screening. 18 participants, 1 day + exercises.
  - Summer Schools 2025 University of Applied Sciences Western Switzerland to validate Citiwatts 3.0

  Total 250 participants across multiple events

- **Wiesbaden Training Event (Germany, 2025)**
  - Training event targeting local authorities. Primarily heat planning toolchain. 30 participants, 1½ days.

- **CET Partnership Event (2025)**
  - On-line co-creation workshop 10.2024
  - Presentation of Citiwatts platform and demonstration of Agile Project management with multi-teams
  - On-line co-creation workshop 10.2025

Publications:

Peer-Reviewed Academic Publications:

- EPFL – Noémie Jeannin, Alejandro Pena-Bello, Christophe Ballif, Nicolas Wyrsch, (2024) "Mapping the charging demand for Electric Vehicles in 2050 from mobility habits", paper submitted in Sustainable Energy, Grids and Networks (SEGAN). htttps://doi.org/10.1016/j.segan.2024.101468
- EPFL - Jeannin, N., Pena-Bello, A., Dumoulin, J., Wannier, D., Ballif, C., & Wyrsch, N. (2024). “From PV to EV: Mapping the Potential for Electric Vehicle Charging with Solar Energy in Europe”. International Journal of Sustainable Energy Planning and Management, 41, 45–57. https://doi.org/10.54337/ijsepm.8151
- EPFL - Jeannin, N., Pena-Bello, A., Wannier, D., Dumoulin, J., Ballif, C., & Wyrsch, N. (2025). A Spatiotemporal Analysis of Photovoltaic Electricity Storage Potential in Electric Vehicles.

International Journal of Sustainable Energy Planning and Management, 44, 91-106. https://doi.org/10.54337/ijsepm.9825

- TU Wien - Malla, A., Kranzl, L., Fallahnejad, M., & Hummel, M. (2025). Strategic Planning and Viability Assessment for Implementing District Cooling Networks. Energy (submitted/in press)
- HESSO - A. Pena-Bello, N. Jeannin, N. Wyrsch, D. Wannier, and J. Rager, (2025) “Citiwatts: a secure, open-source platform for regional energy planning”, IET Conf. Proc., vol. 2025, no. 14, pp. 2016–2020, Oct. 2025, doi: https://doi.org/10.1049/icp.2025.1987.
- EPFL - N. Jeannin, A. Pena Bello, J. Dumoulin, D. Wannier, C. Ballif, and N. Wyrsch, (2025) “Potential for EV charging from PV: a geographic assessment”, IET Conf. Proc., vol. 2025, no. 14, pp. 2430–2434, doi: https://doi.org/10.1049/icp.2025.2107.

Conference Proceedings:

- Book of Abstracts: 9th International Conference on Smart Energy Systems - "Modeling the potential for District cooling: Vienna" by TU Wien (Aadit Malla and Lukas Kranzl). Available at: https://vbn.aau.dk/da/publications/book-of-abstracts-9th-international-conference-on-smart-energy-sy

Professional Publications (Non-Peer Reviewed):

- Jeannin, N., Wyrsch, N., & Pena-Bello, A. "Vers l'infrastructure de recharge de 2050." Bulletin.ch. Available at: https://www.bulletin.ch/fr/news-detail/vers-l-infrastructure-de-recharge-de-2050.html
- Wannier, D., Vianin, J., Mabillard, M.-E., Gustin, G., Pouget, J., & Guo, B. "Résilience du réseau face aux black-out." Bulletin.ch. Available at: https://www.bulletin.ch/fr/news-detail/resilience-du-reseau-face-aux-black-out.html
- Müller, S., Jeannin, N., Wyrsch, N., & Dumoulin, J. "Les atouts des plateformes de covoiturage." Bulletin.ch. Available at: https://www.bulletin.ch/fr/news-detail/les-atouts-des-plateformes-de-covoiturage.html

Online Documentation and Resources:

- Comprehensive wiki documentation deployed at https://citiwatts.eu with tutorials and training materials
- Tutorial video series covering all major platform functionalities
- Developer documentation for calculation module integration
- Project website: https://citiwatts.eu

APPENDIX II – Detailed data management plan

Data management plan

Project Overview and Data Processing

The OpenGIS4ET project extends the H2020 Hotmaps platform, an open-source toolkit initially developed to facilitate heating and cooling mapping and planning across EU28 at national and local levels. This extension integrates new open APIs and calculation modules (CM) to support the development of local, regional, and national strategies for heating, cooling, mobility, and sector coupling flexibility. These enhancements are aimed at aligning with RES and CO2 emission targets set at national and European levels.

The platform provides energy planning tools while enabling users, including public authorities and energy planners, to securely upload and manage private data relevant to their energy planning activities. Personal data is collected through the registration process in online forms including names and email addresses. Moreover, once registered on the platform and authenticated through email, any data uploaded through the platform is also stored. The data is used primarily for user identification. There is no IP tracking. The user authorizes the processing of personal data through consent, given when the policy terms are accepted. The personal data is not removed unless the user deletes the account or sends an email asking for the data to be removed.

The personal data is stored in the HES-SO database, as well as the private layers uploaded by the user. However, in the case of the feedback given to the developer team through the feedback form, the data is stored by Microsoft through the Azure DevOps platform, and the GDPR compliance is out of citiwatts' team control.

HES-SO Valais-Wallis stores the data, and it is not shared with third parties. However, the data provided through the feedback form is managed through Azure, being this the only third party with access to data such as name, email, and company name, as well as the type of feedback provided, and any file shared within such form.

Data Protection Measures and Compliance Implemented

The OpenGIS4ET project implemented comprehensive data protection measures to ensure compliance with GDPR and Swiss nFADP standards:

1) Security Infrastructure:

- Data transmission is secured using HTTPS to prevent interception during transfer
- Stored passwords are encrypted in the database to safeguard against unauthorized access
- Access controls are limited to authorized internal staff, specifically the HES-SO WP2 team
- Database can only be accessed within the HES-SO network
- Keycloak authentication system implemented with two-factor authentication (2FA) for user accounts
- Strict role-based access control is enforced; only authorized HES-SO members can access Keycloak credentials for managing user identities (email addresses, names, and hashed passwords)
- DevSecOps tools incorporated into development pipeline with SonarQube, SCA, DAST tools, Prometheus, for continuous security monitoring and code quality maintenance

2) Data Privacy and Analytics:

- Matomo analytics platform deployed on HES-SO servers, replacing Google Analytics
- Only essential analytics data are collected (browser, operating system, country, city, and IP address) and only when users consent to analytics cookies. These analytics data are strictly used for statistical purposes and are fully separated from personal user data stored in Keycloak
- All user data is stored locally and fully controlled within HES-SO infrastructure

- No external third-party analytics services with access to user behavior data

3) Data Management:

- Unverified accounts are deleted within 48 hours
- Inactive accounts are deleted after one year, with reminders sent to users before deletion
- Automated deletion processes implemented
- Users can request data deletion via email
- Explicit user consent is mandatory before any data processing occurs
- Privacy policy transparently provided through website link and during consent process

4) Interoperability and Open Data:

- Common data descriptors and formats (CSV and TIF) established for publication
- Data confidentiality framework established in line with GDPR and Swiss nFADP standards
- Each dataset is accompanied by a comprehensive data descriptor containing title, authors, affiliations, license information, summary, version details, and usage notes to ensure transparency, reproducibility, and clarity regarding data quality and limitations

5) User Data Control:

- User-uploaded layers remain private or shared only with explicit user consent (email-specific sharing)
- Personal GeoJSON layer upload functionality enables users greater flexibility in data input while maintaining control
- Multiple output formats supported (CSV, ZIP) while maintaining data security

Environmental Impact Assessment

A comprehensive analysis of the CO_2 impact of project servers was performed to assess and mitigate the environmental footprint of the infrastructure. This assessment informed decisions about resource optimization and containerization strategies implemented in the final platform architecture.

Conclusion

The OpenGIS4ET project successfully implemented a robust data protection framework achieving full compliance with GDPR and Swiss nFADP requirements. The combination of secure infrastructure (HTTPS, encryption, Keycloak with 2FA), privacy-focused analytics (Matomo), continuous security monitoring (DevSecOps with SonarQube), and transparent data policies ensures the protection of personal data and user privacy.

APPENDIX III – Energy Impact Estimate

Energy Impact Estimation

There are three physical Hardware (HW) servers running all virtual machines. Their specs are listed in Server specs.
Added to this but not accounted for in this estimation, there are:

- Shared Storage: Proper tracking would require tracking of data exchanges
- Network infrastructure: Would require tracking of amount of data exchanged over entire building

The current setup for the Citiwatts application is based on two Virtual Machines (VMs). One for the production version and one for the development version. Their specs are given in VM specs.
As a VM does not have a physical power connection, we can only give an estimation of the power consumption generated by a specific VM.
To do so, we take the percentage use of the CPU by the VM. However a VM is granted only access to 8 cores out of the 32 of a physical machine so it's usage percent needs to be scaled to the total number of cores. Additionally, the system places the VM where needed on the three physical machines and can move it for load balancing purposes. This is not eay to track as it is done automatically and would make the estimation of power consumption too advanced for our purposes. Instead, we scale the percent cpu usage to 96 cores for the three machines.
Once we established the VM's cpu usage over all three machines, we use it to get the ratio of total power to the three machines that is used by the VM.

Weaknesses

The weak points of this estimation are as follows

- Tangential power demands: as mentioned in the previous section, we cannot account for some of the power usages that exist in support of the VM servers.
- Simple ratios: the basic ratio of cpu usage to power usage of VM to HW over a week does not give an accurate representation of how different VMs' instant consumption might influence total consumption.
- Flat behavior assumption: we assume that servers generally have a very constant power usage so that we can port the consumption of a week to a year. While overviews showed that this was a reasonable assumption, we could get more data over a longer period in the future.

Power estimation

$$\frac{p_{vm}}{p_{hw}} = \frac{P_{vm}}{P_{hw}}$$

$$\text{Total HW CPU usage percent: } p_{hw} = \frac{1}{N_{cores}} \sum_{i=1}^{3} p_i \cdot N_i = 0.12709$$

$$\text{Total HW average power consumption: } P_{hw} = \sum_{i=1}^{3} P_i = 1523W$$

$$\text{Total VM CPU usage percent: } p_{vm} = \frac{1}{N_{cores}} \sum_{j=1}^{2} p_j \cdot N_j = 0.005216$$

$$P_{vm} = \frac{p_{vm}}{p_{hw}} \cdot P_{hw} = 62.507W$$

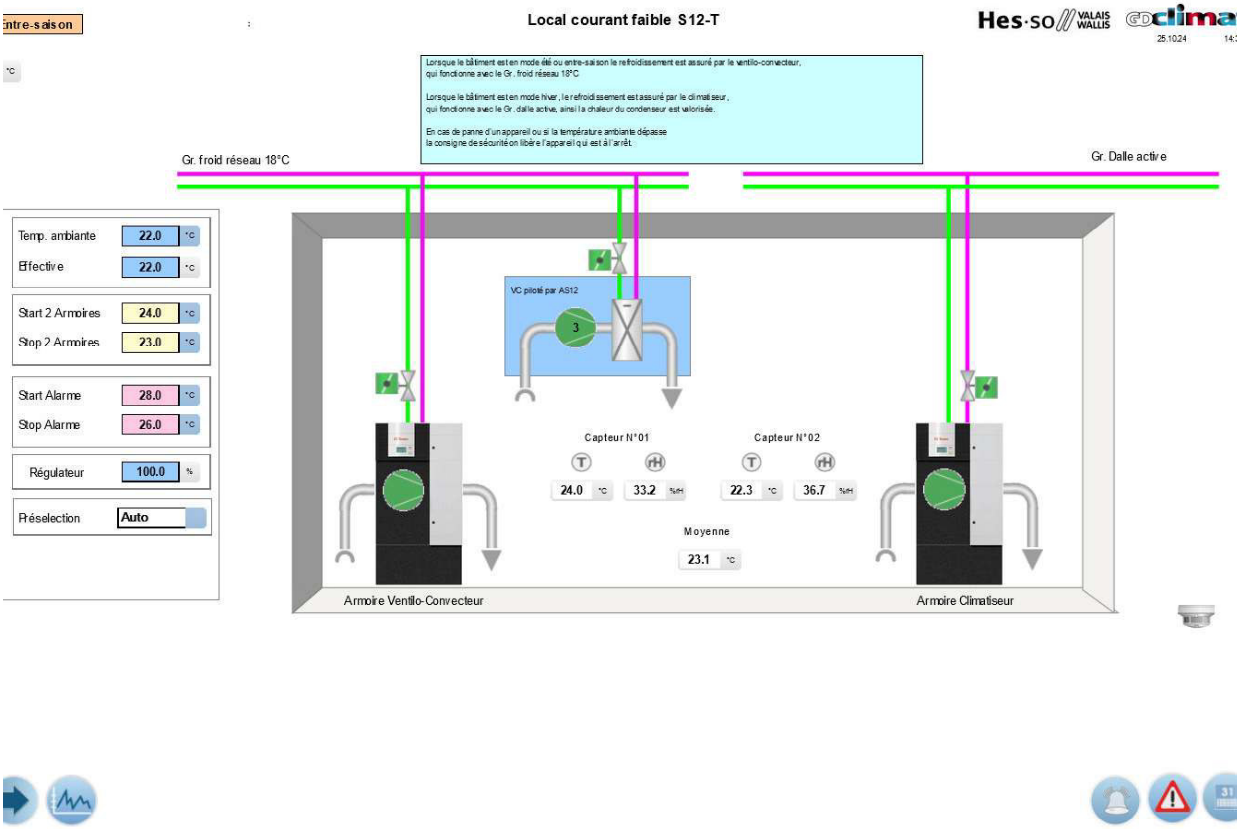
Where P_{vm} is the power used by the VM, p_{usage} is the percentage use of the allotted CPUs by the VM, N^{vcpu} is the number of CPU cores allotted to the VM, N_i^{hcpu} is the number of CPU cores of server i, and P_i is the power of server i.

Yearly energy usage estimate

$$E_{servers} = \frac{P_{vm} \cdot N_{hours} \cdot N_{days}}{1000} = \frac{62.507 \cdot 24 \cdot 365}{1000} = 547kWh$$

Yearly cooling energy estimate

As any electrical energy input to a computer will result in the same amount of heat energy that computer produces, we can simply assume that, to maintain a stable temperature in the server room, the same amount of cooling power is needed to take out the heat as the server generated.
Hence: $E_{cooling} = E_{servers} = 547kWh$.
The server room is equipped with two systems for the cooling as illustrated in the following schema



One of the two systems is a fan-coil unit which generates around 9W of cooling power per 1W of electricity used. The second system is a heat pump which generates about 3W of cooling power per 1W of electricity used. This second system is used mainly in winter and can recycle the generated heat to heat the building. How much of this heat is reused is out of the range of this estimation work for now but might be included in future improvements. The two systems can be used in conjunction and often do work together but we do not have data on how much cooling power each provides at a given moment. To still give an estimation, we will assume that each provides approximately 50% of the cooling energy over the year which means we can take the average value of 6W cooling power generated per 1W electricity used which also implies that we get a heat-electricity ratio of $r_{he} = 6$ cooling to electricity.

$$E_{elec} = \frac{E_{cooling}}{r_{he}} = 91.2568kWh$$

Added together, these two values give us the total energy consumption of our server.

$$E_{tot} = E_{servers} + E_{elec} = 638.7974kWh$$

Power source breakdown

The power used to run these servers is partly generated by Solar panels placed on the building rooftops and partly provided by OIKEN (a Swiss energy provider).
For the year 2023, the average percentage of power used by the building that was generated by solar panels is: $p_s = 0.2$.

Hence the amount of energy provided by the solar panels to run the project servers divides as follows:

Source	Energy
HES-Solar	$128.37kWh$
Oiken	$510.43kWh$

For the year 2023, the energy provided by Oiken was generated from multiple sources of which the percentages are as indicated bellow

Oiken Sources	Percentage	Energy for project
Hydrolic	0.805	$410.89kWh$
Private generation	0.06	$30.62kWh$
Urban waste burning	0.002	$1.02kWh$
Nuclear and fossile	0.09	$45.94kWh$
Solar	0.043	$21.95kWh$

CO2-equivalents

For Swiss energy sources, the following document, found on the following page gives a breakdown of CO2 equivalents for various energy sources. The ones we are interested in are given in the following table.

Energy source	CO2-eq kg/kWh	Project yearly CO2-eq kg
Hydrolic	0.012	4.93
Private generation	0.125	3.83
Urban waste burning	0.007	0.007
Nuclear and fossile	0.024	1.1
Solar	0.048	1.05
Self-produced solar	0.037	4.75

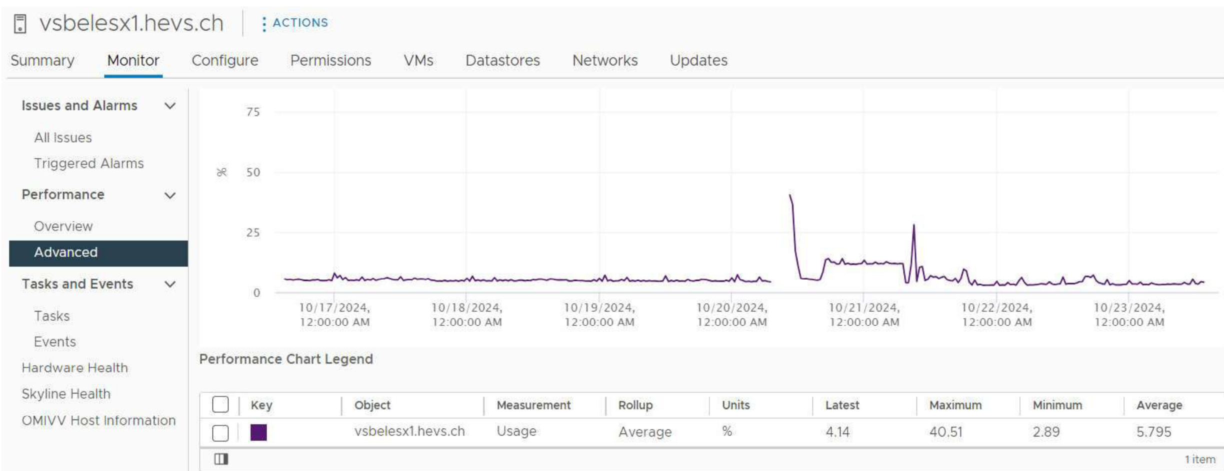
Regarding the Nuclear and fossile energy part of this table, it should be noted that we do not have a ratio of nuclear to fossile energy given by Oiken. We made the assumption that most of such energy would be Nuclear but the CO2 equivalent might turn out to be higher if we get more information on this in the future.
Given all of this we can create the final CO2 equivalent table.

	HES-solar	Oiken	Total
CO2-eq kg	4.75	10.92	15.67

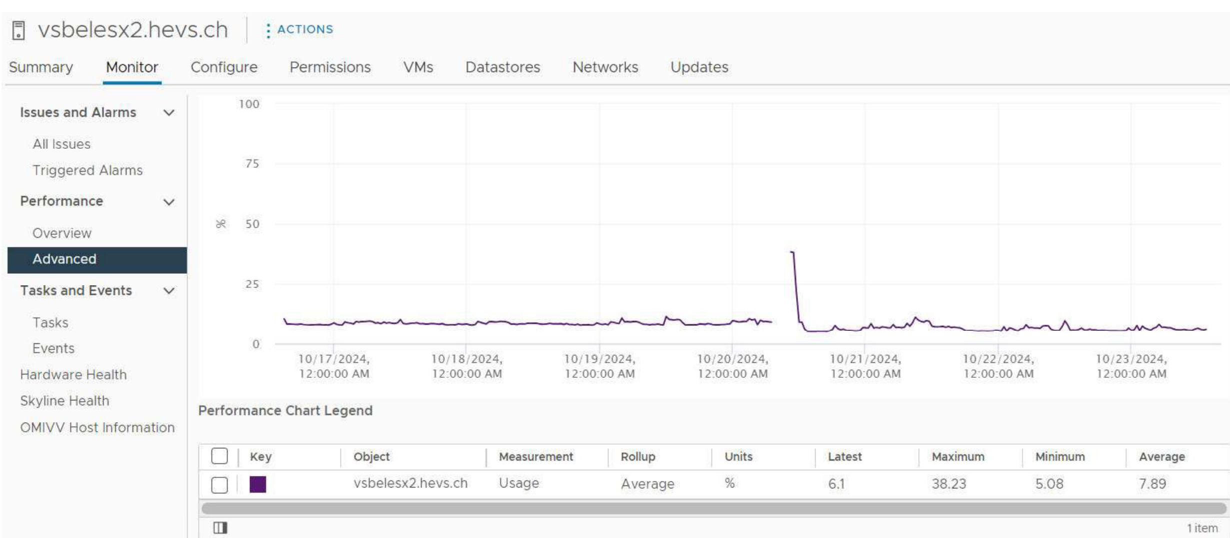
Servers specs

Machine	Average Power (W)	CPU cores	Average CPU usage (%)
VSBELESX1	487	32	5.795
VSBELESX2	490	32	7.89
VSBELESX3	546	32	24.442

Server CPU



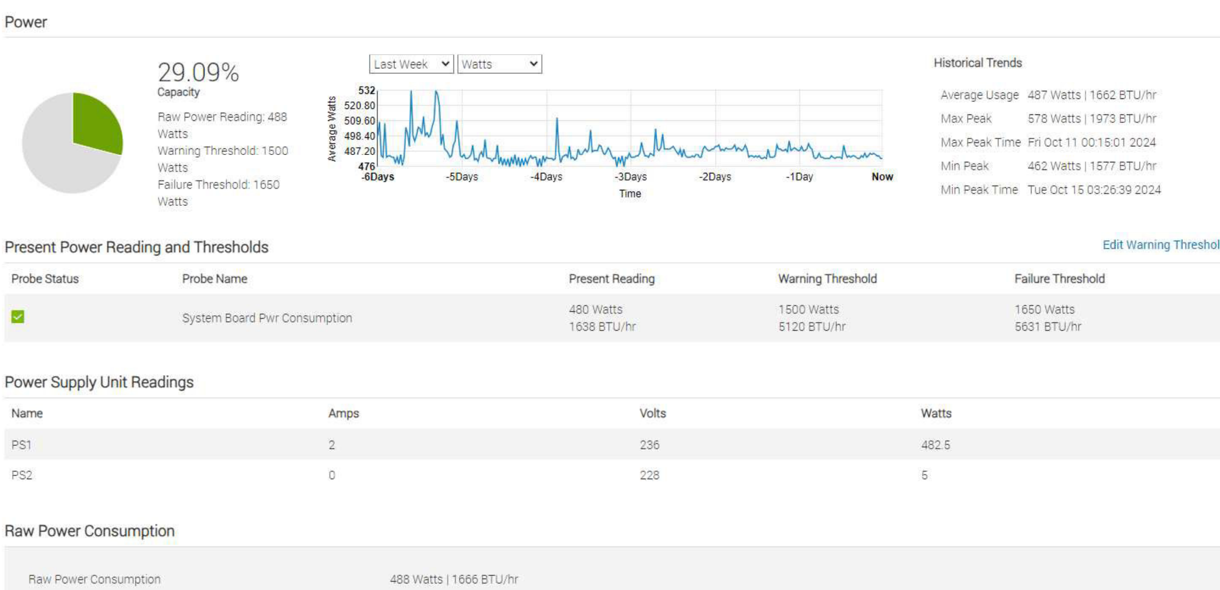
VSBELESX1 cpu usage over a week



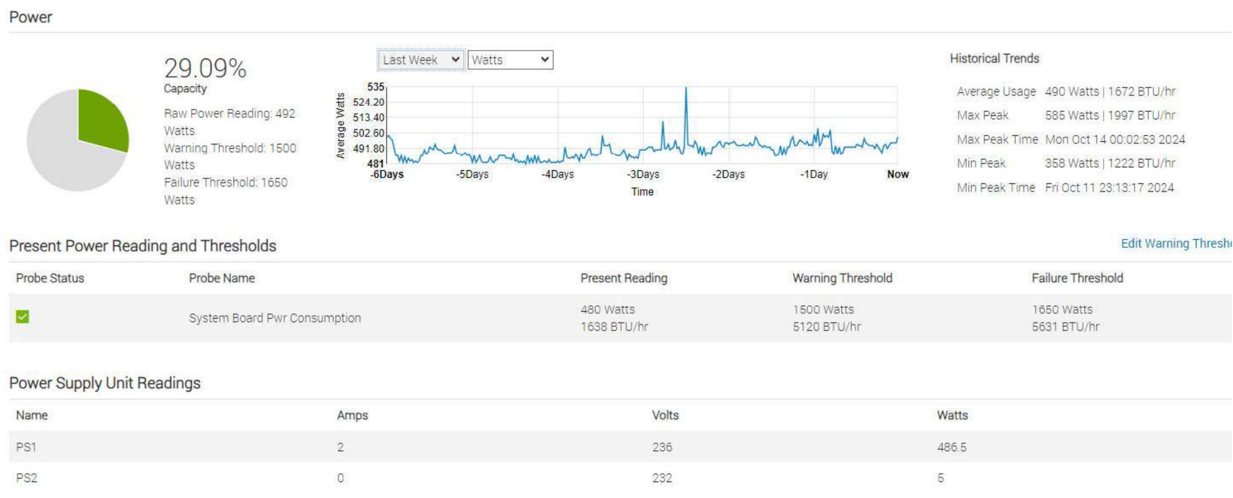
VSBELESX2 cpu usage over a week

VSBELESX2 cpu usage over a week

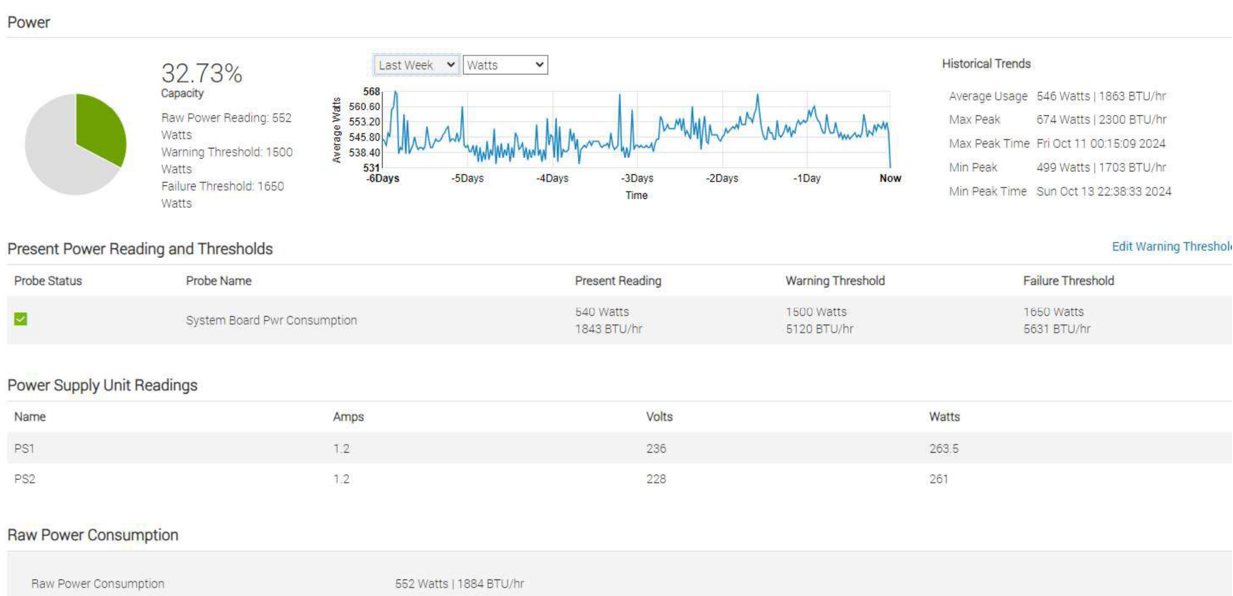
Server Power



VSBELESX1 power consumption over a week



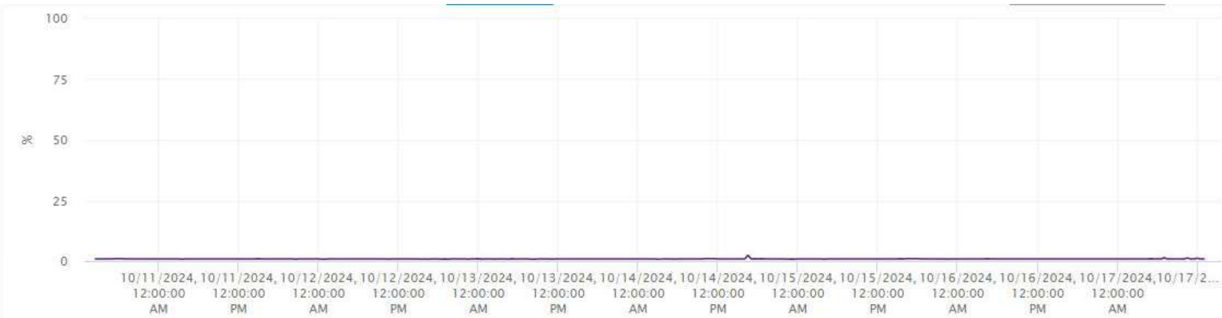
VSBELESX2 power consumption over a week



VSBELESX3 power consumption over a week

VM specs

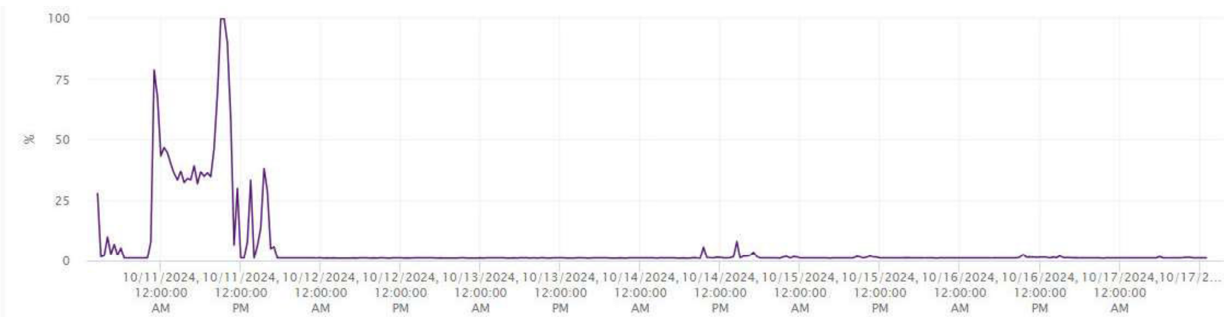
Virtual Machine	Avg CPU usage (%)	Allotted CPU cores
VLHOPENGIS4ETP	0.887	8
VLHOPENGIS4ETD	5.372	8



Performance Chart Legend

Key	Object	Measurement	Rollup	Units	Latest	Maximum	Minimum	Average
■	VLHOPENGIS4ETP	Usage	Average	%	0.88	2.37	0.83	0.887

VLHOPENGIS4ETP production machine cpu usage over a week



Performance Chart Legend

Key	Object	Measurement	Rollup	Units	Latest	Maximum	Minimum	Average
■	VLHOPENGIS4ETD	Usage	Average	%	1.14	99.93	1.01	5.372

VLHOPENGIS4ETD development machine cpu usage over a week

Summary

To establish the CO2 impact of the OpenGIS4ET project, we created an estimation of the power consumption generated by the project servers using measured power consumptions of the servers on which the OpenGIS4ET virtual machines are located and some simple assumptions.
We conclude that server processing power and cooling demands generate roughly 638kWh of energy consumption per year, of which about 20% are generated by solar panels on the building where the servers are located. The rest of the power is provided by Oiken and comes from various sources.
In total, based on Swiss energy reports, we estimate our CO2-equivalent to be 15.67 kg/year for the project.

APPENDIX IV– ISEC-2026 Optimization of CO2 Emissions taxation in Switzerland using machine learning

ISEC 2026 - OPTIMIZATION OF CO_2 EMISSION TAXATION IN SWITZERLAND USING MACHINE LEARNING

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1 SUMMARY

This research investigates how Machine Learning can optimize CO_2 taxation of passenger cars in Switzerland. Using OBFCM data, The Hotmaps data, SFOE OpenGIS4ET data and predictive models (LightGBM, Random Forest), it shows that real emissions can be estimated more accurately from vehicle characteristics such as weight, power, and engine displacement than from WLTP values. Expert and political validation supports reforming cantonal taxation—especially for hybrids—replacing the A–G energy label with continuous indicators, and building a fairer, more climate-aligned tax system.

2 ABSTRACT

This research aims to optimize CO_2 emission taxation of internal combustion engine (ICE) passenger vehicles in Switzerland using a Machine Learning (ML) approach. The current tax system has limitations, particularly because it relies on WLTP homologation values, which often differ significantly from real-world vehicle consumption.
Using European OBFCM data, The Hotmaps data and SFOE OpenGIS4ET data, this study develops predictive models to estimate real-world fuel consumption—and thus CO_2 emissions—based on technical vehicle characteristics such as weight, power, and engine displacement. The performance of ensemble algorithms like LightGBM and Random Forest demonstrates ML's ability to accurately predict consumption and emissions.

The flow below (see Fig.1) represents all the data processing and analysis steps, organized sequentially to transform raw data into usable results, integrating operations such as import, preparation, modeling, and export (see Fig.1)

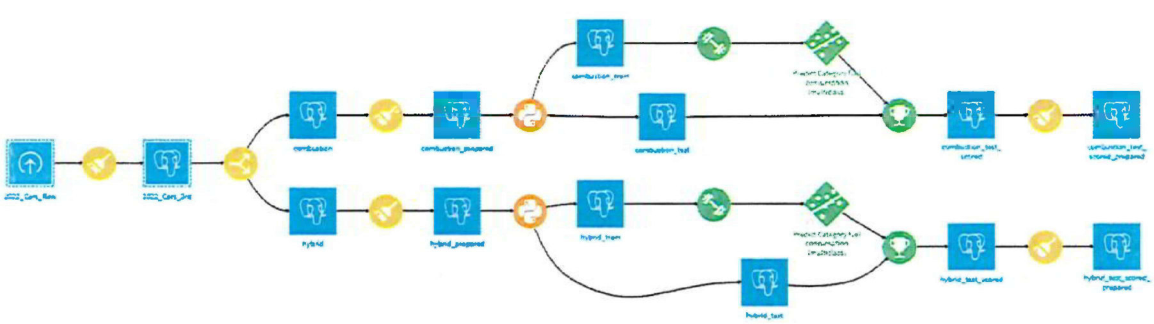

Fig. 1: Data processing and analysis steps

To ensure model robustness, qualitative validation was conducted using the Delphi method with mobility experts, a questionnaire targeting Swiss corporate fleet managers, and interviews with politicians from various Swiss political parties. These steps root the recommendations in Switzerland's political and economic realities.

The results suggest the need for revising cantonal taxation to better reflect real emissions and to more strictly regulate hybrid vehicle taxation. The study proposes introducing a differentiated, science-based tax system that could help Switzerland meet its climate goals while enhancing tax fairness.

This work shows that in Switzerland, a fairer and more environmentally conscious vehicle tax system can be built through ML models capable of accurately predicting real CO_2 emissions of ICE and hybrid vehicles from their technical specifications. Weight, power, and engine displacement emerge as more relevant fiscal levers than current criteria. This ML-driven approach, validated by experts and political stakeholders, opens the way for a differentiated tax system better aligned with vehicles' real environmental impacts.

The study also recommends increasing public awareness, improving the assessment of hybrids (whose emissions are often underestimated), and abandoning the A–G energy label in favor of more precise and continuous indicators for a tax system truly aligned with vehicles' environmental impact.

3 SYNTHESIS OF ML MODEL RESULTS

This synthesis confirms that the ML model offers a robust approach to predicting and classifying vehicle CO_2 emissions based on their intrinsic characteristics. It also supports the relevance of a differentiated tax policy based on precise, individualized predictions aligned with the technical realities of the Swiss and European vehicle fleets

Table 1 Summary of the Machine Learning Model

Category	Main Results
Datasets	OBFCM european dataset. Technical characteristics and real consumption of vehicles
Key correlations	Total distance traveled ↔ Total fuel consumed Average consumption ↔ CO_2 emissions (WLTP) Engine power ↔ Engine displacement Electric range ↔ Reduction in overall consumption |
Influential Variables	With official data: WLTP emissions = most important variable Without official data: Fuel type, powertrain mode, vehicle mass, engine power, engine displacement
Algorithmic Performance	Best performance achieved with ensemble learning algorithms such as LightGBM, Random Forest, and Gradient Boosted Trees.
Observed Limitations	To overcome the difficulty of distinguishing the intermediate consumption levels, a continuous approach will provide better results.
Recommendations	Increase the volume and quality of data. Integrate additional variables (e.g., driving cycle, detailed electric consumption). Adjust classification thresholds and hyperparameters
Political & Fiscal Impact	ML enables precise association of technical characteristics with emissions and helps define tax brackets better calibrated to the environmental performance of vehicles.

4 RECOMMANDATIONS

At the conclusion of this study, several recommendations can be made for policymakers and stakeholders in the Swiss automotive sector:

1. Implement a differentiated taxation system based on real-world fuel consumption: The current tax system often relies on homologation values that poorly reflect actual usage. Machine Learning algorithms enable the estimation of real-world consumption based on reliable technical characteristics such as vehicle mass, engine displacement, or power.

2. Include vehicle mass and power in fiscal brackets: These variables have a significant impact on real CO_2 consumption and emissions. A taxation framework that incorporates them would be fairer and more environmentally sound.