D5.2 Calculation modules on space cooling demand, technologies, user behaviour, economics and demand response

Cool LIFE

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Deliverable Information Sheet

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Executive summary

Deliverable D5.2 presents the collection of open-source calculation modules (CMs) developed to operationalize the CoolLIFE platform, supporting spatially detailed, data-driven analysis and scenario planning for sustainable space cooling (SC) across the EU-27. These modules, implemented as Python scripts, are designed to help planners, policymakers, and technical users assess current and future cooling demand, evaluate technological and behavioural options, and support investment and policy decisions at various administrative levels.

The CMs are accessible through the CoolLIFE platform under the "Calculation Modules" tab, once the appropriate spatial level (e.g. NUTS1–3, LAU2, hectare) is selected. For practical guidance, users are referred to Deliverable D5.1 and the CoolLIFE Wiki. The modules are grouped into four thematic categories—Cooling, District Heating and Cooling, Policy, and Finance—each targeting a distinct aspect of sustainable cooling planning.

Key modules include:

- **Space Cooling Demand,** which maps cooling needs down to 100×100 m grids, supporting both current and future scenario development.
- **Technologies and Measures**, which evaluates energy use, technology diffusion, and mitigation impacts such as shading and ventilation.
- **Comfort, Lifestyle and User Behaviour**, which contextualizes SC demand through behavioural data and thermal comfort expectations.
- **Economic Feasibility**, which estimates costs and savings from passive and active cooling strategies using levelized cost indicators.
- **Demand-side Management**, which explores the potential of pre-cooling and load shifting to align cooling demand with PV supply.
- **Mapping of Legal and Regulatory Layers and Financing Instruments**, which provide structured overviews of national and EU-level frameworks, enabling policy alignment and funding access.
- **District Cooling**, a newly developed CM outside the original Grant Agreement, which assesses the techno-economic feasibility of DC networks at high spatial resolution—demonstrating the platform's commitment to emerging energy trends.

Each module is independently usable, yet designed to interoperate in structured toolchains. These toolchains reflect real-world planning workflows and are built around seven practical use cases, from regional strategy development to local implementation, including applications for energy communities, poverty reduction, behavioural change, and national reporting in line with the Energy Efficiency Directive.

All CMs are open source and hosted in the Tuleap repository under a Creative Commons CC BY 4.0 license, allowing technical users to access, modify, and extend the tools as needed. This approach ensures transparency, replicability, and adaptability to national and local contexts.

Together, these components form the analytical backbone of the CoolLIFE platform, providing robust, flexible, and transparent support for sustainable space cooling planning across Europe.

1. Introduction

Deliverable D5.2 provides a comprehensive set of open-source calculation modules designed to support the CoolLIFE platform in analyzing and planning for space cooling (SC) across the EU27. These modules are built on the results of earlier work packages and serve as core building blocks for assessing SC demand, evaluating technological options, incorporating user behaviour and comfort preferences, and performing economic, regulatory, and demand-side analyses.

The developed modules cover a wide range of functions. They enable high-resolution mapping of SC energy demand down to 100 x 100 meter grids for both a base year and future scenarios up to 2050. This is achieved by combining detailed building stock and climate data with both bottom-up approaches (e.g. building archetypes) and top-down statistical methods. Users can also compare different SC supply options—such as district cooling versus individual systems—and assess how passive measures or behavioural interventions can reduce demand. Financial and economic feasibility can be evaluated through simplified cost-benefit calculations, while behavioural aspects such as comfort expectations and daily routines can be taken into account to better reflect real-world user patterns. Furthermore, the potential for demand-side flexibility and increased PV self-consumption is considered by analyzing load shifting strategies like pre-cooling.

While each calculation module can be used on its own, their full potential is realized when they are applied together through toolchains. These toolchains represent structured sequences of analysis steps that reflect practical user stories and planning needs, as identified in Task 7.1. For example, a user may begin by estimating the SC demand of a specific region, then explore how this demand could be reduced using passive measures or behavioural changes. Next, the user could compare different active supply concepts, assess the economic implications, evaluate comfort and lifestyle aspects, and review relevant legal and regulatory conditions. Finally, the analysis may include demand-side management options to better align SC loads with renewable energy availability.

The modular and flexible architecture of the CoolLIFE tool allows these toolchains to be adapted to different decision-making contexts, whether for municipal planners, national policymakers, or energy system analysts. All calculation modules are implemented as Python scripts and are openly available to facilitate transparent and replicable analyses.

Deliverable D5.2 thus provides the essential analytical backbone of the CoolLIFE platform, ensuring that users can perform integrated, spatially detailed, and scenario-based assessments to support informed decision-making on sustainable space cooling strategies across Europe.

2. Accessing the CoolLIFE Calculation modules

The calculation modules (CMs) can be accessed within the CoolLIFE platform under the "Calculation Modules" tab, once the appropriate NUTS level has been selected. For detailed guidance on their structure and use, refer to **Deliverable 5.1** and the **CoolLIFE Wiki**. The section below provides an overview of the CMs developed in the CoolLIFE project, which support data-driven analysis of cooling demand, technologies, user behaviour, and policy to guide sustainable cooling planning.

The CoolLIFE tool includes a set of calculation modules (CMs) designed to support data-driven cooling planning. These modules compute and visualize key indicators across four thematic categories:

- **Cooling**
- **District Heating and Cooling**
- **Policy**
- **Finance**

Each module is available at specific administrative levels (e.g. NUTS1, NUTS2). If a module cannot be applied at the currently selected level, it appears inactive (in red). The applicable level for each CM is specified in its introduction section.

Users can access detailed descriptions by clicking on the module names in the interface. An overview of the CMs is shown in Figure 1.

Cooling Modules:

Space Cooling Demand

- Economic Feasibility
- Comfort, Lifestyle, and User Behaviour
- Technologies and Measures
- Demand-Side Management / Demand Response

District Heating and Cooling:

- District Cooling

Policy

- Legal and Regulatory Layers

Finance

- Mapping of Financial Instruments

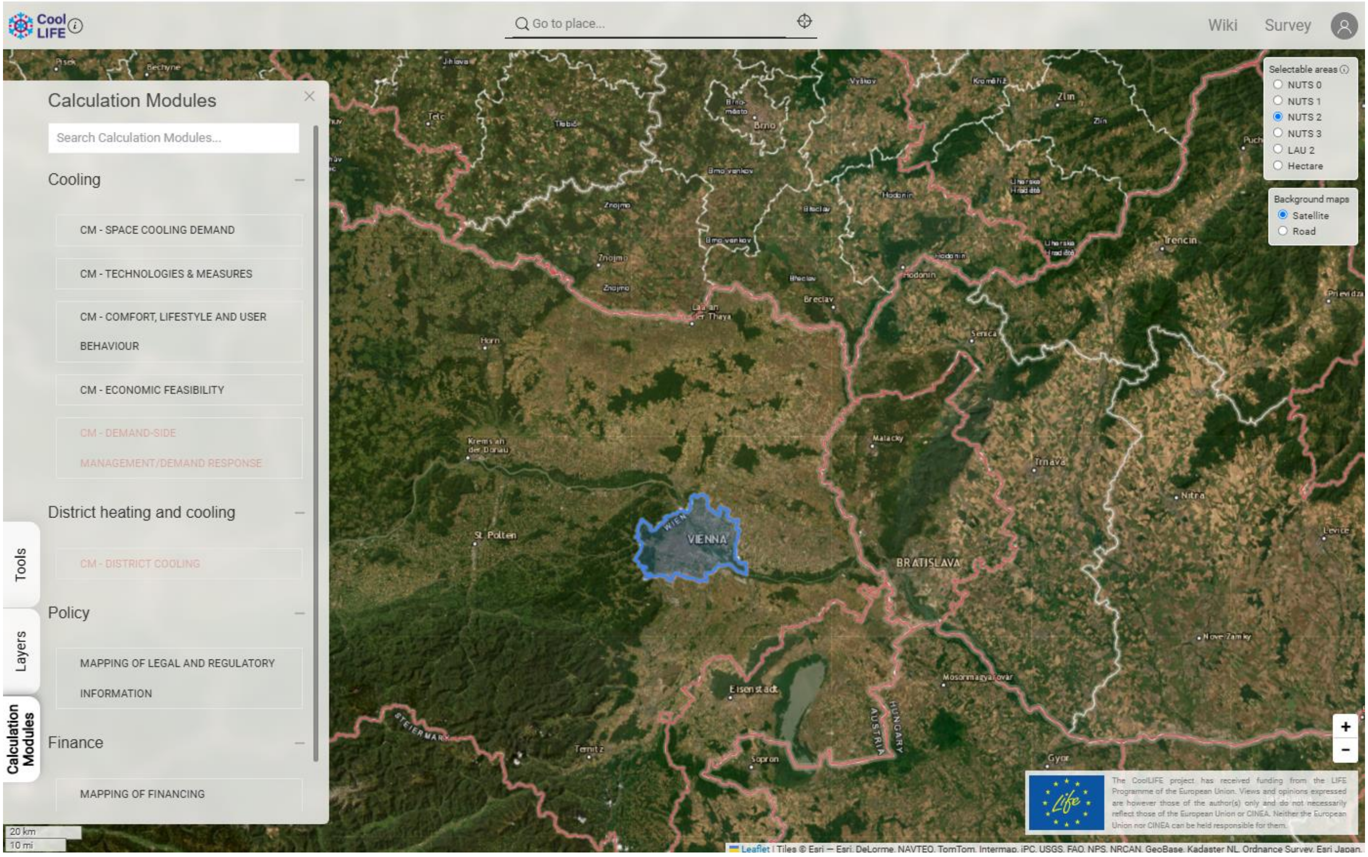


Figure 1. Accessing Calculation Modules

3. Calculation Modules

The section below provides an overview of the calculation modules developed in the CoolLIFE project, which support data-driven analysis of cooling demand, technologies, behaviour, and policy to guide sustainable cooling planning.

3.1. Space Cooling Demand

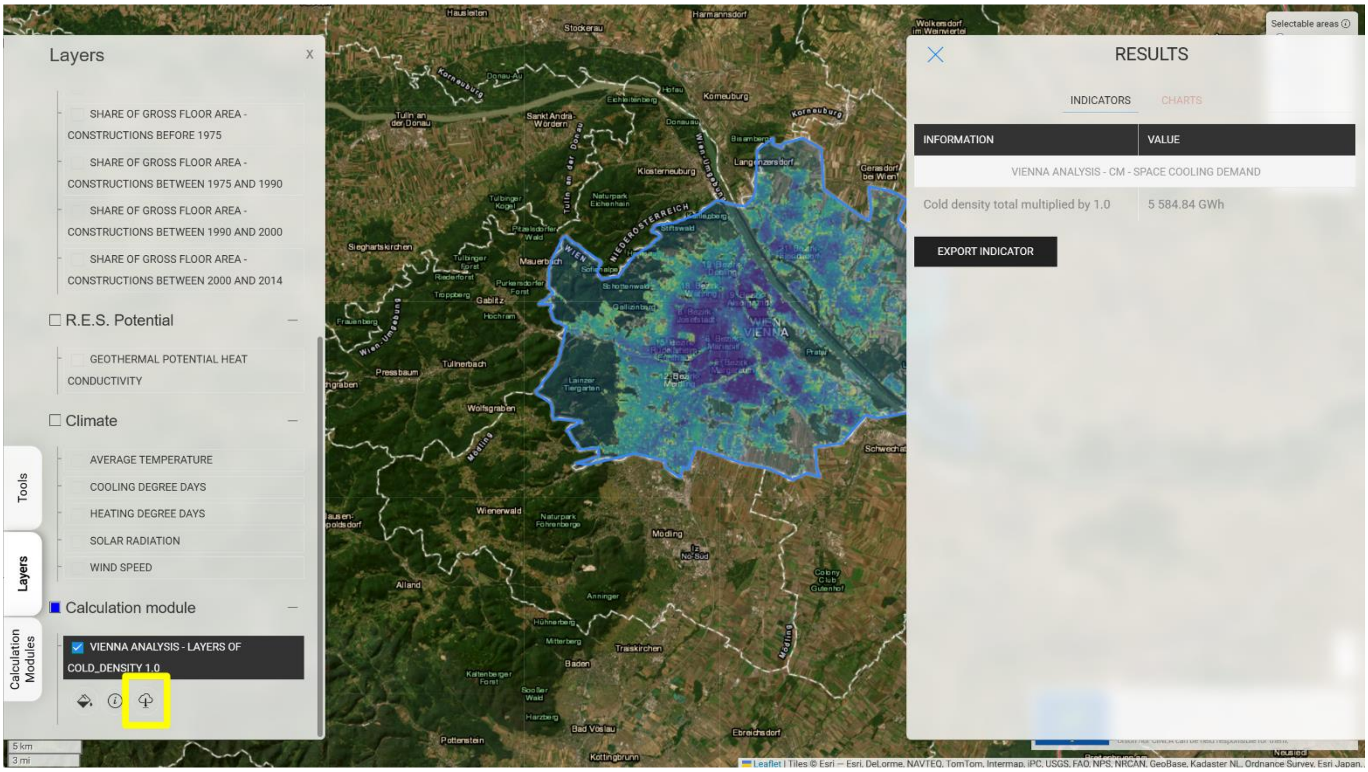


Figure 2. CM-Space Cooling Demand

This module estimates and visualizes space cooling (SC) demand across the EU-27 at a high spatial resolution (100 x 100 m). It supports the development of cooling demand scenarios for visualization of spatial distribution for further analysis. Overview of the results of the CM is seen in Figure 2.Users can apply a scaling factor to adjust demand values and generate updated raster maps, helping to localize planning efforts and identify priority areas.

The module operates at multiple administrative levels (NUTS1–3, LAU2, hectare) and supports planning by enabling scenario adjustments and visual outputs.

More detailed instructions and examples are available in the **CoolLIFE WIki.**

3.2. Technologies and measures

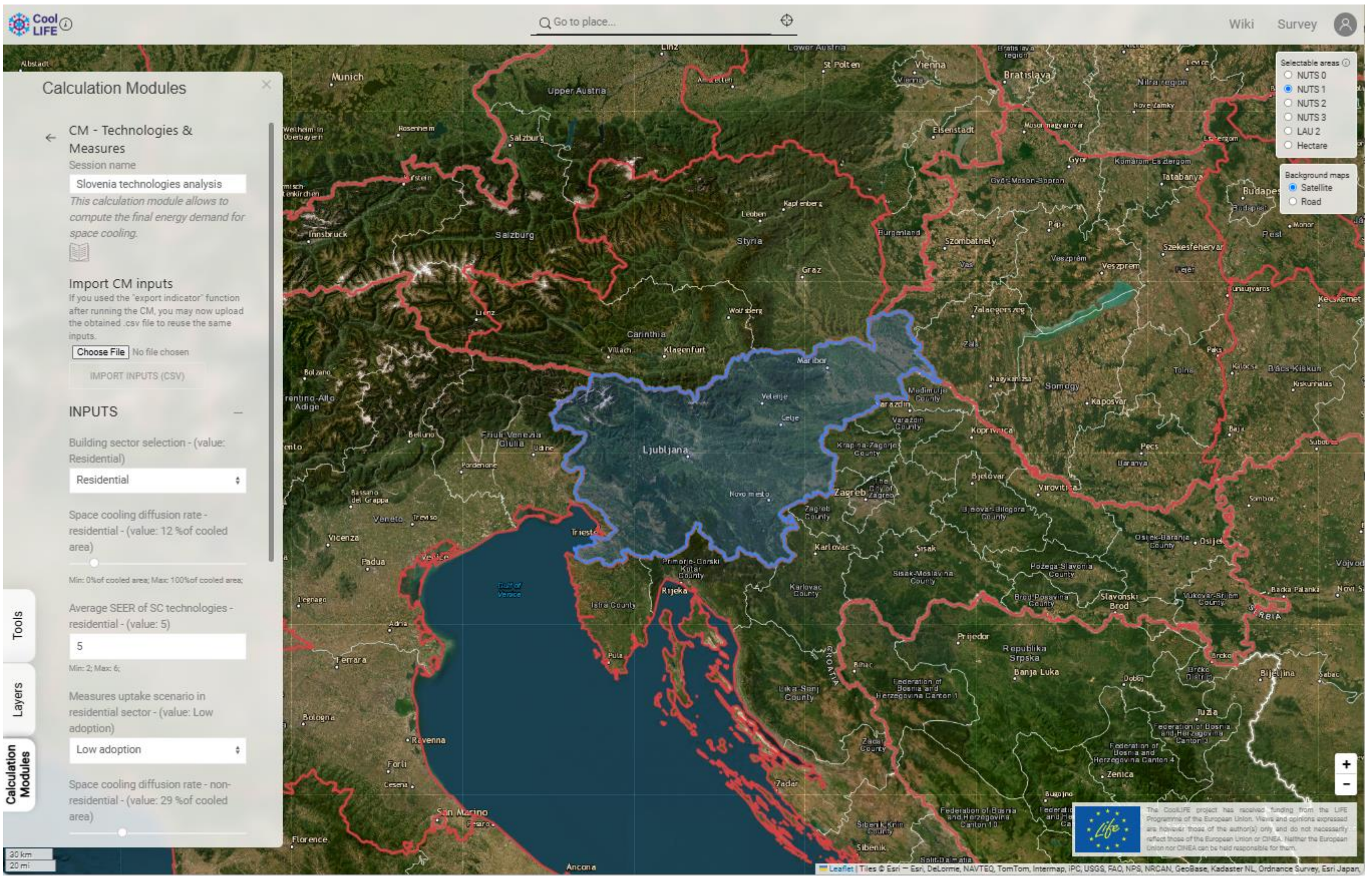


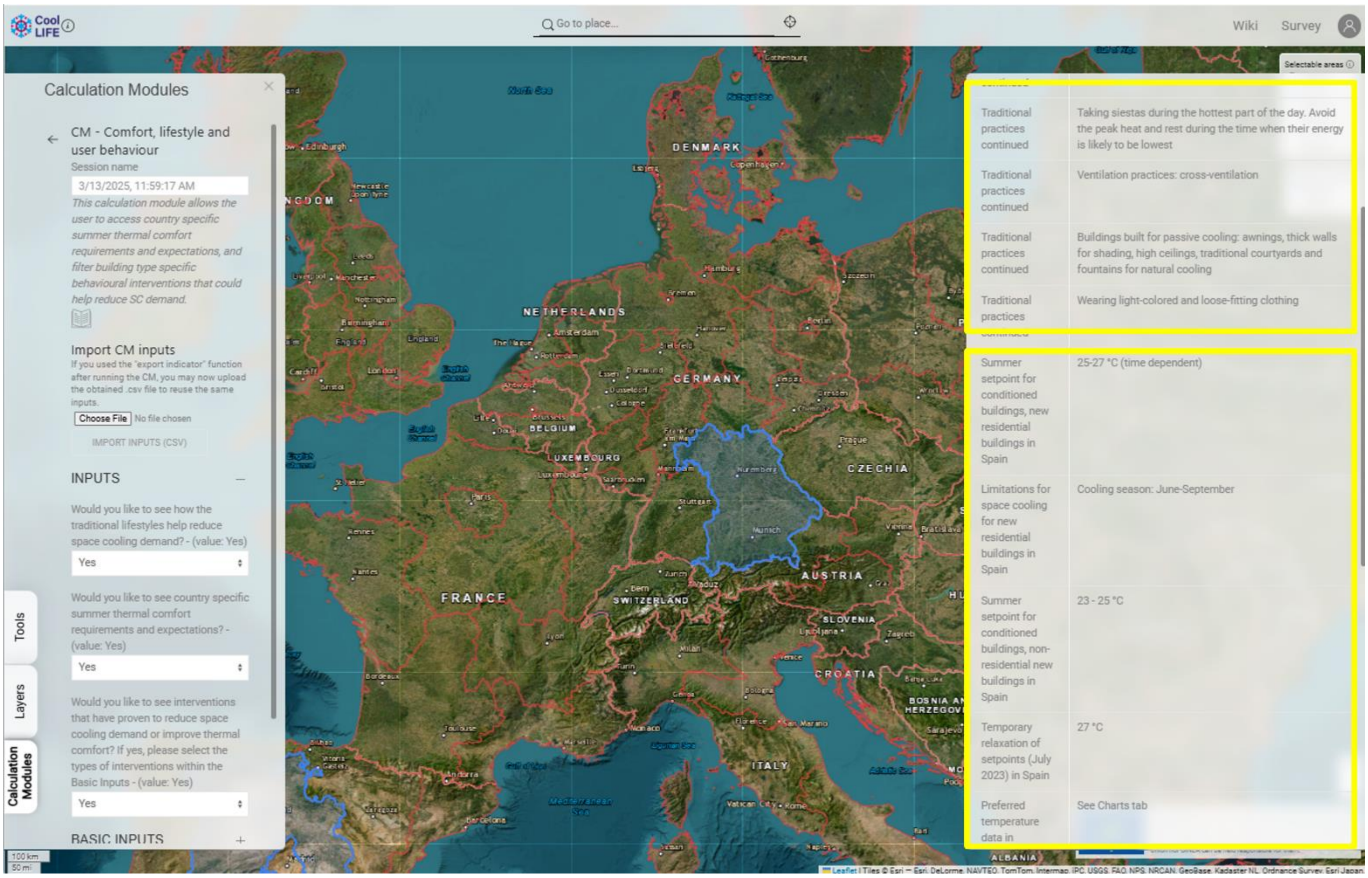
Figure 3. CM-Technologies and Measures

This module estimates the electricity consumption and cooling capacity required to meet space cooling (SC) needs across the EU-27, covering both residential and non-residential sectors. It is based on cooling degree days (CDD) and allows users to explore different technology diffusion rates, energy efficiency levels (SEER), and the impact of mitigation measures such as shading, fans, and natural ventilation. The module supports scenario-based analysis to help assess how energy efficiency improvements and behavioural actions can reduce cooling demand and energy use.

Users can configure parameters including sector type, diffusion rates, SEER values, and measure adoption levels. The module outputs key indicators such as cooled floor area, total cooling demand, final energy consumption, and installed cooling capacity. The layout of the CM can be viewd in 3.2.

More details and guidance are available in the **CoolLIFE Wiki**.

3.3. Comfort, lifestyle, and user behavior



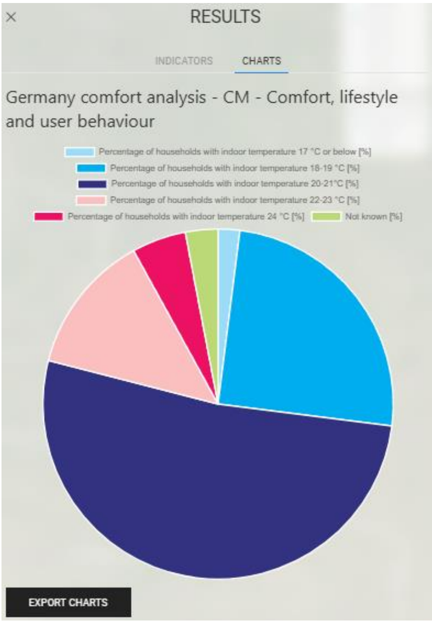


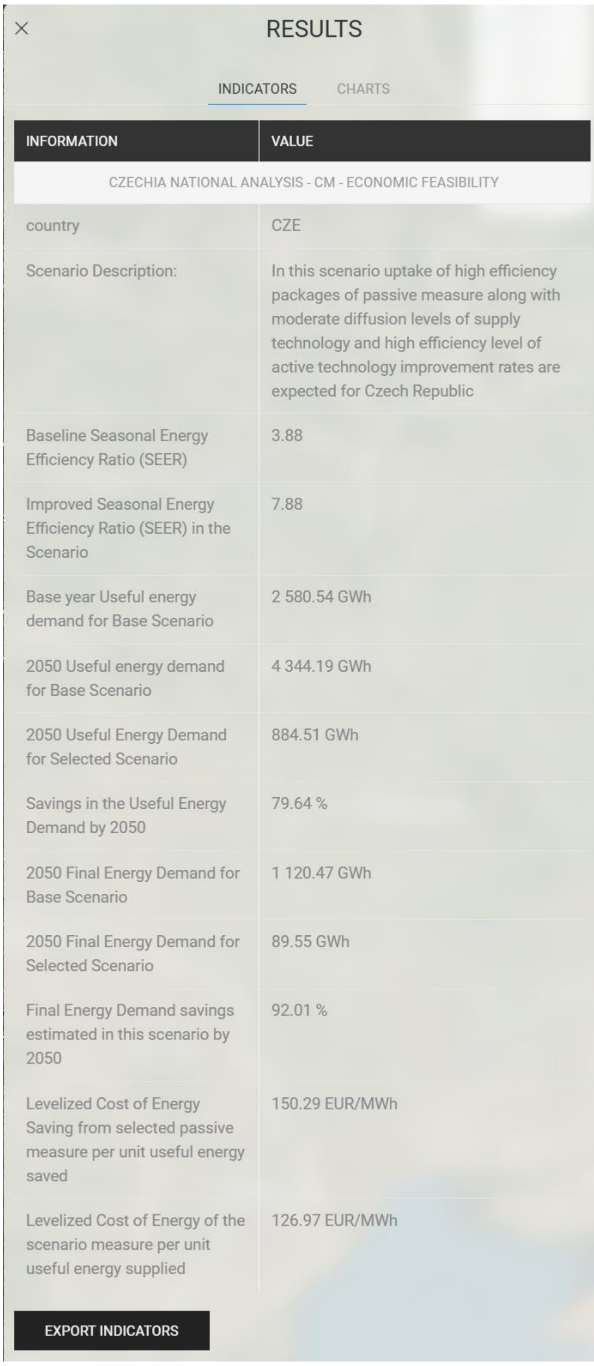
Figure 4. CM-Comfort, lifestyle, and user behaviour

This module presents behavioural patterns, lifestyle practices, and thermal comfort expectations that influence space cooling demand across EU member states. It highlights traditional and modern adaptive behaviours, such as natural ventilation and thermostat use, and provides examples of effective behavioural interventions that reduce SC demand while maintaining indoor comfort.

Users can explore national-level data on comfort standards, preferred indoor temperatures, and successful case studies of behavioural change, filtered by sector, behaviour type, and intervention category. The module supports planners and policymakers in designing culturally adapted, user-focused cooling strategies. The layout of the user interface and the CM results is presented in Figure 4.

More details and guidance are available in the **CoolLIFE Wiki**.

3.4. Economic Feasibility


RESULTS

INDICATORS CHARTS

INFORMATION	VALUE
CZECHIA NATIONAL ANALYSIS - CM - ECONOMIC FEASIBILITY	
country	CZE
Scenario Description:	In this scenario uptake of high efficiency packages of passive measure along with moderate diffusion levels of supply technology and high efficiency level of active technology improvement rates are expected for Czech Republic
Baseline Seasonal Energy Efficiency Ratio (SEER)	3.88
Improved Seasonal Energy Efficiency Ratio (SEER) in the Scenario	7.88
Base year Useful energy demand for Base Scenario	2 580.54 GWh
2050 Useful energy demand for Base Scenario	4 344.19 GWh
2050 Useful Energy Demand for Selected Scenario	884.51 GWh
Savings in the Useful Energy Demand by 2050	79.64 %
2050 Final Energy Demand for Base Scenario	1 120.47 GWh
2050 Final Energy Demand for Selected Scenario	89.55 GWh
Final Energy Demand savings estimated in this scenario by 2050	92.01 %
Levelized Cost of Energy Saving from selected passive measure per unit useful energy saved	150.29 EUR/MWh
Levelized Cost of Energy of the scenario measure per unit useful energy supplied	126.97 EUR/MWh

EXPORT INDICATORS

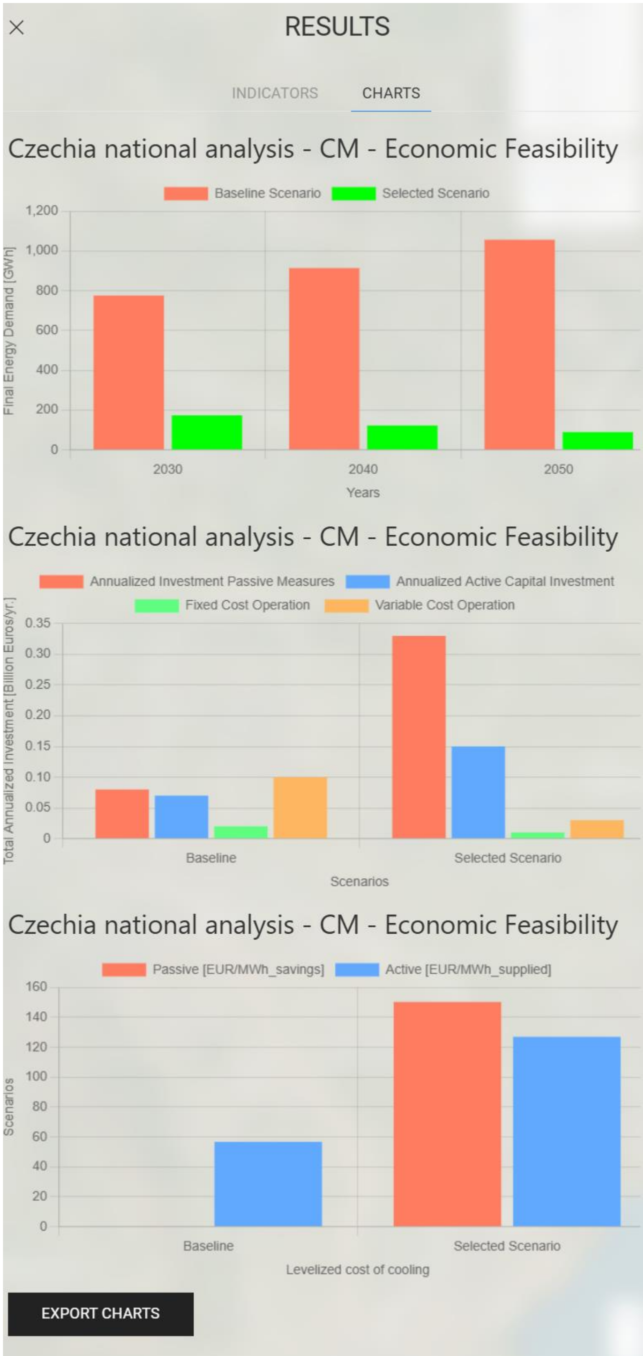


Figure 5. CM-Economic Feasibility

This module enables users to assess the financial viability of space cooling (SC) investments, considering both active and passive measures. It supports two assessment types: national-level, for evaluating broader policy and investment scenarios, and building-level, for estimating SC costs and savings for specific building types. Users can adjust parameters such as technology efficiency (SEER), passive measure uptake, and diffusion rates.

The tool calculates energy demand, savings, and investment needs, and provides economic indicators like the levelized cost of cooling (LCOC) and levelized cost of energy savings (LCES). Results are presented through indicators and charts, supporting strategic planning and policy development. The sample results generated from the CM is seen in Figure 5.

More details and guidance are available in the CoolLIFE Wiki.

3.5. Demand side Management/ Demand Response

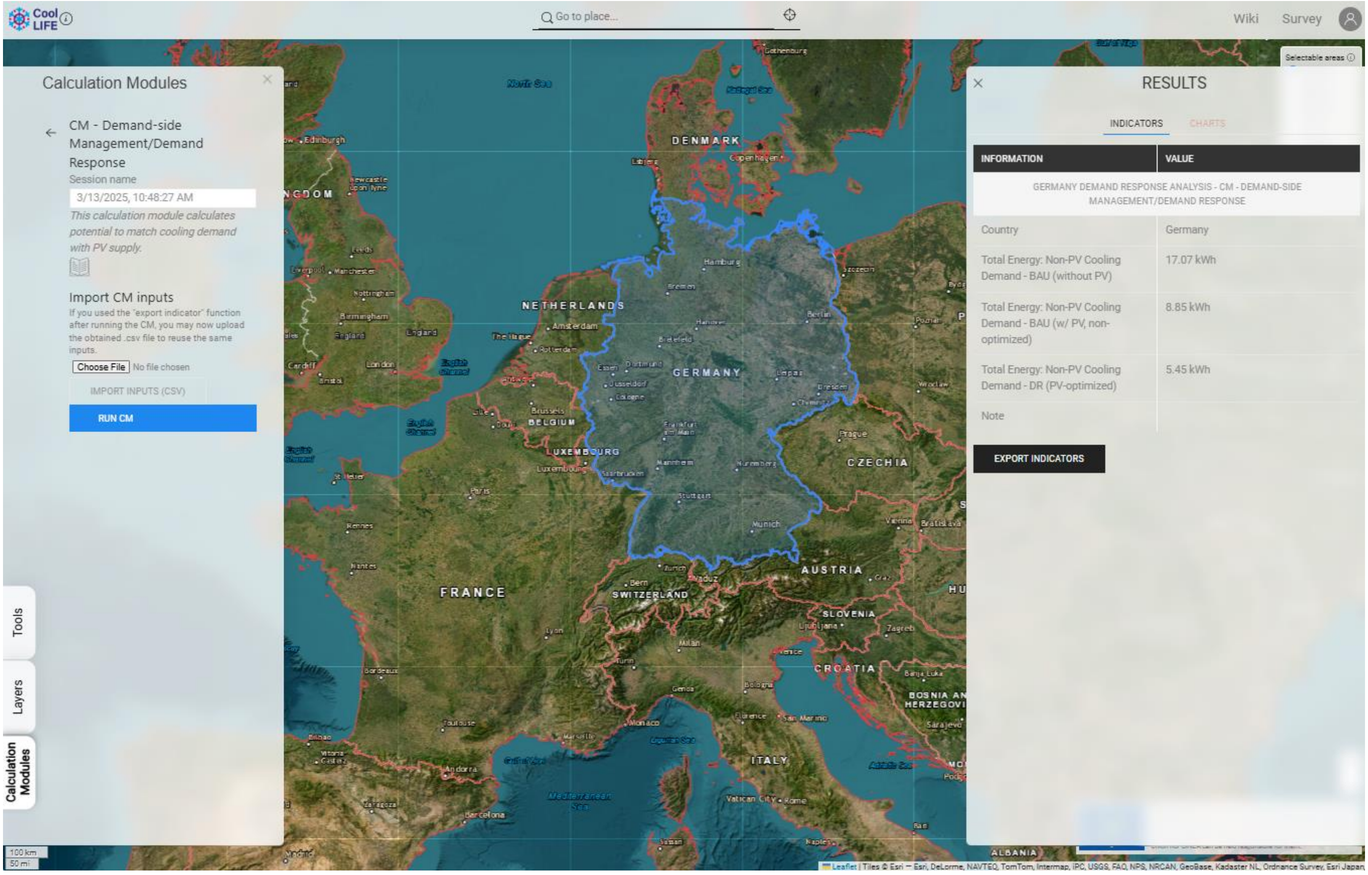


Figure 6. CM-Demand side Management

This module estimates the potential for shifting cooling demand to align with PV electricity supply through pre-cooling strategies in new single-family homes. It simulates a reference summer day (August 2020) using national-level building archetype data and evaluates how much of the cooling load can be matched with PV generation.

Users select a country (NUTS0 level), and the tool outputs three indicators showing daily cooling demand under business-as-usual, with PV supply but no demand optimization, and with optimized demand response. The layout of the CM is available in Figure 6.

More details and guidance are available in the **CoolLIFE Wiki**.

3.6. Mapping of Legal and Regulatory Information

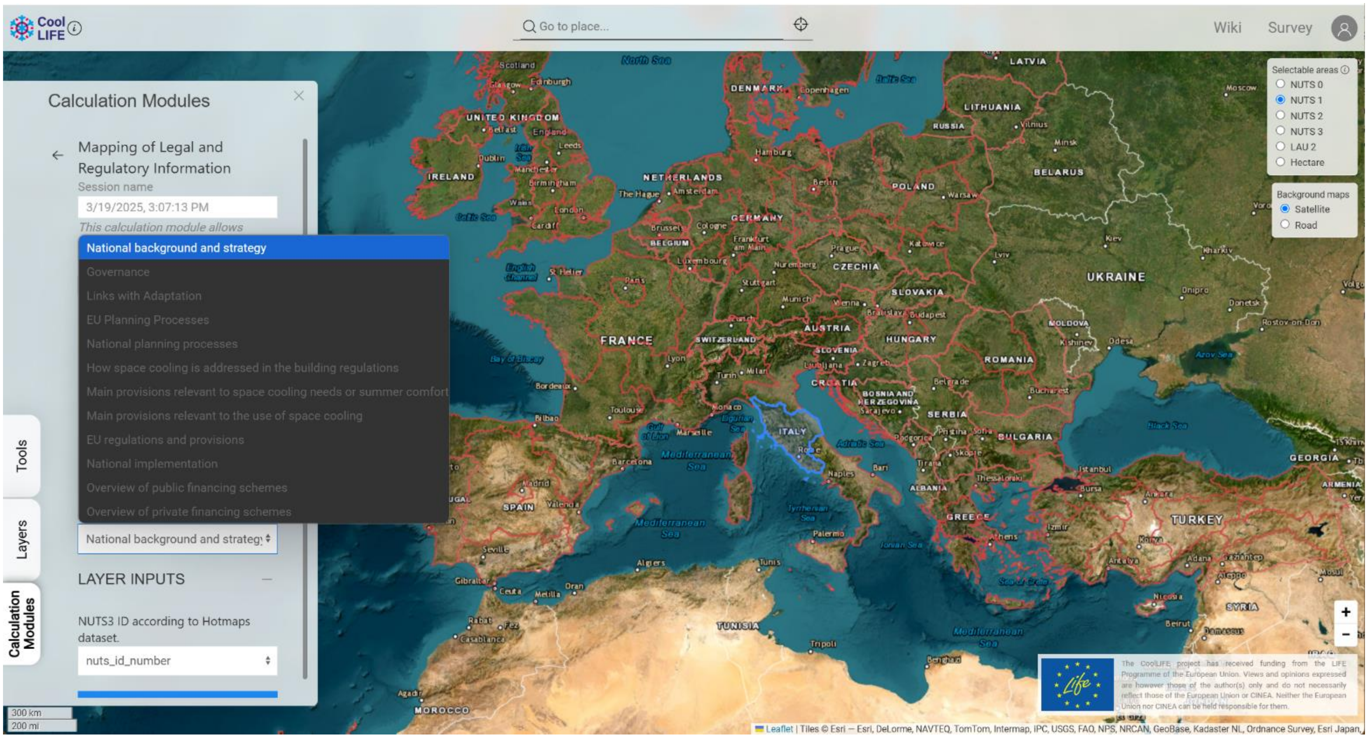


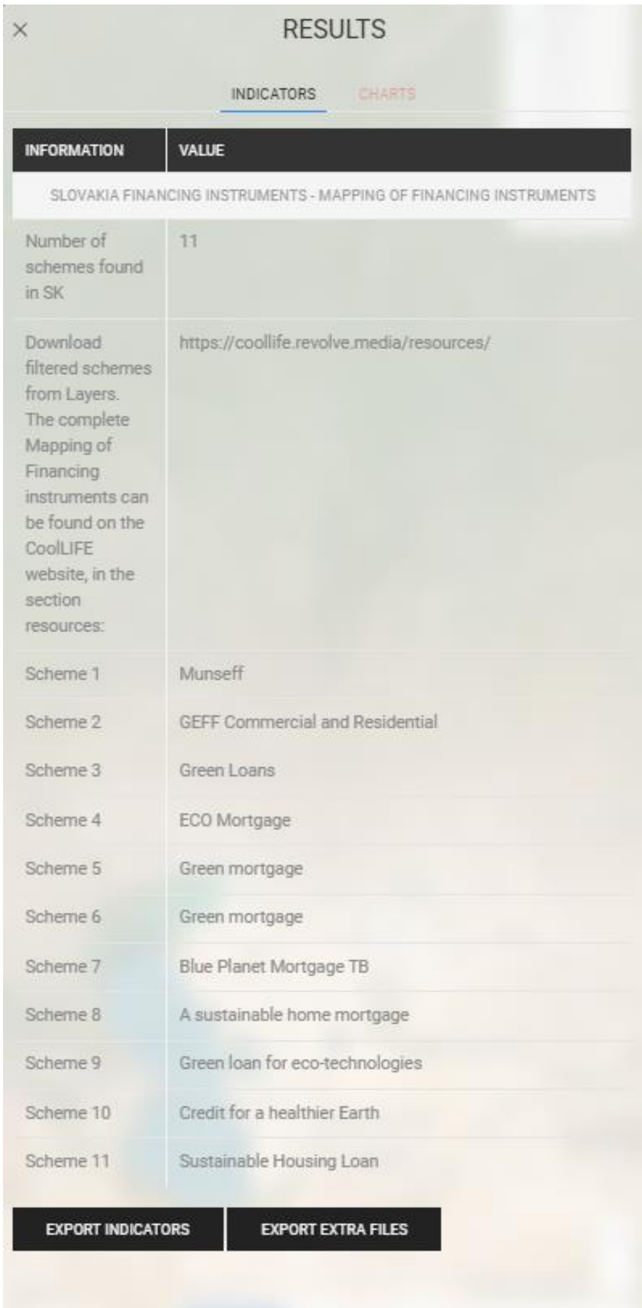
Figure 7. CM-Mapping of Legal and Regulatory Layers

This module provides structured access to policy-relevant information on space cooling, covering EU legislation and national strategies, regulations, and financing schemes. Users can explore how space cooling is addressed in planning processes, building codes, adaptation strategies, and financial support instruments across selected EU Member States.

The module allows the selection of different policy indicators, with results presented at the national level regardless of the chosen spatial scale. The layout of the CM is seen in Figure 7.

More details and guidance are available in the **CoolLIFE Wiki**.

3.7. Mapping of Financing Instruments



INFORMATION	VALUE
SLOVAKIA FINANCING INSTRUMENTS - MAPPING OF FINANCING INSTRUMENTS	
Number of schemes found in SK	11
Download filtered schemes from Layers. The complete Mapping of Financing instruments can be found on the CoolLIFE website, in the section resources:	https://coollife.revolve.media/resources/
Scheme 1	Munseff
Scheme 2	GEFF Commercial and Residential
Scheme 3	Green Loans
Scheme 4	ECO Mortgage
Scheme 5	Green mortgage
Scheme 6	Green mortgage
Scheme 7	Blue Planet Mortgage TB
Scheme 8	A sustainable home mortgage
Scheme 9	Green loan for eco-technologies
Scheme 10	Credit for a healthier Earth
Scheme 11	Sustainable Housing Loan

Figure 8. CM-Mapping of Financing Instruments

This module provides access to a searchable database of public and private financing schemes relevant to sustainable space cooling across the EU27. Users can filter schemes by country, administrative level, and funding source, and view key details such as scheme name, type, issuer, and covered sectors.

The module draws from the CoolLIFE EU27 Mapping of Financing Instruments and allows export of filtered results for further analysis. Results are displayed at the national level, regardless of the selected area. The structure of the results is presented in Figure 8.

More details and guidance are available in the CoolLIFE Wiki.

3.8. District Cooling

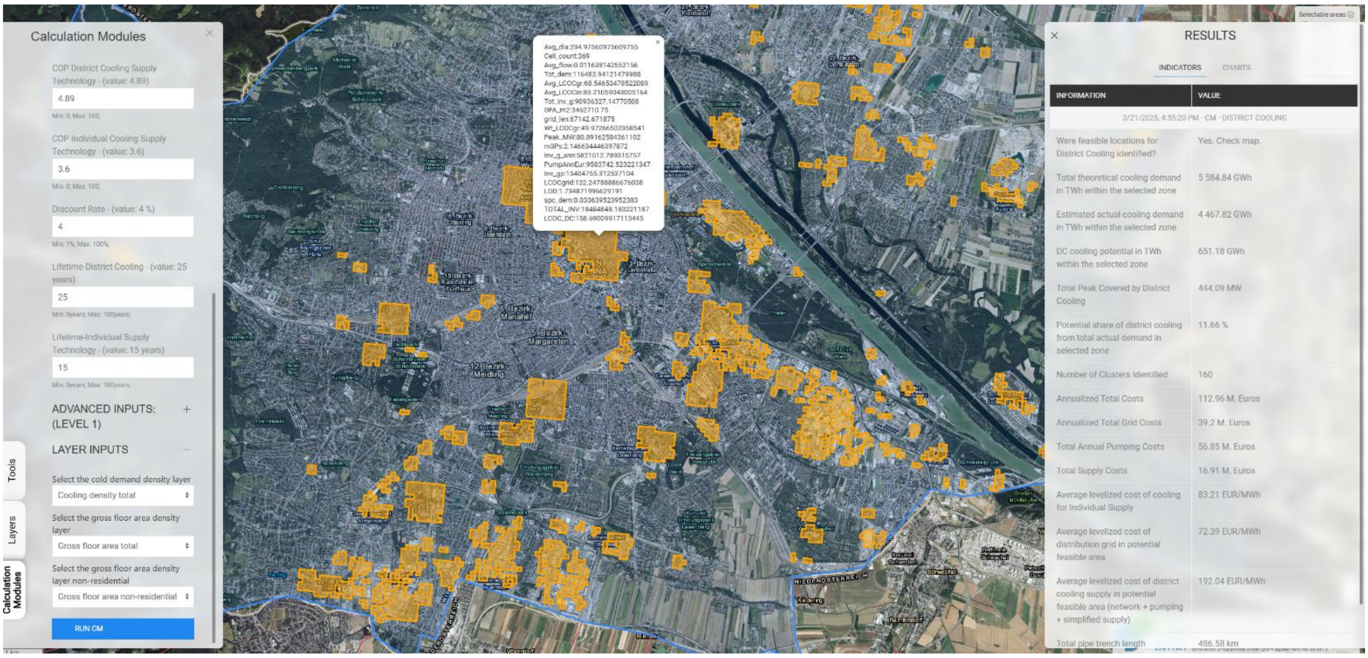


Figure 9. CM-District Cooling

This module assesses the techno-economic feasibility of district cooling (DC) systems at a high spatial resolution (100×100 m), helping identify areas where DC could be a cost-effective alternative to individual cooling solutions. It enables planners and policymakers to compare levelized cooling costs and evaluate the viability of DC networks based on demand density, infrastructure needs, and cost assumptions.

The tool estimates key indicators such as potential DC coverage, peak demand, number of feasible areas, and investment needs. It also provides downloadable shapefiles to support spatial planning.

This module was developed beyond the scope of the original Grant Agreement, reflecting the recognition of the growing importance of district cooling in future energy systems. It was created to provide planners with a practical tool to assess DC opportunities and support integrated cooling strategies. The layout of the sample results generated from the CM is presented in Figure 9.

More details and guidance are available in the **CoolLIFE Wiki**.

4. Open-source code

All calculation modules developed within the CoolLIFE project are made available as open-source code to promote transparency, collaboration, and continued development beyond the scope of the project. The code can be accessed through the Tuleap repository, enabling users—especially technical experts and advanced analysts—to explore, adapt, or extend the modules for their own applications or more detailed assessments.

The open-source approach ensures that the methods and assumptions used in the CoolLIFE platform are fully transparent and verifiable. It also allows public authorities, researchers, and practitioners to integrate the tools into their own workflows or tailor them to local planning needs.

The code is licensed under the Creative Commons Attribution 4.0 International License (CC BY 4.0), which permits reuse and modification, provided that appropriate credit is given. This licensing model supports knowledge sharing and encourages community-driven innovation in sustainable space cooling planning.

Figure 10 shows the user interface of the Tuleap repository where all the CMs can be accessed. Figure 11 gives the structure of the Tuleap repository.

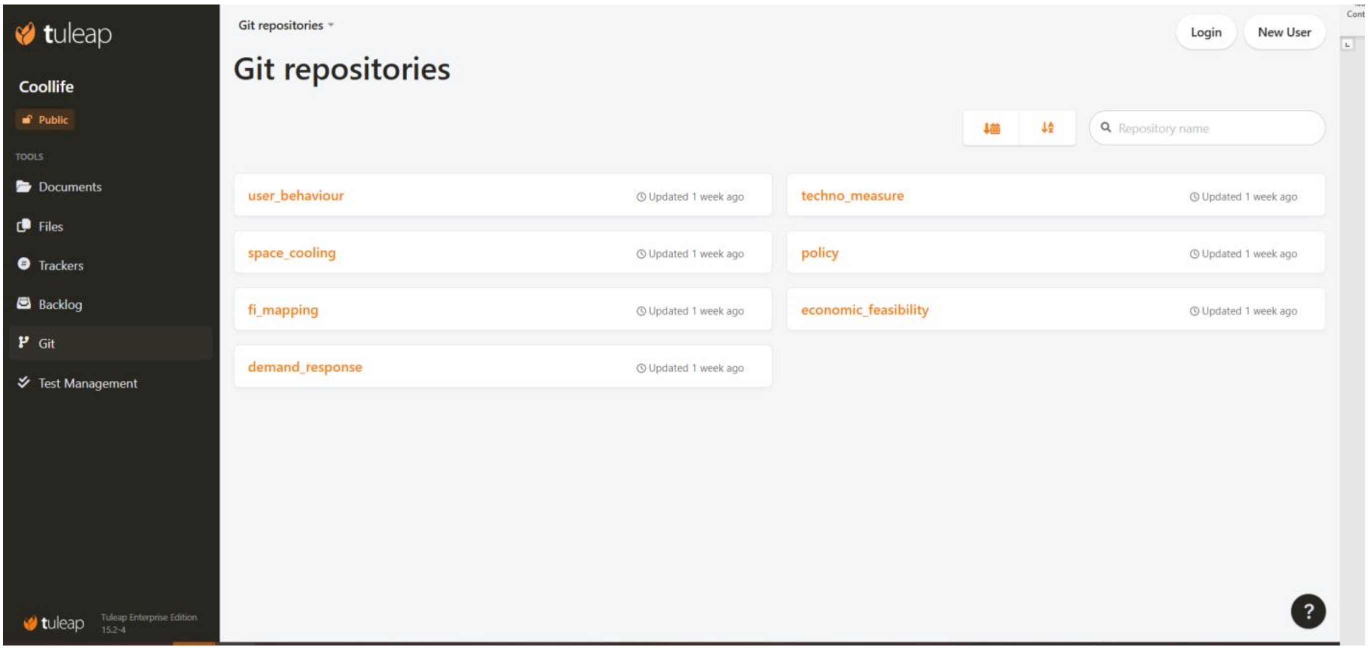


Figure 10. Overview of TULEAP repository

```
cm/
├── app/
│     ├── api_v1/
│     │      ├── __init__.py
│     │      ├── calculation_module.py
│     │      ├── errors.py
│     │      └── transactions.py
│     │
│     │
│     |— decorators/
│     │     ├── __init__.py
│     │     ├── caching.py
│     │     ├── json.py
│     │     ├── paginate.py
│     │     └─rate_limit.py
│     │
│     │
│     ├── __init__.py
│     |— constant.py
│     |— logging.conf
│     |— utils.py
│     │
│     │
│     |— config/
│     │         ├── __init__.py
│     │         ├── development.py
│     │         ├── production.py
│     │         └── transactions.py
│     │
│     |— tests/
│     │         ├── __init__.py
│     │         ├── test_client.py
│     │         └── test.py
│     ├── __init__.py
│     ├── aync_consumer.py
│     ├── Dockerfile.py
│     ├── gunicorn-config.py
│     ├── requirements.txt
│     ├── run.py
│     ├── run_cm_services.sh
│     └── test.py
│
├── .gitiginore
├── docker-compose-der.yml
├── LICENCE
└── README.md
```

Figure 11. Structure of TULEAP Repostiory

5. Tool Chain

The full potential of the CoolLIFE platform is realized not only through individual calculation modules but through their combined application as toolchains—structured workflows that integrate multiple modules to address specific planning and policy needs. These toolchains reflect real-world use cases and enable targeted assessments for different user groups, such as public administrations, engineers, energy communities, civil society, and national authorities.

Each toolchain links relevant modules in a logical sequence, guiding users through data analysis on cooling demand, technology options, user behaviour, financial viability, and policy frameworks. By doing so, they support informed decision-making aligned with energy efficiency, equity, and climate goals.

The toolchains were developed based on practical user stories and include seven distinct use cases, each designed to support a specific policy or planning challenge:

1. **Strategic Planning for Energy Efficiency and Renewable Energy Integration.**
   Enables regional authorities and policymakers to integrate space cooling into broader energy efficiency strategies using demand mapping, economic assessments, and supply scenario evaluations.
2. **Reducing Energy Poverty and Ensuring Summer Comfort**
   Supports municipalities and NGOs in identifying cost-effective and equitable cooling interventions for vulnerable households, emphasizing financial feasibility and comfort requirements.
3. **Strategic and Building-Level Planning for Low-Carbon Cooling**
   Helps planners and building owners assess efficient technology options, district cooling feasibility, and behavioural factors at both system-wide and individual-building levels.
4. **Supporting Data-Driven Interventions for Technicians**
   Provides engineers and energy consultants with tools to estimate energy demand, evaluate cooling technologies, and design tailored interventions based on real-world data.
5. **Promoting Behavioral Change for Energy Savings**
   Equips public administrations and civil society with insights into cooling behaviours, demand-side management, and policy levers to support long-term behaviour change.
6. **Integrating Space Cooling into Energy Communities**
   Facilitates the inclusion of cooling in community energy projects by assessing technical, economic, and behavioural factors alongside regulatory and financial frameworks.
7. **Supporting the National Comprehensive Assessment Report**
   Enables national authorities to meet the Energy Efficiency Directive requirements by generating first-level inputs on space cooling demand, technology scenarios, and cost-effectiveness for national reporting.

These toolchains ensure that CoolLIFE is more than a set of technical tools—it is a decision-support system tailored to the diverse realities of sustainable cooling planning across Europe. For detailed walkthroughs of each use case and corresponding toolchain, refer to the CoolLIFE Wiki or the use case tutorials available within the platform.

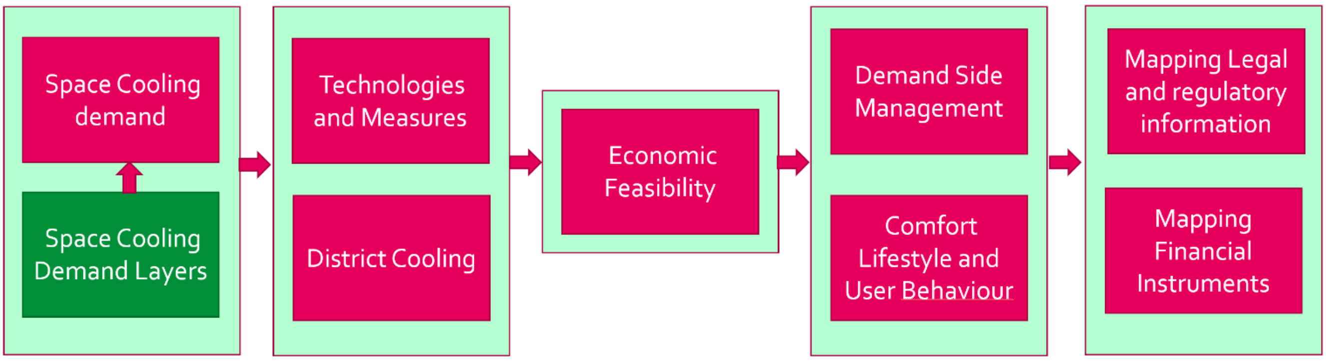


Figure 12. Example CoolLIFE Toolchain