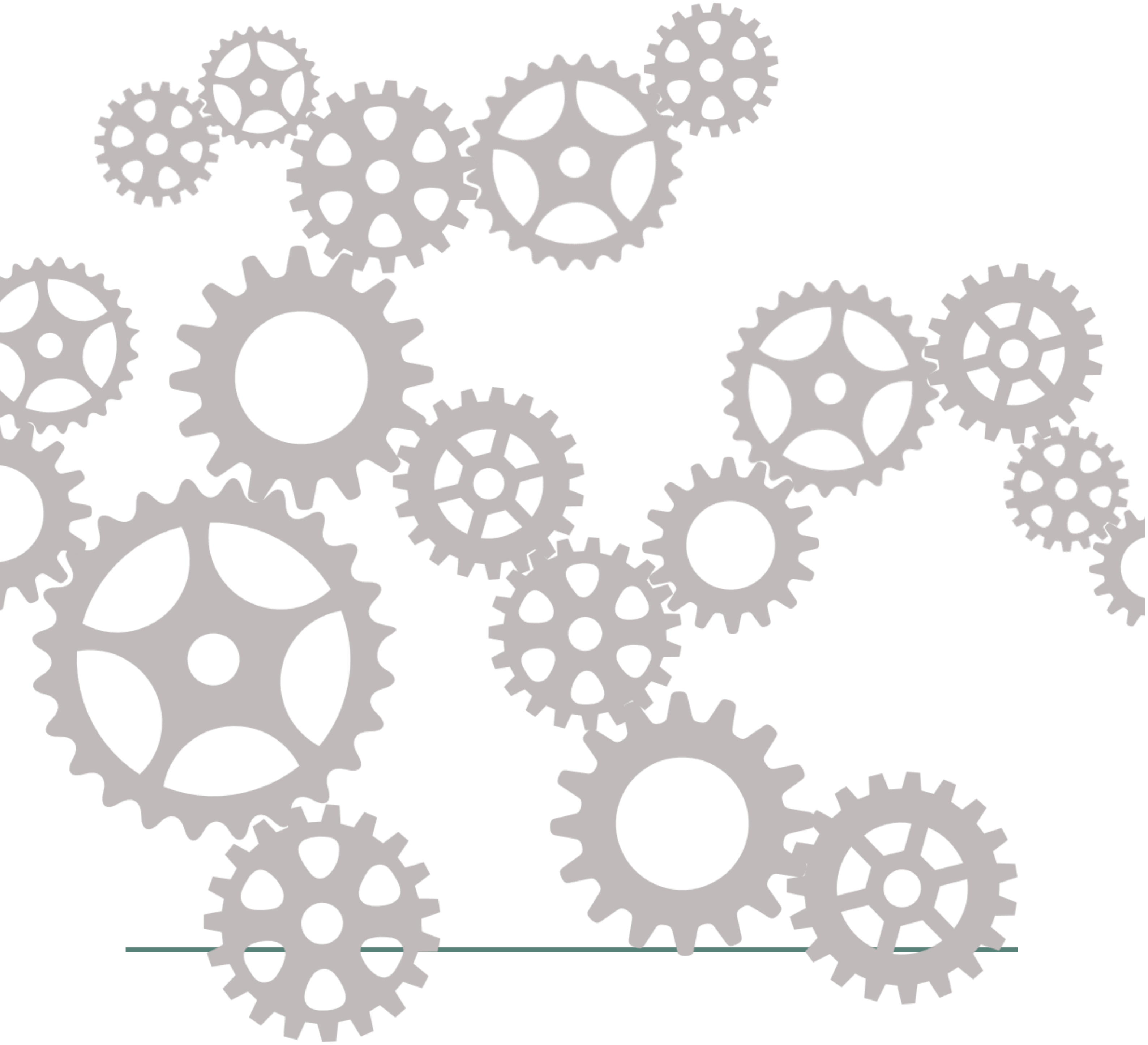
IMPACT INTERACTION MODEL FRAMEWORK

Project KNOWING

Work package 2, Deliverable D2.3



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Work package 2, Deliverable D2.3

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Deliverable details	
Description:	This Deliverable describes the initial version of the KNOWING Impact Interaction Model Framework, which integrates System Dynamics (SD) models with domain models (DMs) to assess adaptation and mitigation strategies. It introduces a calibration concept to be applied to each Demonstrator region, analyses key input and output variables to determine the calibration parameters, and provides conceptual diagrams for describing the interactions between the SD sub-models in each Climate Impact Context (CIC). The approach will be refined and expanded in D2.4 - *"Expandable Impact Interaction Model Framework".*
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TABLE OF CONTENTS

List of Figures

List of Tables

List of Acronyms

CIC	Climate Interaction Context
CL	Climate variable
CLD	Causal Loop Diagram
DEMO	Demonstrator (region)
DH	District Heating
DM	Domain Model
DMD	Domain Model Dialogue
EEAB	External Expert Advisory Board
GHG	Greenhouse gases
HP	Heat pump
IPCC	Intergovernmental Panel on Climate Change
KER	Key Exploitable Result
KPI	Key Performance Indicator
NBS	Nature Based Solution
PH	Public Health variable

PV	Photovoltaics
RES	Renewable Energy Sources
SD	System Dynamics
WIP	Work in Progress
WP	Work Package

Glossary

Note: A project-wide glossary is currently under development. The following table only contains the most relevant terms for this Deliverable. The definition of System Dynamics-related terms has been taken over from (Ford, 2019).

Adaptation	The process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities. In some natural systems, human intervention may facilitate adjustment to the expected climate and its effects (IPCC, 2014). This can be specific for climate change (United Nations Framework Convention on Climate Change - UNFCCC), but also apply for other challenges such as soil erosion, migration and structural economic changes. Adaptation can occur autonomously, for example through market changes, or as a result of intentional adaptation policies and plans at the International, National or local scale (UNISDR, 2009).
Adaptation measures	Adaptation measures are technologies, processes, and activities directed at enhancing our capacity to adapt (building adaptive capacity) and at minimizing, adjusting to and taking advantage of the consequences of climatic change (delivering adaptation) (Climate-ADAPT, 2012). They can be separated into Hard and source-oriented measures, Hard and receptor-oriented measures and Soft measures (CLARITY Project Glossary; CLARITY, 2017). In the context of EU-GL, the term generally refers to the Actions reducing vulnerability to climate change and climate variability by preventing negative effects or by enhancing resilience to climate change (ClimWatAdapt 2012) (European Commission, 2013).
Balancing feedback loop	A feedback loop in which the resulting effect of the causal links over time limits or constrains the change of variables. Balancing loops seek equilibrium, trying to bring stocks to a desired state and keep them there. Also called a negative, compensating, goal-seeking or controlling feedback loop.
Causal	Driving or influencing the relationship between two variables; in contrast to correlations, when two variables change together in time and/or space, but one does not necessarily drive or influence the other.
Causal link	An arrow in a Causal Loop diagram or system structure diagram that describes a relationship between two variables with the direction of causality (from cause variable to impacted variable) and the nature of impact (same direction of change or opposite direction of change). If there is a significant delay in the influence of the driving variable on the driving variable, it can be represented by a link “broken” by parallel lines.

Causal link polarity	A positive (+) or negative (−) sign that indicates the direction of impact of the driving variable on the driven variable. Positive polarity indicates that the impacted variable moves in the same direction (increase or decrease) as the driving variable. Negative polarity indicates that the impacted variable moves in the opposite direction (increase or decrease) to the driving variable. Note: Within this report, blue (+) and red (-) colour is used for the arrows to indicate their polarity. This improves the readability of complex CLDs.
Causal Loop Diagram (CLD)	A tool that represents closed loops of cause-effect linkages (causal links) as a diagram intended to capture how the system variables interrelate and how external variables impact them. Causal Loop Diagrams identify and label feedback loops to facilitate understanding, dynamic reasoning and formal modelling.
Climate impacts	The consequences of realized risks on natural and human systems, where risks result from the interactions of climate-related hazards (including extreme weather and climate events), exposure, and vulnerability. Impacts generally refer to effects on lives; livelihoods; health and well-being; ecosystems and species; economic, social and cultural assets; services (inincluding ecosystem services); and infrastructure (based on IPCC, 2018).
Climate Impact Contexts (CIC)	Within KNOWING three CICs (Heat Waves & Health, Soil fertility & Agriculture, Flooding & Infrastructure) are investigated, representing emerging risks for the Demonstrators due to climate change.
Delay	A phenomenon in which the effect of one variable on another does not occur immediately. A process by which the output lags behind its input in time.
Demonstrators (DEMO)	Regions that are part of the KNOWING consortium and for which the mitigation pathways are developed.
Domain Model (DM)	A detailed computational model of a domain that covers its relevant structure and interfaces with other domains. A Domain Model incorporates both behaviour and data. In KNOWING, the used Domain Models can be classified into three main groups: Sector models, Climate models and climate Impact assessment models. The term “Domain“ refers to a specific discipline or field. This is more generic than using the term “Sector” which is sometimes used as a synonym for “Domain” in the literature. In this Deliverable, however, the term “Sector” is only used for the main economic sectors relevant in the KNOWING context (e.g., Energy, Transport, and Land Use & Agriculture).
Endogenous variable / view	Internal, opposite of exogenous. An endogenous view approaches a problem searching for its causes and solutions within the system boundary. Endogenous variables are affected by other system variables.
Exogenous variable / view	External, opposite of endogenous. An exogenous view assumes that a system’s behaviour is dominated by the influence of outside forces or factors. An exogenous variable is an external (input) variable that affects but is not affected by the system.
Exposure	The evaluation of the quantity of the elements at risk (people, infrastructure, housing, production capacities and other tangible human assets) exposed to damage in hazard-prone areas, their quality, sensitivity to the action of one or more hazardous events, and spatial and temporal distribution. Exposure can include the number of people or types of assets in an area. These can be combined with the specific vulnerability and capacity of the exposed elements to any

	particular hazard to estimate the quantitative risks associated with that hazard in the area of interest (UNISDR, 2017). The Intergovernmental Panel on Climate Change (IPCC) defines "exposure" as "the presence of people, livelihoods, species or ecosystems, environmental functions, services, and resources, infrastructure, or economic, social, or cultural assets in places and settings that could be adversely affected" (IPCC, 2014). Set of elements at risk located in areas subject to hazardous events. The measurement of exposure requires the quantification and spatial location of these elements in the area to be analysed. Exposure estimation is also closely linked to vulnerability analyses; in fact, to define the exposure it is necessary to know the quality of these elements that are sensible to the response to the hazardous action. For this reason, the elements exposed are grouped into homogeneous classes based on the expected damage following the occurrence of a particularly dangerous event, in order to "estimate in quantitative terms the risks and/or the impacts associated with a given hazard intensity in the area of interest" (UNDRR, 2017).
Feedback	When the effect of a causal impact comes back to influence the original cause of that effect. A feedback loop is a sequence of variables and causal links that creates a closed ring of causal influences. See reinforcing feedback loop and balancing feedback loop.
Follower	Regions that are part of the KNOWING consortium and which represent the first regions for testing the transferability of the mitigation pathways developed for the Demonstrators.
Greenhouse gases (GHGs)	Gaseous constituents of the atmosphere, both natural and anthropogenic, absorb and emit radiation at specific wavelengths within the spectrum of radiation emitted by the Earth's surface, by the atmosphere itself, and by clouds. Includes Water vapour (H_2O), carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4) ozone (O_3) sulphur hexafluoride (SF_6), hydrofluorocarbons (HFCs), chlorofluorocarbons (CFCs) and perfluorocarbons (PFCs).
Hazard	The potential occurrence of a natural or human-induced physical event or trend that may cause loss of life, injury or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems and environmental resources. See also Impacts and Risk (AR6; IPCC, 2023).
High-leverage point / parameter	Part of a system where small changes can have a very large impact on system behaviour and is therefore effective for focusing system design, management attention and resources.
Human behaviour	The responses of persons or groups to a particular situation, in this case probably related to climate change. Human behaviour covers the range of actions by individuals, communities, organisations, governments and at the international level (AR6; IPCC, 2023). Note: This is a broad definition of human behaviour including actions of organisations and governments.
Impact	The probable spatial/temporal damage distribution according to a predefined scale of damage expected on the element at risk under consideration. The impact scenario therefore represents the probabilistic distribution, in a given geographical area, of the damage caused by a single hazardous event with an assigned probability of occurrence (assumed as the reference hazard scenario) (Zuccaro et al., 2018). The impact can be measured in several ways: physical, economic, social, functional etc. and it can be evaluated as a direct and/or indirect consequence of the event at a given time (snapshot) or projected in the future. In literature, impact is defined as "consequences of a hazardous event, on natural and human systems, once it materializes, i.e. actually affects a societal system.

	The term “impact” is used primarily to refer to the effects on natural and human systems of extreme weather and climate events and climate change. Impacts generally refer to effects on lives, livelihoods, health, ecosystems, economies, societies, cultures, services, and infrastructure due to the interaction of climate changes or hazardous climate events occurring within a specific time period and the vulnerability of an exposed society or system. The impacts of climate change on geophysical systems, including floods, droughts, and sea level rise, are a subset of impacts called physical impacts (IPCC, 2014).
Land use	The total of arrangements, activities and inputs applied to a parcel of land. The term land use is also used in the sense of the social and economic purposes for which land is managed (e.g., grazing, timber extraction, conservation and city dwelling) (AR6; IPCC, 2023).
Measure	Measures here refer to technologies, processes or practices that directly affect climate resilience and/or emissions and may have subsequent impacts on the dynamics of social and economic systems, rather than supporting policies. Also, see definitions of adaptation measures and mitigation measures.
Mitigation	In climate change the term is used to indicate "a human intervention to reduce the sources or enhance the sinks of greenhouse gases (GHGs)" (IPCC, 2014), that are the source of climate change. More in general is the lessening or minimizing of the adverse impacts of a hazardous event (UNISDR, 2017), through actions that reduce hazard, exposure, and vulnerability (IPCC, 2014). Annotation: The adverse impacts of hazards, especially natural hazards, cannot be completely prevented, but their scale or severity can be substantially reduced by various strategies and actions. Mitigation measures include engineering techniques and hazard-resistant construction as well as improved environmental and social policies and public awareness.
Mitigation measures	In climate policy, mitigation measures are technologies, processes or practices that contribute to mitigation, for example, renewable energy technologies, waste minimisation processes and public transport commuting practices (AR6; IPCC, 2023).
Negative feedback	Feedback that works against deviations from a goal. In isolation or if dominant, negative feedback generates goal-seeking behaviour.
Positive feedback	A structure that produces exponential growth or collapse. Change in one direction results in more and faster change in the same direction.
Reinforcing feedback loop	A feedback loop in which the sum effect of the causal links tends to strengthen (reinforce) the movement of variable values in a given direction due to positive feedback.
Response (in climate adaptation and mitigation)	Actions or behaviours (including inaction) by individuals, groups, organisations, companies, institutions or governments related to climate adaptation and mitigation. This includes actions related directly to reducing the impacts of climate change and or emissions (see ‘adaptation measures’ and ‘mitigation measures) as well as actions or behaviours to reduce/capitalize on the intended and unintended consequences of such actions (see ‘response risks’ and ‘opportunities’).
Response opportunity	Same as response risk (see below), but referring to co-benefits, or positive side effects.

Response risk	Result from the potential for such responses not achieving the intended objective(s), or from potential trade-offs with, or negative side-effects on, other societal objectives, such as the Sustainable Development Goals (SDGs) (AR6; IPCC, 2023). Note: response risks may occur in the same sector or other sectors.
Risk	Result of the interaction between hazard (H), exposure (E) and vulnerability (V), defined as the product (in terms of probabilistic convolution) of the three factors, according to the well-known relationship R=HxExV (IPCC, 2014). The risk therefore represents the probability that a given level of damage (for example on people, buildings, infrastructures, etc.), due to a hazard, will be reached in a given time, in a specific geographical area. Therefore, the risk must be understood as a cumulative assessment that considers the total potential damage that can be induced in the same area by several dangerous events (with different intensity or return periods) in a pre-set time window.
Side effect	An unplanned and typically undesirable side effect of well-meaning intentions and actions, often occurring after a time delay and across an organizational boundary from the intended action.
Stock (level)	An accumulation of quantities in specific locations or conditions in a system. A component of a system that accumulates or drains over time. Stocks are the memory of a system and can only be changed by flows.
Stock and flow diagram	A visual depiction of the stock, flow and auxiliary (converter) variables in a system and how they are connected.
System Dynamics (SD) model	Systems Dynamics models are continuous simulation models using hypothesized relations across activities and processes. Systems dynamics was developed by Forester in 1961 and was initially applied to dealing with the complexity of industrial economic systems and world environmental and population problems. These models are very closely related to the general systems approach and allow modellers to insert qualitative relationships (expressed in general quantitative forms).
System structure	How system elements are organized or interrelated. The totality of feedback loops, stocks, flows and time delays in the system. The building blocks and connections of a system.
Systems thinking	The use of conceptual system models and other tools to improve the understanding of how the feedback, delays and decision-making policies in a system's structure generate the system's behaviour over time. Systems thinking does not use computer simulation. Systems thinking involves (i) seeing interrelationships and feedback loops instead of linear cause-effect chains, and (ii) seeking processes of change over time rather than events/snapshots. Systems thinking helps people see things on three levels: events, patterns of behaviour and system structure.
Urban Heat Island	The relative warmth of a city compared with surrounding rural areas is associated with heat-trapping due to land use, the configuration and design of the built environment, including street layout and building size, the heat-absorbing properties of urban building materials, reduced ventilation, reduced greenery and water features, and domestic and industrial heat emissions generated directly from human activities (AR6; IPCC, 2023).
View	In System Dynamics modelling, Views can be thought of as similar to chapters of a book, or different photos of a complex artefact, each of them telling a portion of the whole story.

Vulnerability	The propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt (AR6; IPCC, 2023).

EXECUTIVE SUMMARY

This Deliverable D2.3 - *"Impact Interaction Model Framework",* presents the KNOWING approach for calibrating quantitative System Dynamics (SD) models using domain models (DMs) to improve the representation of Climate Impact Contexts (CICs) for the four Demonstrators regions. The framework aims to enhance the accuracy and applicability of SD models by integrating insights from detailed process-based simulations, provided by domain experts, ensuring consistency across different sectors and regional scales.

To achieve this, we introduce in this document a structured calibration framework that systematically aligns SD model outputs with trusted reference baselines derived from DMs. This process requires identifying key model variables and calibration parameters at the level of each SD sub-model to ensure meaningful integration of adaptation and mitigation pathways. Additionally, we develop conceptual calibration structures for each CIC, visualized through conceptual diagrams that illustrate the interactions between SD sub-models and DMs. These elements collectively provide a foundation for improving the coherence and robustness of cross-sectoral climate impact assessments.

A key challenge addressed in this work is the absence of real-world ground truth for future climate impacts, requiring a cross-calibration approach using outputs from high-resolution DMs as a reference. Additionally, limitations such as the regional specificity of DM simulations, potential geographical biases, and the need to better capture spatial climate impact dynamics are discussed.

While this deliverable establishes the calibration framework, several aspects remain work in progress. The SD sub-models and their interfaces with DMs are still being refined, as the results from DM simulations become available, and additional data is required to fully establish calibration for all pathways. Furthermore, mechanisms such as backcasting and the consideration of rebound effects need to be integrated to enhance scenario exploration and decision-making support. These open challenges will be further addressed in D2.4 – *"Expandable Impact Interaction Model Framework"* and D2.5 – *"Backcasting/Transferability Concept"*, ensuring a more comprehensive and scalable approach to climate impact assessment.

1. KNOWING summary

Climate change has been globally recognised as an existential threat requiring urgent action to avoid catastrophic consequences. Hence, the EU's Green Deal has been proposed "to make Europe the first climate-neutral continent in the world". This includes not only the elimination of net emissions of greenhouse gases by 2050; this is to be achieved while decoupling economic growth from resource use and striving for a fair implementation, leaving no person and no place behind. This ambitious goal is additionally challenged by the need to adapt to unavoidable impacts.

According to the EU's Climate Adaptation Strategy (European Commission, 2021), "improving knowledge and managing uncertainty" is key to realising the vision of a climate-neutral and climate-resilient Union, as "Climate change is having such a pervasive impact that our response to it must be systemic". Thus, there is an **urgent need for an integrated approach for enhanced understanding of the interaction, complementarity and trade-offs** between adaptation and mitigation measures, especially regarding the expected increase in regional mean temperature, changing precipitation pattern and soil moisture (AR6 WG IPCC, 2021). Furthermore, this **understanding and knowledge needs to be provided to a broad audience to support local authorities** in EU countries in developing regional programmes.

KNOWING aims to develop a **modelling framework to help understand and quantify the interactions** between impacts and risks of climate change, mitigation pathways and adaptation strategies. The framework will be used to assess the **interrelationship between public and private adaptation and mitigation strategies** in order to **identify mitigation pathways along optimised combinations of interventions** in different sectors (e.g. energy, mobility, land use, construction, agriculture). The framework will focus on **three main Climate Impact Contexts** (CICs): (1) Heat Waves & Health, (2) Soil fertility & Agriculture, and (3) Flooding & Infrastructure (including river and coastal flooding). It will be applied **in four Demonstrator (DEMO) and five Follower Regions by involving authorities, stakeholders and citizens** to develop **enhanced activation and empowerment services, providing target-group-specific awareness, education and decision support tools** to improve the comprehensibility of complex interrelationship and support strategic planning of combined adaptation and mitigation measures.

To achieve this goal, KNOWING will produce the following **key exploitable results (KERs)**:

KER1	an **Impact Interaction Knowledge Base** comprising causal relations of climate and intervention impacts, rebound effects, coping strategies, etc. to inform Climate-ADAPT and IPCC Working Groups I, II & III;
KER2	an **Impact Interaction Model Framework** consisting of a System Dynamics (SD) model, climate and sector models for integrated assessment of impacts (direct and indirect) of climate change and countermeasures;
KER3	a Typology of transferable **Climate Mitigation Pathways** including optimised bundles of adaptation and mitigation measures for different typical Climate Impact Contexts (heat waves, soil fertility, flooding);
KER4	**Climate Activation and Empowerment Services,** addressing different target groups (citizens, businesses, authorities) to enhance climate literacy, provide playful training and support decision-making.

These results, developed with the support of an External Expert Advisory Board (EEAB) and a Stakeholder Reference Group (SRG), will **accelerate the transition to a climate-neutral and resilient society and economy** enabled through advanced climate science, mitigation and adaptation pathways and behavioural transformations.

2. Objectives of the Deliverable

Deliverable 2.3 – “*Impact Interaction Model Framework*” describes the developed KNOWING concept for calibrating the quantitative system dynamics models with the help of domain models. It builds upon the results of T2.1 and T2.2, summarizes the outcomes of Task 2.3 - “*Model calibration & validation*” and consolidates the findings of Task 2.3 - “Model Calibration & Validation”. By doing so, it bridges the efforts of WP2 with those of WP3, ensuring continuity between model development, calibration, and validation.

The calibration concept introduced in this deliverable lays the foundation for an “Expandable Impact Interaction Model Framework”, to be further developed and described in D2.4. This framework is designed to allow for scalability and adaptability, enabling the continuous integration of new insights and refinements based on demonstrator results and stakeholder feedback.

To achieve these goals, this deliverable addresses the following key objectives:

i) **Development of the KNOWING Calibration Concept:**
    - A comprehensive description of the calibration methodology to be applied for each demonstrator region.
    - Explanation of the underlying principles and rationale for aligning SD models with domain models through a structured calibration process.

ii) **Analysis of Key Input and Output Variables for each Domain Model (DM):**
    - A detailed examination of the input and output variables for each DM, identifying their roles in the calibration process.
    - Specification of the calibration parameters required to align the SD sub-models with the respective DM outputs, ensuring consistency and reliability.

iii) **Conceptual Diagrams for each Climate Impact Context (CIC):**
    - Development of visual representations (conceptual diagrams) for each CIC, illustrating the interactions between domain models and SD sub-models.
    - Provision of a structured “recipe” for applying the calibration methodology to each SD sub-model, facilitating reproducibility and application across different demonstrator regions.

This deliverable serves as a critical step toward integrating diverse modeling approaches within the KNOWING framework, supporting a systematic calibration process that enhances the accuracy and applicability of SD models in assessing adaptation and mitigation strategies. As this is a work in progress, further refinements and improvements will be incorporated based on ongoing research activities.

3. Introduction and Scope

The increasing complexity of climate change and its multifaceted impacts on socio-economic and environmental systems necessitate advanced modelling approaches to inform effective decision-making. **System dynamics (SD) models** are instrumental in analysing feedback loops, time delays, and non-linear interactions within these complex systems (Andrew, 2010; Juhola et al., 2022). However, the precision and predictive capability of SD models heavily rely on accurately **calibrated parameters**, intended as values that define the relationships and dynamics within the model. These are often challenging to derive from empirical data alone and it is important to ensure that the outcome of a calibrated SD model aligns with observed data and theoretical expectations. Integrating SD models with **domain models (DMs)**, incorporating specialized knowledge from fields such as climate science, mobility, and energy systems, enhances the representation of real-world interactions, thereby improving the reliability of simulations and scenario analyses (Goosse, 2015) This combined approach is particularly vital in addressing climate change, as it facilitates a comprehensive understanding of long-term systemic transformations, supports robust policy development, and aids in evaluating the effectiveness of mitigation and adaptation strategies (Pruyt et al., 2011).By leveraging both system dynamics and domain-specific insights, stakeholders can better capture the interdependencies among technological, economic, and behavioural factors, leading to more effective and sustainable climate resilience strategies (Redivo, 2021).

Within KNOWING, we are developing the Impact Interaction Model Framework, which aims to **integrate system dynamics and domain models at the scale of demonstrator regions for different Climate Impact Contexts (CICs)**. The overarching goal is to create a flexible and adaptive framework that incorporates insights from both, Demonstrator and Follower modeling activities, as well as input from stakeholder groups. This approach allows for the exploration of different pathways – such as how the expansion of green areas and tree-lined streets, by reducing outdoor heat conditions and improving walkability, can increase the attractiveness of public transport and contribute to reducing greenhouse gas emissions in a specific region - without necessitating new simulation runs from all involved domain models. To achieve this, we require a **calibration framework** for the SD (sub-)models developed in D2.2, providing a structured, step-by-step approach for calibrating complex systems. This ensures that models can accurately describe multi-dimensional impacts, such as the effect of heat waves on hospitalizations, energy demand, and supply. In this deliverable, we focus on developing a calibration concept tailored to each SD model at the demonstrator level. A generalization of this framework as well as additional functionalities, such as backcasting mechanisms, which are addressed in more detail in D2.5 - *"Backcasting/Transferability Concept"*, will be incorporated in D2.4 – *"Expandable Impact Interaction Model Framework."*

3.1. Calibration Concept

The concept of calibration originates from the field of engineering and measurement science, where technical devices must be adjusted to ensure their output aligns with known reference values. This process is essential for maintaining accuracy and reliability in various applications, from laboratory instruments to industrial machinery. In the context of SD modeling, calibration serves a similar purpose: it ensures that model outputs accurately reflect real-world dynamics by systematically aligning them with empirical data and expert knowledge.

As in any calibration process, we need to identify the target variables and compare them against a reference baseline, adjusting the calibration parameters to minimize discrepancies with respect to real measurements. In KNOWING, our goal is to calibrate the SD models developed in Task T2.2 and documented in D2.2 to estimate the effects of adaptation and mitigation measures across domains. However, the calibration process faces several challenges, including the limitation of DM runs to local or regional scales, which may not fully capture broader systemic interactions. Additionally, geographical biases and missing spatial information can hinder the accurate representation of climate impact dynamics, affecting the reliability of model outputs in describing real-world adaptation and mitigation effects.

To address this, and in the absence of real-world measurements for future climate impacts, we adopt a cross-calibration approach. Assuming that the DMs produce reliable results in their simulations, we use their outputs as a reference for SD model calibration. In this process, SD model target variables are systematically compared to the corresponding DM output variables, ensuring alignment between the two modeling approaches. Figure 3 illustrates the cross-calibration concept for two key output variables.

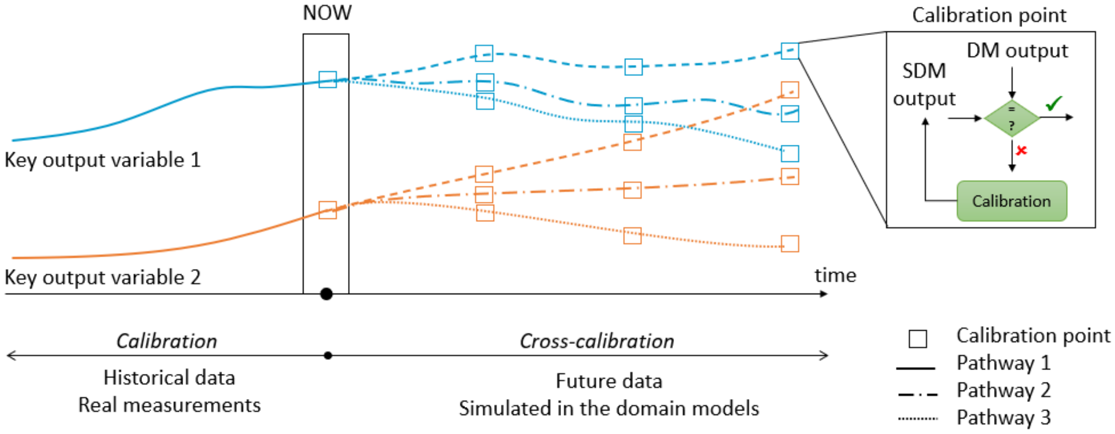

Figure 1 - Calibration approach used in KNOWING.

Given the different temporal and spatial resolutions provided by the DMs, we follow an initial point-calibration approach, represented with small squares in Figure 1, where we define, together with the SD modelers, the SD resolution that we should use for calibrating the system.

Moreover, to ensure a proper model dynamics, the calibration process involves **multiple scenarios**, each defined by the different adaptation and mitigation measures incorporated into both the DM and SD models. As illustrated in Figure 3, these scenarios are represented using different line formats. In the following, we refer to these calibration scenarios as **pathways**, aligning with the terminology used throughout the KNOWING project. This approach enables us to account for the sensitivities of key output variables in response to various interventions, ensuring a more comprehensive and robust calibration process.

3.2. Common Ground for each Calibration Point

Due to the complex nature of this calibration task, our approach is applied iteratively at each calibration point and starts at the level of the domain models (as illustrated in the calibration point box in Figure 3). The common ground for the calibration is the assumption that at each point in time the corresponding key output variable of each SD sub-model should be equal to the output variable of the corresponding DM. It is therefore crucial to have the data corresponding to the output variables of the DMs. Once this is stablished, calibration can start, and the calibration parameters can be tuned.

In Chapter 4, we describe this calibration process in more detail (per SD sub-model and CIC level), then Chapter 5 applies the SD models for each CIC to the KNOWING demonstrator regions also providing an overview of all available data at the time of submission of this deliverable.

4. Calibration Model Framework

4.1. KNOWING Calibration Approach

The different Climate Impact Contexts (CICs) identified in KNOWING are meant to be simulated using a system dynamic modelling approach. Given the complexity of all dependencies in each CIC, the SD model is broken down into several SD sub-models. The SD sub-models can be understood as modules that "replicate" in a simplified way the input-output structure of the DMs in a SD modelling environment, and that are linked together to achieve the full SD model configuration. We base our calibration approach on these modules and define an iterative calibration process, as depicted in **Error! Reference source not found.**.

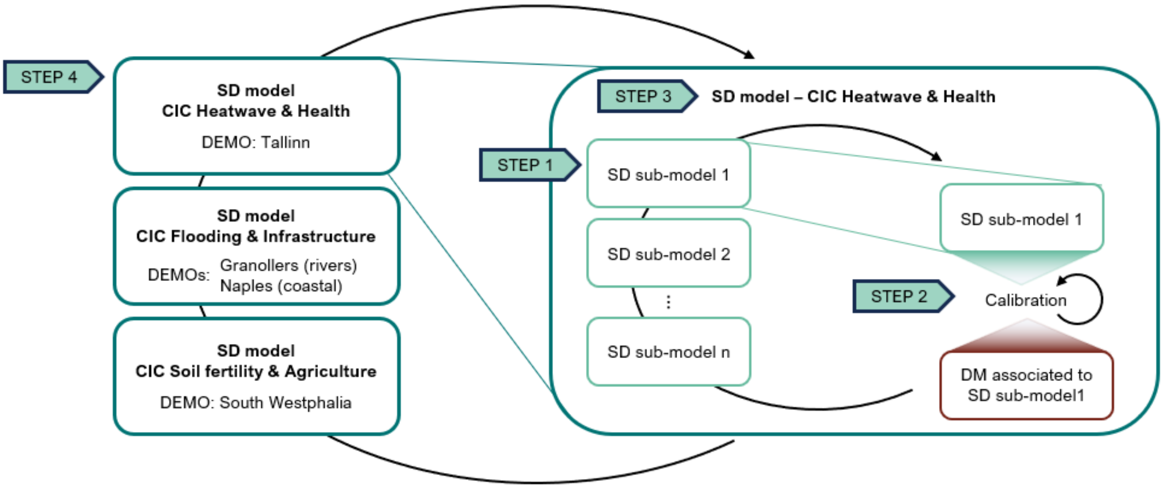

Figure 2 - KNOWING iterative calibration workflow: STEP 1: Identification of all SD sub-models; STEP 2: Calibration of single SD sub-model against its associated DM; STEP 3: Full SD model calibration; STEP 4: Calibration of all SD models representing the different CICs. Refer to text for further explanations.

The steps defined in the iterative calibration process are:

1. **SD sub-models' identification**: A SD model is defined per CIC, in this first step, all SD sub-models are defined and assigned to the CIC where they are used. Then, one sub-model is selected to begin with the calibration.
2. **Sub-model calibration**: All calibration elements are identified for each SD sub-model. We start with a single SD sub-model calibration. A first set of parameters is selected, and an initial calibration is performed. Then we add new (set of) calibration parameters in each calibration iteration until the SD sub-model is fully calibrated. Once one sub-model is calibrated, we continue with the next one until we have calibrated all SD sub-models identified in step 1.
3. **Full SD model calibration**: We integrate all calibrated SD sub-models and adjust the calibration of the full SD model.

4. **Calibration of all models**: we go back to step 3 and start over with another SD model.

In Section 4.3 we focus on steps 1 and 2, and in Section 4.4 we continue with steps 3 and 4.

4.2. Variables Overview

Keeping a clear vision of all the variables (those used in the DM that are relevant for the SD sub-models, as well as those used in the SD models) is crucial for selecting the right elements for the calibration. Figure **3** - KNOWING variables landscape.Figure **3** depicts the KNOWING variables landscape.

For a better understanding, we separate the DMs and the SD models into two layers, then we define an intermediate layer, the calibration layer, where the calibration is conducted, as depicted in Figure 3. The elements used for calibration are coming either from the DM layer or the SD sub-models layer.

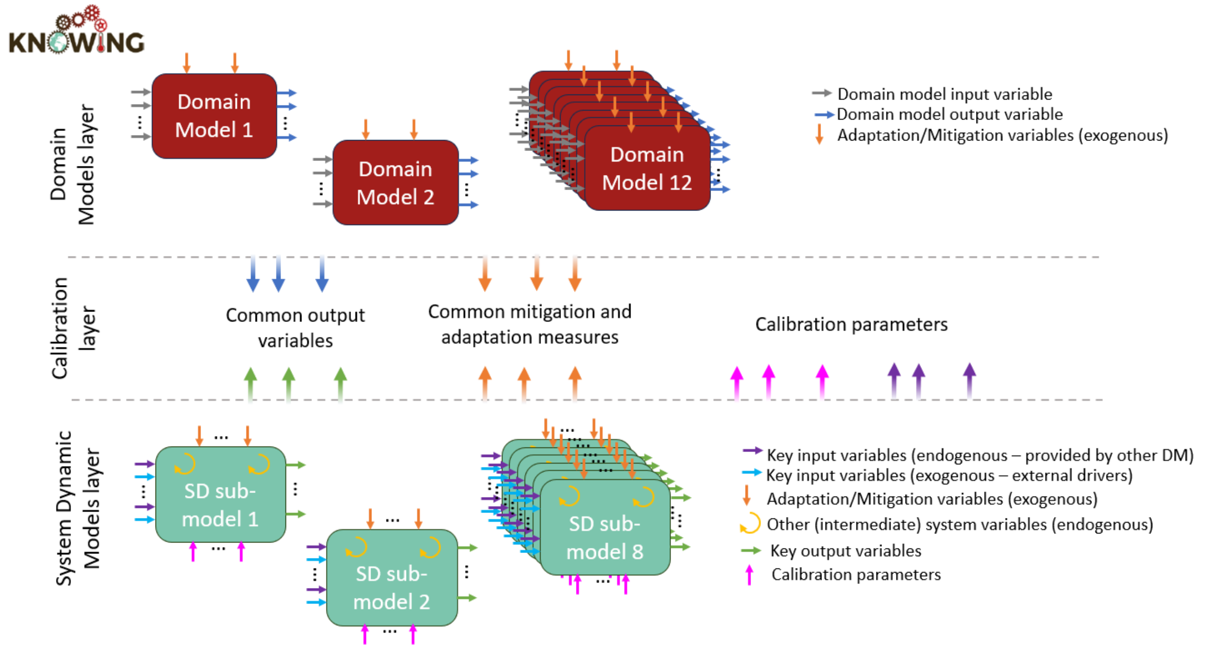

Figure 3 - KNOWING variables landscape.

In the KNOWING DMs layer, we distinguish between three different types of variables:

- Input variables – from external data sources or other DMs
- Output variables – the output produced by each DM
- Adaptation and mitigation variables – exogenous

In the KNOWING SD models layer, there are five different types of variables, as listed in D2.2:

- Key input variables – endogenous, provided by other DMs
- Key input variables – exogenous, provided by external drivers
- Adaptation and mitigation variables – exogenous
- Other (intermediate) variables – endogenous
- Key output variables – the output produced in each SD model

In the KNOWING calibration layer, we select the relevant variables and parameters to calibrate the different SD models for each CIC:

- Common output variables
- Common mitigation and adaptation measures

- SD calibration parameters

Focusing on the calibration layer, the *common output variables* are the overlapping DM output variables that can be mapped to the SD sub-model key output variables and therefore can be used for comparison in the calibration process. The calibrated SD model shall reproduce these key outputs as precisely as possible.

The *common adaptation and mitigation measures* in the calibration layer represent those used for simulating the same pathway/scenario in both the DMs and the SD models. We call them simply “measures” because the adaptation and mitigation variables applied in the different DMs might differ from the ones applied in the SD models, which sometimes will be an aggregated bundle of measures represented in one variable to be applied in the SD models.

Finally, the *SD calibration parameters* are those we can tune during the calibration process. These are input parameters in the SD model; some might be only used in the SD models (i.e. there is no equivalent in the DMs) and others will represent an aggregation or simplification of one or more variables used in the DMs.

Since each domain model uses its own input and output variables, in order to identify the key output variables used for the calibration, we asked the DM owners to complement the tables already outlined in D3.2. and listed in

Annex C. Note that these tables represent the currently identified variables, nevertheless, they might change as the DM evolve and therefore, they will need to be updated in the corresponding data set (refer to Annex A for more details).
It is worth mentioning that some of the input variables will be common for both the DMs and the SD models and provided by external sources (e.g. population). It is important to check before starting the calibration that the same sources have been used in the DM runs as well as in the SD model runs in order to have a trustful calibration.

4.3. SD sub-model calibration

Each CIC is modelled using a combination of SD sub-models, as described in D2.2. Following the iterative stepwise KNOWING calibration approach presented in the previous section, we focus on the calibration of the different sub-models individually. Some sub-models are common to all CICs, others are CIC specific, as listed in Table 1. Despite the fact that there are sub-models common to all CICs, we calibrate them within the different CICs separately, as the calibration parameters might differ depending on their application region and the data provided for calibration. In the next sections we will analyse all the elements needed for the calibration of the different SD sub-models (the output variables and the calibration parameters for each SD sub-model per CIC). And in Chapter 5, the full CIC SD models will be configurated using the needed SD sub-models.

Table 1 - CICs and their SD sub-models.

CIC		Heatwave & Health	Flooding & Infrastructure	Soil Fertility & Agriculture
SD sub-model	**Related DM**			
Transport	Mobility	X	X	X
Energy Demand	MAED-City	X	X	X
Energy Supply	IES-Opt	X	X	X
Microclimate	PALM4U, HWLEM	X	X	
Health	D-MERF	X		
Housing	MAED-City	X	X	
Land Use	CLUMondo			X
Flooding (coastal/pluvial)	ICM-Infoworks SFINCS		X	

Important for calibration are the key output variables of the different SD models and all DM related output variables (sometimes aggregation might be needed).

4.3.1. Transport SD sub-model

The calibration of the transport sub-model has started earlier than that of other models and will therefore be used to discuss and illustrate some of the concepts of the calibration approach in KNOWING in more detail. It is also important to mention, however, that details of the calibration vary significantly across the different SD sub-models (due to different nature of the domain models), and therefore different strategies have been selected.

Similar to other domain models applied in KNOWING, the transport DM, a macroscopic transport model (PTV Visum) – refer also to (Bügelmayer-Blaschek and Scussolini, D2.3), section 7.1.10 – relies on and produces data on a fine-grained spatial granularity. While microscopic or agent-based models would even simulate each entity (car, train or bus, person …) of reality is individually, in a macroscopic model the description of reality is already shifted from individuals to "more aggregated" variables like flow and density, which is a first step towards the aggregation level targeted in the system dynamics approach. Spatial granularity, however, is on small cells (traffic zones) connected by network links where the traffic flows (network loads) are an output of the simulation.

Therefore, one of the main questions for designing and cross-calibrating an SD model against these data is the following: Which level of segmentation of traffic flows (trips) should the SD model include, in order to reproduce the main dynamics of the transport system, but avoiding too much segmentation (level of spatial detail) that would not support to give additional insights but makes the overall model too complex and slow to simulate?

In KNOWING, based on experience in previous applications of SD modelling in the transport domain (Zach et al., 2022) and analysing preliminary results of the macroscopic transport model outputs for Tallinn, it was decided to distinguish (and segment) trips by following two criteria:

1. Trip Length: short (0-2km), medium (2-10km), and long (>10km) – because the mode choice will obviously significantly depend on that
2. Traffic type: internal (within city / region boundaries), origin – destination (to and from the city / region, from / to outside) – representing a high-level segmentation into two zones

Before documenting the calibration process on the level of individual variables used, let’s briefly summarize the main categories of these variables that are relevant from a calibration perspective:

- Common input variables: These are taken over directly from the domain model simulations and therefore don’t need any further consideration during the calibration process.
- Calibration parameters: These are also input variables to the SD sub-model (usually constants, i.e. exogenous variables that do not change over time), but in contrast to the above category the values of these variables cannot be taken directly from the domain model runs but shall be determined in the calibration process (by variation).
- (Common) key output variables that are used for the calibration: The calibrated SD sub-model shall reproduce these key outputs as precisely as possible – these are the common output variables as described in section 4.1. For the transport sub-model these are
    - The number of trips (per mode, trip length and traffic type) – which also implies the modal split as a key output of the model (note that the trips are also the only (subscripted) stock variables which are changed over time through the “flows” DemandChangeRate and ModeChangeRate)
    - The average speed (also per mode, trip length and traffic type) – also translating into the travel time which should be reflected in the SD model

This overview can also be seen in the visualisation (main view) of the transport sub-model in Vensim in Figure 4.

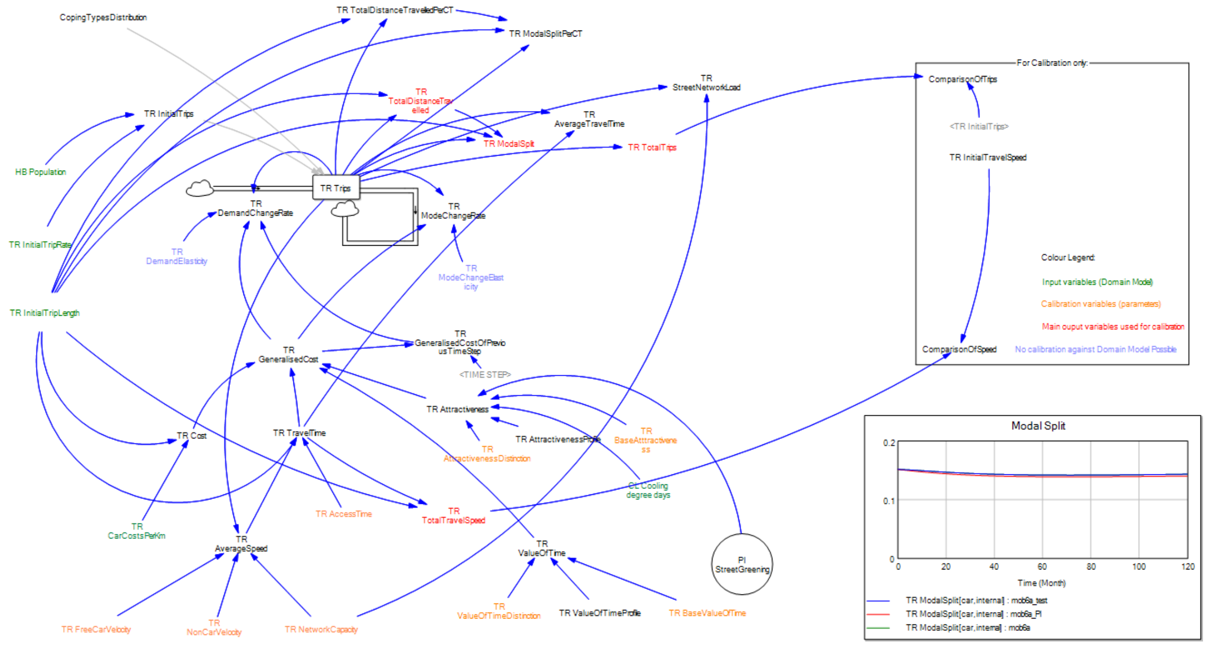

Figure 4: Main view of the transport sub-model, showing common input variables (green), calibration parameters (orange) and key output variables used for calibration (red).

The mitigation and adaptation measures, or more precisely, the variables in the SD model that are used to represent these measures, have not explicitly been discussed within the categories described above. As explained for the overall calibration approach in section 4.1, in general *common adaptation and mitigation measures* (i.e., common definition in SD sub-model and domain model) can be assumed – which means that variables representing them can be directly taken over from domain model runs and therefore fall into the first category described above – the common input variables. In some cases, however, further aggregation or representing a bundle of single interventions by one proxy parameter[1] is more feasible in the SD model. This means introducing an additional calibration parameter in the SD model (second category) that can be easily determined by an additional calibration run. Examples are discussed below.

Finally, let's discuss the aspect of time dependency for the calibration of the SD sub-model: The macroscopic transport domain model (like most of other domain models in KNOWING) always provides a "snapshot" – detailed figures of network load (outputs) depending on the specific population and network characteristics along with any interventions applied (inputs) at one point in time. In contrast, SD models always describe the evolution of a system over time – this would include the gradual change of exogeneous system variables (e.g. population increase, but also ramp-up of policy interventions over time), as well as the corresponding change of key output variables like the modal split. For the calibration this means that we are starting with "equilibrium" calibration runs where the calibration parameters are determined separately for each of the domain model runs available. These have then to be checked for consistency, and a final set of calibration parameter values is determined in a run that considers domain model runs for multiple points in time.

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[1] A proxy parameter is representing a set of other parameters which are defined in more detail, or with higher granularity.

Table 2 - Variables for the Transport SD sub-model.

Transport sub-model				
SDM Variable Name	**Type**	**Related DM**	**Related DM Variable Name**	**Comments**
TR_ModalSplit [mode] [2]	KeyOut-endo	DM: Mobility	Modal split	Calculated from Trips
TR_TotalDistanceTravelled [mode]	KeyOut-endo	DM: Mobility	Tot. Distance travelled per transport mode	Calculated from Trips
TR_TotalTravelTime [mode]	KeyOut-endo	DM: Mobility	Tot. Time travelled per transport mode	Calculated from Total Travel Speed
TR_TotalTrips	KeyOut-endo	DM: Mobility	obtained by post-processing	Used for calibration
TR_TotalTravelSpeed	KeyOut-endo	DM: Mobility	obtained by post-processing	Used for calibration
List of calibration parameters for transport sub-model				
Parameter Name	**Type**	**Related SDM**	**Range of possible values**	**Comments**
TR_DemandElasticity	CalPar-exo	SDM: Transport	0.01 – 0.1	To be confirmed during calibration
TR_ModeChangeElasticity	CalPar-exo	SDM: Transport	0.01 – 0.1	To be confirmed during calibration
TR_FreeCarVelocity	KeyIn-exoDM	SDM: Transport	20 - 60km/h	To be confirmed during calibration
TR_NonCarVelocity	KeyIn-exoDM	SDM: Transport	3 – 30 km/h	Depending on modes
TR_NetworkCapacity	KeyIn-exoDM	SDM: Transport	600000 - 2000000	To be confirmed during calibration
TR_AccessTime	KeyIn-exoDM	SDM: Transport	0 – 0.5 h	Depending on modes
TR_BaseAttractiveness	KeyIn-exoDM	SDM: Transport	-5 – 10	Depending on modes
TR_AttractivenessDistinction	KeyIn-exoDM	SDM: Transport	0.1 – 3	To be confirmed during calibration
TR_BaseValueOfTime	KeyIn-exoDM	SDM: Transport	5 – 20 EUR/h	
TR_ValueOfTimeDistinction	KeyIn-exoDM	SDM: Transport	0.1 – 3	To be confirmed during calibration

Brief discussion of example calibration parameters:

- TR_DemandElasticity, TR_ModeChangeElasticity: These parameters specify how fast humans will adapt the number of travels and their mode choice to changes (or shifts) in the generalised costs for their trips (using a specific mode of transport). Note that these two parameters cannot be determined by means of single (snap-shot) domain model runs, since they take into account the development over time

- TR_FreeCarVelocity, TR_NonCarVelocity, TR_NetworkCapacity: These parameters correspond to aggregated (average) values present in the SD model that cannot obtained directly from the domain model runs but which clearly are depending on the specific transport infrastructure of a city / region (topology, street network, public transport system etc.)

- TR_BaseAttractiveness, TR_AttractivenessDistinction: The attractiveness is introduced as part of the generalised costs of trips (contributing negatively) in addition to the pure costs and the consumed time multiplied by the value of time, to account for a specific offset for each mode of

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[2] The notation used here ([mode]) refers to the use of subscripts: “mode” can take the following values: “car”, “car passenger”, “public transport”, “bicycle”, “walk”.

transport, depending on the specific infrastructure, climate conditions but also the coping typology. The amount how this attractiveness differs between coping types is determined by the parameter TR_AttractivenessDistinction.

- Calibration parameters related to measures: As mentioned above, for certain measures no direct take-over from domain model runs is possible, and either some of the (already determined) calibration parameters have to be used here with modified values, or new calibration parameters have to be defined, Examples:
    - Traffic calming (Speed limit reductions + Capacity reductions): This will be represented in SD model by modifying the existing calibration parameter TR_NetworkCapacity (which cannot be obtained in this aggregated form from the DM run).
    - UVAR (congestion pricing, area toll): This will add extra costs for car trips into the city which can only be handled on aggregated level in the SD model, however. The amount of these (average) extra costs will therefore be an additionally introduced calibration parameter.
    - Cycling optimization (optimization and new infra): This will be represented in SD model by modifying the existing calibration parameter TR_BaseAttractiveness.

4.3.2. Energy demand SD sub-model

The sub-model for energy demand is one of the most complex sub-models as it is highly connected with the other sub-models. The calibration of the energy demand sub-model has not started so far. The following table however shows important output variables from the DM Mead-City and corresponding calibration parameters which shall be used in the sub-model. The list will be extended during the calibration process.

Table 3 - Variables for the Energy Demand SD sub-model.

Energy demand sub-model			
SDM Variable Name	**Type**	**Related DM**	**Related DM Variable Name**
EN_UsefulEnergy[sector[3] and category[4]]	KeyOut-endo	DM: MAED-City	Sectorial Useful Energy demand for motive power, heat and electricity/year [MWh/yr]
EN_TotalFinalEnergy[energy] carrier	KeyOut-endo	DM: MAED-City	Tot. final energy demand by fuel type/year [MWh/yr]
EN_FinalEnergy per sector and energy carrier	KeyOut-endo	DM: MAED-City	Sectorial final Energy demand by fuel type/year [MWh/yr]
List of calibration parameters for energy demand sub-model			
Parameter Name	**Type**	**Related SDM**	**Range of possible values**
EN_PerCapita_UsefulEnergyDemand_heat[sector]	CalPar-endo	SDM: EnegyDemand	To be defined based on MAED-City results.
EN_PerCapita_UsefulEnergyDemand_motivePower[5][sector]	CalPar-endo	SDM: EnegyDemand	
EN_PerCapita_UsefulEnergyDemand_specificElectricity[sector]	CalPar-endo	SDM: EnegyDemand	
EN_UsefuEnergy_to_FinalEnergy_conversionFactor[energy carrier]	CalPar-endo	SDM: EnergyDemand	
EN_incrEnergyEff_heat[sector]	CalPar-endo	SDM: EnergyDemand	

Brief discussion of example calibration parameters:

- EN_PerCapita_UsefulEnergyDemand_heat[sector]: This calibration parameter enables to calibrate the total Useful heat demand. This parameter contains of subscripts to calibrate the useful heat demand from the household, service, transport and industry sector.
- EN_PerCapita_UsefulEnergyDemand_motivePower[sector]: This calibration parameter enables to calibrate the total Useful motive power demand. This parameter contains of subscripts to calibrate the useful motive power demand from the household, service, transport and industry sector.
- EN_PerCapita_UsefulEnergyDemand_specificElectricity[sector]: This calibration parameter enables to calibrate the total Useful specific electricity demand. This parameter contains of subscripts to calibrate the useful specific electricity demand from the household, service, transport and industry sector.
- EN_UsefulEnergy_to_FinalEnergy_conversionFactor[energy carrier]: This calibration parameter enables to calibrate the needed final energy demand by energy carriers (fuel type). This parameter contains of subscripts to calibrate the conversion by energy carrier.

These main calibration parameters can be used to calibrate the current state of the energy demand system in the demonstrator regions. For the scenarios with interventions (mitigation and adaptation measures) additional calibration parameters are needed. Some important intervention related calibration parameters are mentioned below.

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[3] Here **sectors** mean: Household, Service, Transport & Industry

[4] Here **category** means: Motive power demand, Heat for thermal use demand, Specific use of electricity

[5] Motive power: e.g. Energy for Electricity for Heat pumps, motor from MEAD-City

Calibration parameters related to measures:

- EN_incrEnergyEff_heat[sector]: This calibration parameter is used to calibrate the useful heat demand per sector. Within the household sector, refurbishment activities or different building structure and even behaviour changes (lowering heating temperature). This calibration parameter also uses subscripts[6] for the sectors. Thus, factors for the service transport and industry sectors for the useful heating demand are used too.
- Similar to the useful heat demand are two calibration parameters EN_incrEnergyEff_motive Power[sector] & EN_incrEnergyEff_specificElectricity[sector] are used to calibrate interventions, which influence the useful motive power and useful specific electricity demand within the sectors.

The calibration parameter EN_UsefulEnergy_to_FinalEnergy_conversionFactor[energy carrier] will also be used to calibrate interventions e.g. influencing how the useful energy is produced. E.g. a change from fossil fuel driven cars to electric cars will increase the Final energy demand of electricity. Similarly, the change for oil or gas heating systems to heat pumps will increase the electricity demand.

It is important to notice that this section reflects the current state of the calibration for the energy demand sub-model, which is still in the beginning. The next few months will show, which additional calibration parameters and changes are necessary.

4.3.3. Energy supply SD sub-model

Similar to the energy demand model, the calibration of this sub-model has not started yet. The energy supply sub-model developed in KNOWING is less complex in terms of the number of parameters, since it comprises a very aggregated view of the power production sector. In order to reproduce the main dynamics relevant in the context of KNOWING pathways, the installed capacity for fossil, hydro, wind and PV are modelled as stock variables, with the status quo (initial installed capacity) as common in put variables.

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[6] Household, Service, Transport & Industry

Table 4 - Variables for the Energy Supply SD sub-model

Energy supply sub-model			
SDM Variable Name	**Type**	**Related DM**	**Related DM Variable Name**
EN_TotalInvestmentCosts	KeyOut-endo	DM: IES-opt	Investment costs for electricity and DH (Use to be confirmed during calibration)
ES InstalledCapacity (fossile / hydro / wind / PV)	KeyOut-endo	DM: IES-opt	Installed capacity by technology
ES PowerProduction (fossile / hydro / wind / PV)	KeyOut-endo	DM: IES-opt	Power (& DH) production by technology
EN_GHGEmissions	KeyOut-endo	DM: IES-opt	Emissions for the electricity and DH
EN_ElectricityPrice	KeyOut-endo	DM: IES-opt	Electricity price (Use to be confirmed during calibration)
EN_DHPrice	KeyOut-endo	DM: IES-opt	DH price (Use to be confirmed during calibration)
List of calibration parameters for energy supply sub-model			
Parameter Name	**Type**	**Related SDM**	**Range of possible values**
ES CapacityUse (fossile / hydro / wind / PV)	CalPar-endo	SDM: EnergySupply	To be defined based on IES-opt results
ES ImportedElectricityMixFactor	CalPar-endo	SDM: EnergySupply	
ES PowerProductionDependency-OnClimate (fossile / hydro / wind / PV)	CalPar-endo	SDM: EnergySupply	

Brief discussion of example calibration parameters:

- ES CapacityUse (fossile / hydro / wind / PV): The use of capacity (i.e. the power production) for each technology depends on the installed capacity but also other constraints which should be reflected by this calibration parameter in a simplified way.
- ES ImportedElectricityMixFactor (kg CO2 per kWh of imported electrical energy) – to be used as calibration parameter if not obtained directly from DM runs
- ES PowerProductionDependen-cyOnClimate (fossile / hydro / wind / PV): This calibration parameter might mainly be relevant for renewables (hydro / wind / PV) and specifies how the production depends on climate variables (e.g. CDD affecting the PV production) – as in the SD sub-model this dependency is only considered on a highly aggregated level.

Additional calibration parameters related to measures (increase rate of hydro / wind / PV installed capacity) might still have to be defined if the corresponding rates cannot be obtained from DM runs directly.

4.3.4. Microclimate SD sub-model

The approach taken within the Microclimate SD sub-model for calibration against Palm4U results is based on trying to understand the correlation between common urban features and the 2m air temperature there locally. This has been started for Tallinn where the city area was divided in cells of defined size (refer to an illustration in **Figure 5**) where urban features (like water areas, green areas, etc.) are specified for each cell. The key output variables (2m Temp., UTCI) are then obtained for every cell in Palm4U, and classification criteria are defined to automatically allocate cells to chosen classes. Both the urban features (including suitable interventions) and the key output variables are then provided for the SD Model calibration for these classes (groups of “similar” cells) to allow for an aggregated assessment of the impact of relevant adaptation measures.

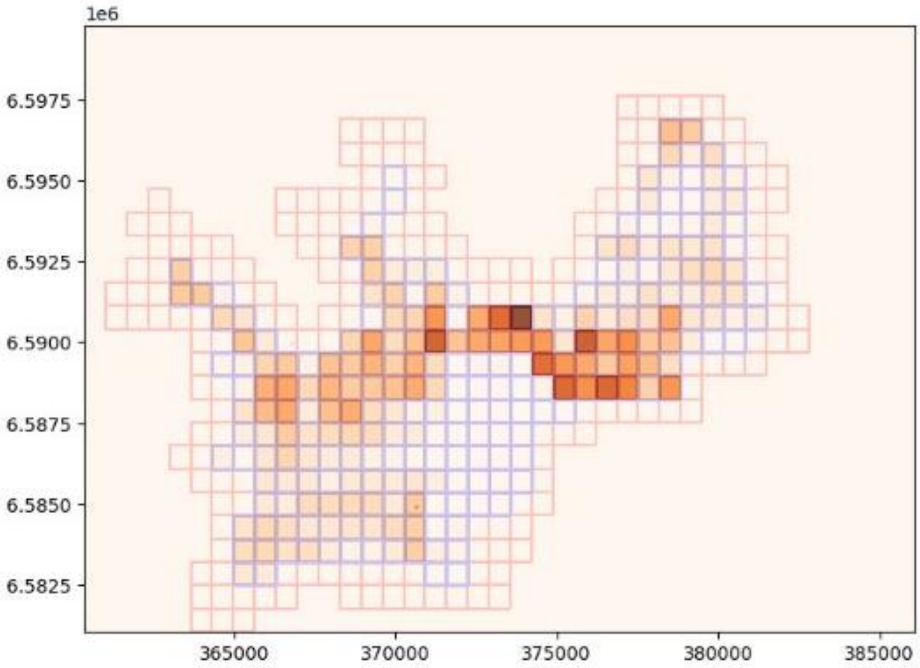

Figure 5: Illustration of the calibration approach for dividing the city area into cells and assigning similar cells to classes (example shown for the city of Tallinn).

Note that, according to the current state of analysis, following four criteria (urban features) will be used for clustering and assigning the cells into (most probably four) different classes:

- Leaf area density (related to but more significant than the number of trees)
- Mean building height
- Mean green area
- Sealed area (built up + paved)

These (common) input variables for class j (I_{ij}) are modelled as stock variables in the SD sub-model; the adaptation measures (planting new trees, new green areas, unsealing parking space, etc.) can then be represented as corresponding in-/out-flows [7]. As previously discussed for other sub-models, *common adaptation and mitigation measures* can be assumed here – which means that variables representing them can be directly taken over from domain model runs.

The dependency of key output variables (per class j) O_j on the input variables (meteorological inputs I_{met} and urban features I_{ij}) can then be expressed in the following way:

$$O_j = f(I_{met}) + \sum_{i=1}^{4} g_{ij}(I_{ij}),$$

where f and g are functions that are still to be parametrised – it might be feasible to assume them as linear functions.

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[7] More precisely, for the Leave area (density) the interventions only account for part of the inflow. In addition, the growth of maturing trees (and the corresponding development of leave area over time also has to be considered.

Table 5 - Variables for the Microclimate SD sub-model.

Microclimate sub-model			
SDM Variable Name	**Type**	**Related DM**	**Related DM Variable Name**
CL_SurfaceTemperature	KeyOut-endo	DM: PALM-4U	LST (Land Surface Temperature), not used for calibration
CL_AirTemperature	KeyOut-endo	DM: PALM-4U	Ta (Air Temperature)
CL_UniversalThermalClimateIndex	KeyOut-endo	DM: PALM-4U	UTCI (Universal Thermal Climate Index)
CL_PhysiologicalEquivalentTemperature	KeyOut-endo	DM: PALM-4U	PET (Physiological Equivalent Temperature), not used for calibration
List of calibration parameters for microclimate sub-model			
Parameter Name	**Type**	**Related SDM**	**Range of possible values**
Detailed definition outstanding (refer to description of approach in text above)	CalPar-endo	SDM: Microclimate	To be defined based on PALM-4U results

4.3.5. Health SD sub-model

As the data analysis and gathering for D-MERF (the DM for Health impacts) and HWLEM (Heatwave local effect model) has started with some delay, the specific calibration approach for this sub-model has not yet been defined. It still has to be decided which of the key output variables listed below are used for calibration.

Table 6 - Variables for the Health SD sub-model.

Health sub-model			
SDM Variable Name	**Type**	**Related DM**	**Related DM Variable Name**
PH_MinimumMortalityTemperature	KeyOut-endo	DM: D-MERF	Minimum mortality temperature (temp level associated to the least N of death cases)
PH_MortalityRate	KeyOut-endo	DM: D-MERF	Excess/Attributable mortality (to climate change)
PH_ RelativeRiskOfMortality	KeyOut-endo	DM: D-MERF	Relative risk of mortality (for the specific cohort, group, compared to overall population mortality)
CL_ ApparentTemperature	KeyOut-endo	DM: HWLEM	Tapp (Apparent Temperature)
PH_HospitalisationCosts	KeyOut-endo	DM: HWLEM	Hospitalization costs
List of calibration parameters for health sub-model			
Parameter Name	**Type**	**Related SDM**	**Range of possible values**
Detailed definition outstanding	CalPar-endo	SDM: Health	To be defined based on D-MERF results

4.3.1. Housing SD sub-model

In an initial SD model that was addressing the CIC Heat Waves & Health (“toy model”, no calibration against DM), a separate Housing sub-model has been introduced, modelling (primarily) the use of air conditioning and its interaction with PV production on (private) rooftops and green roofs, in this way connecting three central adaptation and mitigation measures addressed in this CIC.

In the context of calibrating the SD Model against relevant DMs, it still must be decided if this sub-model will be maintained as separate model, or it will be integrated into the Energy Demand sub-model, which covers the energy demand from all sectors, including heating and cooling for households.

Key output variables and calibration parameters are therefore not listed here.

4.3.2. Land Use SD sub-model

The Land Use SD sub-model calibration did not start so far; thus, the following table of variables is preliminary and will change during the calibration process.

Table 7 - Variables for the Land use SD sub-model.

Land use sub-model			
SDM Variable Name	**Type**	**Related DM**	**Related DM Variable Name**
LU_Carbon sequestration	KeyOut-endo	DM: CLUMondo	Tot. CO2/year
LU_Renewable energy production	KeyOut-endo	DM: CLUMondo	Wind energy production with the forest
LU_shares[LU_categories]	KeyOut-endo	DM: CLUMondo	land use shares (urban, cropland, forest land, others)
LU_cropProduction	KeyOut-endo	DM: CLUMondo	crop production
LU_woodProduction	KeyOut-endo	DM: CLUMondo	wood yield/production
LU_carbonSequestrationRate	KeyOut-endo	DM: CLUMondo	carbon sequestration rate
List of calibration parameters for land use sub-model			
Parameter Name	**Type**	**Source/ related SDM**	**Range of possible values**
LU_carbonSeqRate_perHa	CalPar-endo	SDM: Landuse	To be defined based on CLUMondo results
LU_cropProduction_perHa	CalPar-endo	SDM: Landuse	
LU_woodProduction_perHa	CalPar-endo	SDM: Landuse	
LU_UrbanLandUse_perCapita	CalPar-endo	SDM: Landuse	
LU_CropLandManagement_changes	CalPar-endo	SDM: Landuse	
LU_ForestLandManagement_changes	CalPar-endo	SDM: Landuse	

Brief discussion of example calibration parameters:

- LU_carbonSeqRate_perHa: This calibration parameter is used to calibrate the carbon sequestration over time. It shows the carbon sequestration per hectare for afforested or reforested areas. It is important to notice that this carbon sequestration per year differs over time, meaning depending, when the afforestation and reforestation was initialized and how it was done (all at once or incremental) defines the specific yearly total sequestration.
- LU_cropProduction_perHa: This is a parameter used to calibrate the yearly crop production over time per hectare of crop land. As climate change influences crop production, this parameter changes over time, reflecting the influence of climate change on soil fertility and growth.
- LU_woodProduction_perHa: This is a parameter used to calibrate the yearly wood production over time per hectare of forest land. As climate change influences wood production, this parameter changes over time, reflecting the influence of climate change on soil fertility and growth.

- LU_UrbanLandUse_perCapita: This calibration parameter is used to reflect the needs for Urban land for the population. Especially population increase triggers the need for new settlement (Urban) area, which influences the areas for crop or wood production.

Calibration parameters related to measures:

This measure related calibration factors reflect changes in crop and forest management practices as well as changes in the settlement structure.

- LU_CropLandManagement_changes: According to the climate change adaptation needs will this calibration parameter reflect the changes in crop production per hectare due to the intervention.
- LU_ForestLandManagement_changes: According to the climate change adaptation needs will this calibration parameter reflect the changes in forest production per hectare due to the intervention.
- LU_UrbanLandManagement_changes: This calibration parameter reflects interventions that change the need for settlement areas (Urban areas).

It is important to notice that this section reflects the current state of the calibration for the land use submodel, which is still in the beginning. The next few months will show, which additional calibration parameters and conceptual changes are necessary.

4.3.3. Flooding SD sub-model

The flooding SD sub-model explores surface water absorption dynamics in coastal cities by examining the interplay of various urban water management parameters. It addresses complex flooding events, including combined coastal, pluvial, and river floods. The model identifies and quantifies water stocks in key areas such as coastal flow, surface water, rivers/ponds, soil water, groundwater, city drainage systems, and water harvesting systems.

Centered on a process-based approach, the model assesses water inputs from rainfall and flooding, distributing them across primary urban water stocks, including soil and drainage systems. It uses natural processes like percolation, infiltration, and overflow, while excluding mechanical flows such as those driven by pumps.

The model is implemented using the SIMILE software by Simulistics and functions at both, the overall city level and more granular city subsections, for detailed analysis. Simulations are conducted in hourly increments over extended periods, facilitating thorough analysis and forecasting.

Table 8 - Variables for the Flooding SD sub-model.

Flooding sub-model			
SDM Variable Name	**Type**	**Related DM**	**Related DM Variable Name**
Surface water	KeyOut-endo	DM: ICM-Info	Water depth
Surface water	KeyOut-endo	DM: SFINCS	Water depth
List of calibration parameters for flooding sub-model			
Parameter Name	**Type**	**Related SDM**	**Range of possible values**
R	CalPar-endo	SDM: Flooding	0 - 1
W	CalPar-endo	SDM: Flooding	To be defined
Surface soil permeability	CalPar-endo	SDM: Flooding	0 – 1
Deep soil permeability	CalPar-endo	SDM: Flooding	0 – 1
Evp	CalPar-endo	SDM: Flooding	0 – 0.1

The main calibration parameters used for the flooding SD sub-model are:

- R: Parameter related to the runoff of surface water.
- W: Parameter used for estimating the amount of water in cubic meters coming from waves per time unit.
- Surface soil permeability: soil permeability at higher layers with values around 0,5, to be further specified during calibration.
- Deep soil permeability: soil permeability at lower layers.
- Evp: Evapotranspiration.

4.4. CICs

The KNOWING project considers three Climate Impact Contexts (CICs): (1) Heat Waves & Health, (2) Flooding & Infrastructure, and (3) Soil Fertility & Agriculture, which can be applied to four Demonstrator regions. Each CIC will be modelled using different configurations of the SD sub-models described in the previous section, depending on the hazards targeted in each CIC; for instance, the CIC Flooding & Infrastructure needs to use the flooding SD sub-model, but this won't be needed in the other CICs, on the other hand, the Land Use SD sub-model is relevant to the CIC Soil Fertility & Agriculture and not used in the other CICs as they focus more on urbanized regions. Nevertheless, there are three SD sub-models common to all CICs: the transport SD sub-model, the energy demand SD sub-model, and the energy supply SD sub-model.

Next, the generalized SD model structure will be presented per CIC. In the following conceptual diagrams, the squared elements represent data coming directly from a DM and they are not modelled as a SD sub-model, but the SD model requires them as input data. Therefore, no calibration is needed for those elements.

4.4.1. CIC Heat Waves & Health

The CIC Heat Waves & Health SD model can be simplified into several sub-models that will be interconnected, as shown in Figure **6**.

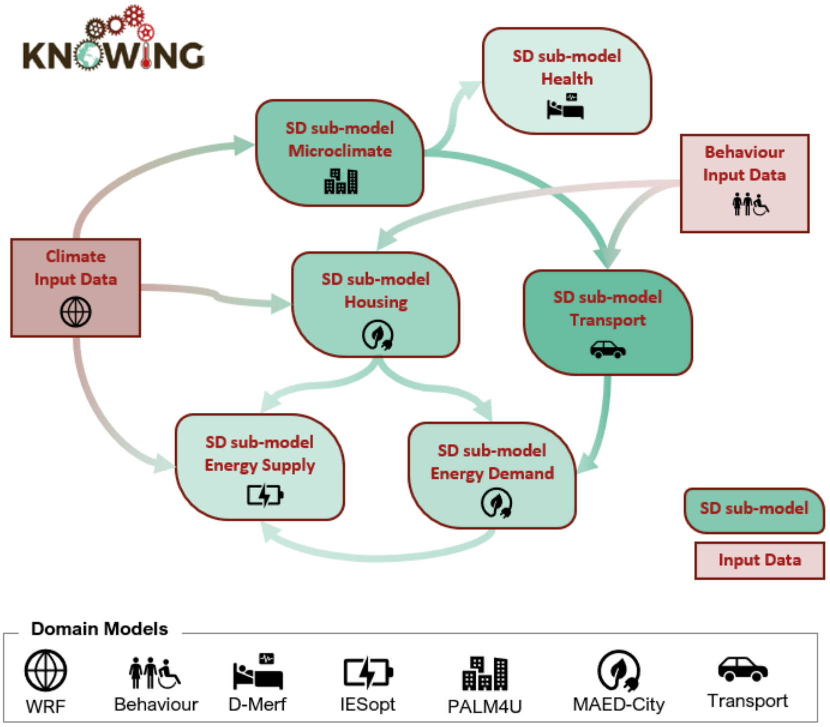

Figure 6 - CIC Heat Waves & Health sub-models and their corresponding DM.

Climate input data (on a regional level, 5-km-grid WRF data)[8] are a main driver for three sub-models: The microclimate sub-model (modelling the influence of land cover and urban features), the housing sub-model / energy demand sub-model (AC usage), and the energy supply sub-model (impact of climate change on renewable energy – PV, wind and hydro). From the climate sub-model, there is further link to the health sub-model (covering the impacts on public health), as well to the transport sub-model (influences on mode choice, impact of measures like street greening). The transport sub-model further provides inputs to the energy demand sub-model, which in turn provides input to the supply sub-model. Finally, the impact of both climatic changes and adaptation / mitigation measures (in the housing and transport sub-model) is also driven by behaviour input data[9].

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[8] Since there will no feedback to climate variables be modelled at this level, this is not considered as a sub-model within the KNOWING SD Model, but just as input data.

[9] Similar to the (regional) climate input data, it is assumed here that these behaviour data (coping typology) is not endogenous in the overall model, i.e. there is no feedback to change this. This assumption is still pending confirmation.

4.4.2. CIC Flooding & Infrastructure

The CIC Flooding & Infrastructure SD model can be simplified into several sub-models that will be inter-connected, as shown in Figure 7.

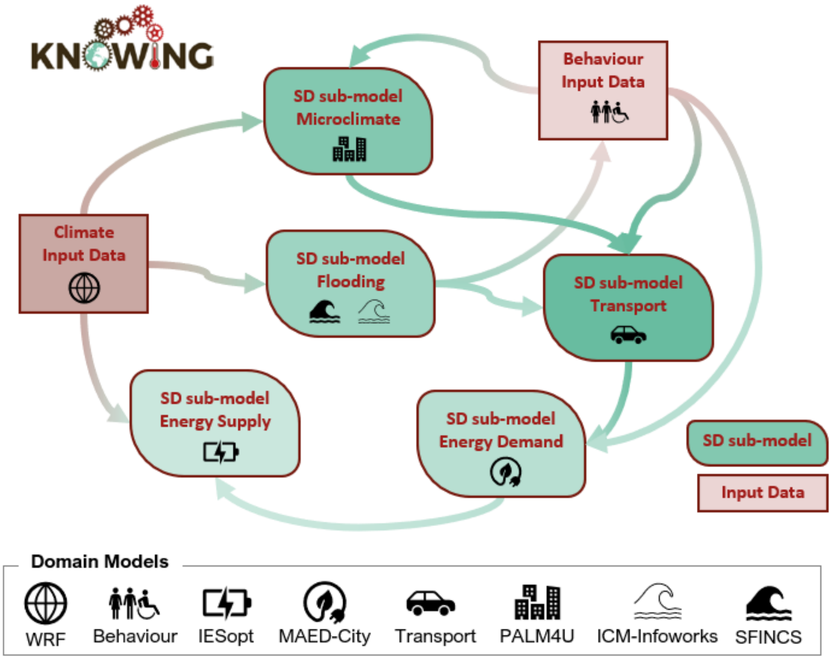

Figure 7 - CIC Flooding & Infrastructure SD Configuration and their corresponding DM.

Similar to the CIC Heat Waves & Health, Climate input data (on a regional level, 5-km-grid WRF data) are a main driver for three sub-models. Here the main focus is on the flooding sub-model which covers the level of impact of (coastal, pluvial and river) flooding events without and with a variety of feasible adaptation measures in place. This impact and / or the consequences of adaptation measures should also be considered as input in the transport model. There might also be direct relationships between the flooding sub-model and the microclimate sub-model (e.g. when applying Nature Based Solutions against flooding) as well as the energy supply sub-model (impact on power generation or distribution infrastructure), although these possible links are not shown in Figure 7. The remaining (CIC-independent) relationships are as described before.

4.4.3. CIC Soil Fertility & Agriculture

The CIC Soil Fertility & Agriculture SD model can be simplified into several sub-models that will be interconnected, as shown in the following image.

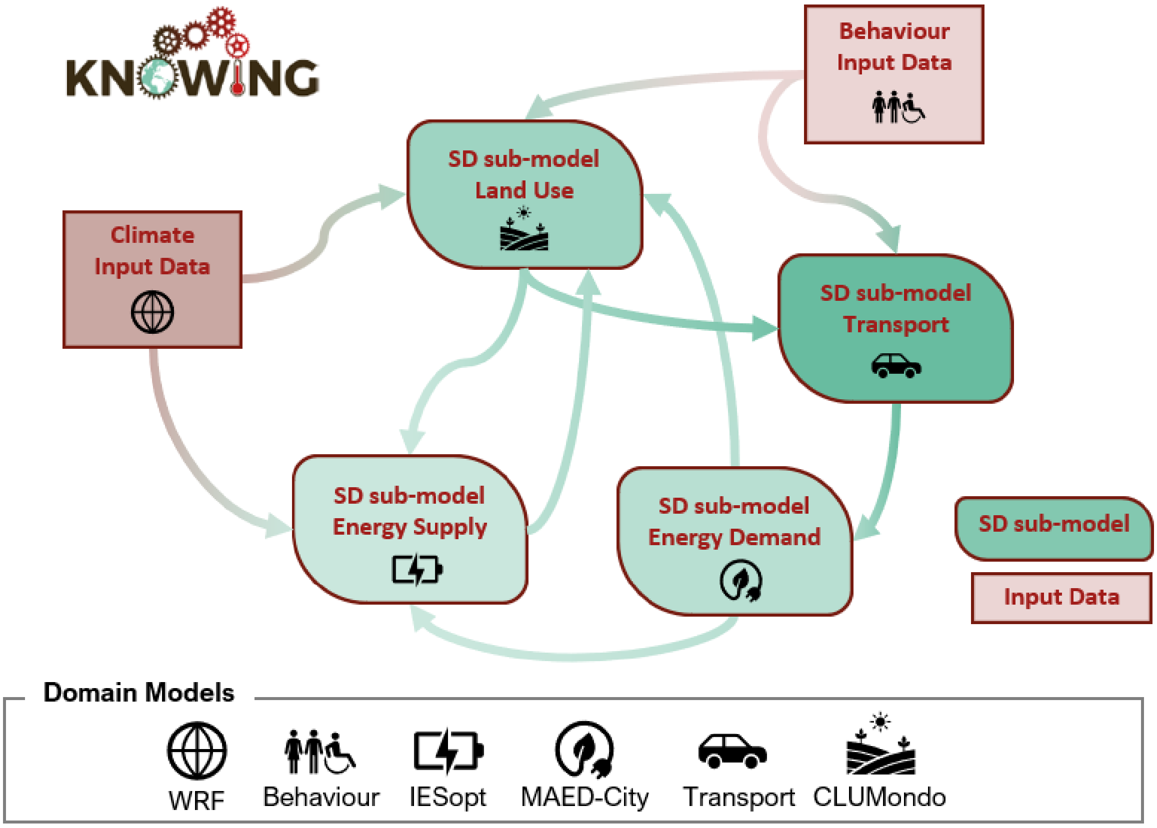

Figure 8 - CIC Soil Fertility & Agriculture SD Configuration and their corresponding DM.

On the one hand side there are direct effects of climate changes to the soil-fertility (Climate input data, crop production) and behaviour changes triggering different land use patterns. Furthermore, from the energy demand sub-model changes due to mitigation measures might significantly impact agriculture especially in regions as SWF.

5. Application to the KNOWING Demonstrator Models

The CICs can be applied to specific regions facing one or various climate hazards. In KNOWING, four different regions have been identified and they are used as demonstrators (refer to KNOWING D3.2-Chap.5.2 – KNOWING Regions – for detailed information on the demo regions). Table 9 shows the classification of the different DEMO regions and their associated CICs, note that Naples is a special case, as the CIC Flooding & Infrastructure is covered at DEMO level and the CIC Heat Waves & Health is considered as follower.

Table 9 – KNOWING DEMOs and CICs overview.

Region	Climate hazard(s)	CIC	Level
Tallinn	Extreme heat	CIC Heat Waves & Health	Demo
Granollers	River flood	CIC Flooding & Infrastructure	Demo
Naples	Coastal flood		Demo
	Extreme heat	CIC Heat Waves & Health	Follower
South Westphalia	Extreme precipitation Drought Extreme temperature	CIC Soil Fertility & Agriculture	Demo

In the rest of this chapter, we will go through all KNOWING DEMO regions and evaluate the completeness of the SD model configuration presented for each CIC in the previous section, the status of the available data provided by the different involved DMs. A common challenge for the calibration is the definition of the interfaces, for which the resolution of the data used in the SD model and the data provided by the DMs should be in a comparable scale. The particularities of each interface will be discussed in D2.4, as currently only very few data sets are available from the DMs.

5.1. Tallinn

Tallinn demonstrates the CIC Heat Waves & Heath. This demonstrator uses all SD sub-models specified in the general SD structure for this CIC (as outlined in 4.4.1). Table 10 shows the available data (as per submission date of this deliverable) for the planned scenario runs for each DM related to its SD sub-model. Currently, complete data availability is limited to the mobility DM, which is used for calibration of the transport SD sub-model. The DMs are currently conducting the simulations and the scheduled date for the availability of the results is also written in the table.

Table 10 - SD modelling for the DEMO region Tallinn and the available data.

CIC Heat Waves & Health SD sub-models	DEMO: Tallinn	Related DM	Scenario runs			
			Reference	2030	2040	2050
Transport	✓	Mobility	✓	✓	✓	✓
Energy Demand	✓	MAED-City	?	Not considered	Not considered	04/25
Energy Supply	✓	IES-opt	?	Not considered	Not considered	03/25
Microclimate	✓	PALM-4U	✓	✓	03/25	04/25
		HWLEM	05/25	Not considered	Not considered	07/25
Health	✓	D-MERF	✓	04/25	04/25	04/25
Housing	✓	MAED-City	?	Not considered	Not considered	04/25

5.2. Granollers

The climate hazard associated to Granollers is river flood and the flooding SD sub-model will use data provided by the ICM-Infoworks impact assessment DM. In the case of the DEMO region Granollers, although the SD configuration includes the transport SD sub-model, it is not considered due to the absence of mobility data for the city. Currently, only PALM-4U data is available for the reference run scenario.

Table 11 - SD modelling for the DEMO region Granollers and the available data.

CIC Flooding & Infrastructure	DEMO: Granollers	Related DM	Scenario runs			
			Reference	2030	2040	2050
Transport	o	Mobility	Not considered	Not considered	Not considered	Not considered
Energy Demand	✓	MAED-City	?	Not considered	Not considered	04/25
Energy Supply	✓	IES-opt	?	Not considered	Not considered	04/25
Microclimate	✓	PALM-4U	✓	Not considered	Not considered	04/25
		HWLEM	Not considered	Not considered	Not considered	Not considered
Housing	✓	MAED-City	?	Not considered	Not considered	04/25
Flooding	✓	ICM-Infoworks	03/25	Not considered	Not considered	05/25

5.3. Naples

Naples serves as a DEMO region for two CICs, but we only focus here on the CIC Flooding & Infrastructure, as CIC Heat Waves & Health is considered a follower demonstrator. The climate hazard in the case of Naples is caused by coastal flooding and the equivalent DM is the SFINCS. Table 12 shows the available data for Naples as DEMO for CIC Flooding & Infrastructure.

Table 12 - SD modelling for the DEMO region Naples and the available data.

CIC Flooding & Infrastructure	DEMO: Naples	Related DM	Scenario runs			
			Reference	2030	2040	2050
Transport	✓	Mobility	04/25	05/25	05/25	05/25
Energy Demand	✓	MAED-City	?	Not considered	Not considered	05/25
Energy Supply	✓	IES-opt	?	Not considered	Not considered	04/25
Microclimate	✓	PALM-4U	✓	Not considered	Not considered	04/25
		HWLEM	✓	✓	Not considered	✓
Housing	✓	MAED-City	?	Not considered	Not considered	06/25
Flooding	✓	SFINCS	03/25	03/25	03/25	03/25

5.4. South Westphalia

The CIC Soil Fertility and Agriculture is demonstrated in the region of South Westphalia. Currently, only data has been generated for the reference run scenario in the context of Land Use.

Table 13 - SD modelling for the DEMO region South Westphalia and the available data.

CIC Soil Fertility & Agriculture	DEMO: SWF	Related DM	Scenario runs			
			Reference	2030	2040	2050
Transport	✓	Mobility	03/25	04/25	05/25	05/25
Energy Demand	✓	MAED-City	?	Not considered	Not considered	05/26
Energy Supply	✓	IES-opt	?	Not considered	Not considered	05/25
Land Use	✓	CLUMondo	✓	06/25	06/25	06/25

6. Conclusions & Outlook

6.1. Results achieved so far and open questions

This deliverable presents the initial version of the KNOWING Impact Interaction Model Framework, outlining a structured approach to calibrating System Dynamics (SD) models with domain models (DMs) to improve the assessment of adaptation and mitigation strategies across three main Climate Impact Contexts (CICs). By addressing the three key objectives - developing a calibration concept, analysing key input and output variables, and providing conceptual diagrams for each CIC - we established a systematic methodology for integrating diverse modelling approaches that can be adapted to different regions and CICs.

The first objective*,* **developing a calibration concept**, has been achieved by designing a methodology that aligns SD models with DM outputs through a cross-calibration process. This ensures that the SD models can effectively incorporate domain knowledge and reflect the expected behaviour of key system variables. Additionally, we have introduced a structured calibration workflow that provides clear step-by-step guidance for model adjustments based on trusted reference baselines provided by the domain models.

The second objective, **analysing key input and output variables**, was accomplished by systematically reviewing the required data flows between DMs and SD sub-models for each CIC. We identified critical calibration parameters that influence the accuracy of the SD model outputs and provided the framework to examine the sensitivity of key system variables to different adaptation and mitigation pathways. This analysis lays the foundation for a more transparent and reproducible calibration process.

The third objective, **providing conceptual diagrams for each CIC**, has been realized by developing visual representations that illustrate the interactions between SD sub-models. These diagrams serve as a practical guide for implementing the calibration process across different demonstrator regions, ensuring consistency and comparability. By explicitly mapping the role of each model component, the diagrams facilitate the identification of dependencies, input requirements, and calibration targets.

Through these efforts, the deliverable establishes a comprehensive calibration framework that ensures consistency between SD and DM outputs, enabling a more accurate and scalable representation of climate impact dynamics. Furthermore, the conceptual framework allows for flexibility in integrating new data and insights, supporting future improvements and refinements. However, we are aware that the current approach still has some limitations. The following aspects remain as open questions – which are clearly beyond the scope of this deliverable, however they might to some extend be addressed by later deliverables:

- Scaling and Generalization: How can the calibration framework be extended beyond local and regional scales to ensure broader applicability across diverse geographical contexts?
- Addressing Geographical Bias: What strategies can be employed to mitigate geographical biases in domain model outputs and ensure more representative climate impact assessments?
- Improving Spatial Resolution: How can missing spatial information be effectively integrated to capture localized climate impact dynamics and their cascading effects across sectors?

- Stakeholder Integration: How can stakeholder input be systematically incorporated into the calibration framework to ensure that modelled adaptation and mitigation pathways align with real-world decision-making processes?
- Automation and Efficiency: To what extent can automation techniques (e.g., machine learning, optimization algorithms) improve the efficiency and robustness of the calibration process beyond the state-of-the-art methodologies provided by tools like Vensim?

6.2. Next Steps

The integration between SD sub-models and domain models remains a work in progress. Establishing well-defined interfaces is crucial for enabling seamless data exchange and ensuring consistency between models. Continued collaboration between modelling teams will be necessary to refine these connections. Additionally, at this stage, not all Demonstrators have sufficient data available for a complete calibration process. Additional data collection and validation efforts are required to enhance the reliability of the calibration framework. Future iterations will incorporate more robust datasets to improve accuracy and applicability.

While the calibration process is underway, integrating backcasting mechanisms has not yet been fully realized. Backcasting is essential for identifying pathways that meet long-term sustainability goals, and future work will focus on incorporating these mechanisms into the model to ensure it captures potential future scenarios effectively.

The current model framework does not yet fully account for rebound effects, where interventions intended to reduce environmental impact may lead to unintended increases in resource consumption or emissions. Future versions of the model framework will aim to include these dynamics, ensuring a more comprehensive understanding of the broader consequences of mitigation and adaptation measures.

These aspects will be further addressed in Deliverable 2.4 – “Expandable Impact Interaction Model Framework”, where the comprehensive approach to calibration as described in this deliverable will be applied using the domain model results from all KNOWING demonstrators.

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Annex A: Data Summary

No (new) data sets relevant to the KNOWING Data Management Plan were produced in preparation of this deliverable.

Security and Ethics:

The work performed for this Deliverable and the data used and produced are not considered sensitive in terms of ethics or security.

Table 27: Data used in the preparation of KNOWING Deliverable D2.3

Dataset name	Format	Size	Owner & re-use conditions	Potential utility within & outside of KNOWING	Unique ID
DataOverview_DM	Table .xlsx	139 kB	Bernadó, L.; consortium only	List of input-output variables for each Domain Model	
Modeling_schedule_per_model	Table .xlsx	27.8 kB	Scussolini, P.; consortium only	Live document with the current foreseen available simulations per DM and scenario	
Figures_D2.3	.pptx	0.99 MB	Bernadó, L.; consortium only	Document containing the figures used in this deliverable	

Annex B: Ethics Considerations

No relevant ethical areas for KNOWING were touched in preparation of this deliverable.

Human Participation:

The work does not involve human participants.

We confirm that:

- The project does not involve **children under the age of 14**, and minors over the age of 14 only participate with parental consent.
- No **persons in dependent positions or vulnerable individuals/groups** are involved in the project, so there is no relationship of dependency between participants and the research partners.
- Data is only processed in **anonymized or pseudonymized** form.

Personal Data:

No genetic, biometric, or health data are processed as part of the project.

Fair Benefit Sharing:

The research activities were not carried out in non-EU countries.

Annex C: Domain Models

Table 14 - Input and output variables for WRF Domain Model and their availability for the different DEMO regions

WRF Responsible institution: ENEA, AIT **Category: Climate model**			**Tallinn**	**Granollers**	**Naples**	**SWF**	**Comments**
DEMO regions involved			**x**	**x**	**x**	**x**	
Input data	***Variables***	***Units***					
	Meteorologic data:						
	relative humidity	kg/kg	x	x	x	x	from GCM MPI-ESM1-2-HR
	wind components	m/s	x	x	x	x	
	pressure	hPa	x	x	x	x	
	geopotential height	m	x	x	x	x	
	temperature	K	x	x	x	x	
	Topography	m	x	x	x	x	USGS topographic maps
	Roughness length	m	x	x	x	x	static input data - Satellite based
	Soil type	-	x	x	x	x	
	Land use	-	x	x	x	x	
	Albedo	%	x	x	x	x	
	SST (Sea Surface Temperature)	K	x	x	x	x	
	Tree areas:						
	LAI (Leaf Area Index)	m^2/m^2	x	x	x	x	static input data - Satellite based
Output data	***Variables***	***Units***					2D output fields will be used as input for PALM4U, SFINCS, ICM Infoworks, IESopt, CLUMondo, D-MERF, WWIII, MAED-city
	Meteorological data:						
	local precipitation	mm (cumulated over output time interval)	x	x	x	x	approx. 5 km, hourly (2D fields) or 3-hourly (3D fields)
	relative humidity	kg/kg	x	x	x	x	
	wind components	m/s	x	x	x	x	
	pressure	hPa	x	x	x	x	
	radiation and fluxes of short- & long-wave radiation	W/m^2	x	x	x	x	
	geopotential height	m	x	x	x	x	
	Ta (Air Temperature)	K	x	x	x	x	CDD as input to IES opt
	LST (Land Surface Temperature)	K	x	x	x	x	

Table 15 - Input and output variables for PALM-4U Domain Model and their availability for the different DEMO regions

PALM-4U Responsible institution: AIT, GST **Category: Climate model**			**Tallinn**	**Granollers**	**Naples**	**SWF**	**Comments**
DEMO regions involved			**x**	**x**	**x**		
Input data	***Variables***	***Units***					
	Meteorological data:						
	specific humidity	kg/kg	x	x	x		**From WRF**
	wind speed and direction	m/s	x	x	X		
	soil moisture	kg/kg	x	x	x		
	surface pressure	hPa	x	x	x		
	soil temperature	K	x	x	x		
	potential temperature	K	x	x	x		
	DEM (Digital Elevation Model)	m	x	x	x		External source
	Land use	-	x		x		Tallinn: the mapping of landuse classes from Estonian system to PALM. External source
	Buildings:						
	location	-	x	x	x		External source
	areas	m^2	x	x	x		
	height	m	x	x	x		
	type	-	x		x		Qualitative assessment. for Tallinn: only PALM building types 1, 2 (residential building < 1950, residential building 1950-2000) are used; a new building type for retrofitted type 2 buildings has been defined; Tallinn representatives provided input, where more type 1 or 2 buildings are located. Granollers, Naples: Owing to insufficient details on building construction and age, building type has been set constant (2) for all buildings.
	Tree areas:						
	location	-	x	x	x		External source
	height	m	x	x	x		
	type	-	x	x	x		External source Tallinn: for Orthophotos (private) trees default settings were taken, for Tree cadaster data the respective tree species or closest one was used
	LAI (Leaf Area Index)	-	x	x	x		**From PALM-4U**

	Water areas:						
	location	-	x	x	x		External source
	type		x	x	x		
Output data	***Variables***	***Units***					
	Meteorological data:						
	wind speed	m/s	x	x	x		Tallinn: 10m resolution in x,y,z; hourly
	cold air channels (air height, air velocity, air flow density)	m, m/s, kg/m^3					
	wind direction	°	x	x	x		
	radiation and fluxes of short- & long-wave radiation	W/m^2					
	Ta (Air Temperature)	K	x	x	x		
	UTCI (Universal Thermal Climate Index)	K	x	x	x		
	PET (Physiological Equivalent Temperature)	K	x	x	x		
	LST (Land Surface Temperature)	K	x	x	x		

Table 16 - Input and output variables for the D-MERF Domain Model and their availability for the different DEMO regions

D-MERF Responsible institution: ENEA **Category: Climate model**			**Tallinn**	**Granollers**	**Naples**	**SWF**	**Comments**
DEMO regions involved			**x**				
Input data	***Variables***	***Units***					
	***Meteorological data*:**						
	Tapp (Apparent Temperature) time series, monthly mean	°C	x				External source
	T (AirTemperature) time series, monthly mean	°C	x				
	Past Mortality, monthly time series (observations)	monthly absolute N of deaths distinguishing males/females	x				
Output data	***Variables***	***Units***					
	Minimum mortality temperature (temp level associated to the least N of death cases)	°C	x				
	Excess/Attributable mortality (to climate change)	fraction & %	x				
	Relative risk of mortality (for the specific cohort, group, compared to overall population mortality)	fraction & %	x				

Table 17 - Input and output variables for the HWLEM Domain Model and their availability for the different DEMO regions

HWLEM Responsible institution: UNINA **Category: Impact assessment model**			**Tallinn**	**Granollers**	**Naples**	**SWF**	**Comments**
DEMO regions involved			**x**		**x**		
Input data	***Variables***	***Units***					
	Meteorological data:						
	relative humidity	%	x		x		**From WRF**
	wind speed	m/s	x		x		
	heatwave duration	n. days	x		x		
	Ta (daily air temperature during HW)	°C	x		x		
	DSM (Digital Surface Model)	m	tbd		x		Tallinn: to be defined Naples: from Municipality of Napoli
	DTM (Digital Terrain Model)	m	tbd		x		
	Land cover (see HWLEM land use input documentation)	-	tbd		x		
	Exposure/Vulnerability information:						
	distribution of the population	n. people (sub-municipal scale)	tbd		x		The resolution of the results depends on the available resolution of the input e.g. in Naples the cell is 125m
	composition of the population (age groups)	-	tbd		x		Tallinn: to be defined Naples: from Municipality of Napoli
	population income	€ (sub municipal scale)	tbd		x		
	Human health intervention costs:						
	average cost per hospitalisation stays	€/hospitalisation stays	x		x		Model preset
Output data	***Variables***	***Units***					
	Meteorological data:						
	Tmrt (Mean Radiant Temperature)	°C	🟥		x		
	UTCI (Universal Thermal Climate Index)	°C	🟥		x		
	Tapp (Apparent Temperature)	°C	🟥		x		
	Hospitalization costs	€	🟥		x		

Table 18 - Input and output variables for the ICM InfoWorks Domain Model and their availability for the different DEMO regions

ICM InfoWorks Responsible institution: AQUATEC **Category: Impact assessment model**			**Tallinn**	**Granollers**	**Naples**	**SWF**	**Comments**
DEMO regions involved				**x**			
Input data	***Variables***	***Units***					
	Meteorological data:						
	local precipitation (daily, hourly, minutely extreme events)	mm		x			External source
	DTM (Digital Terrain Model)	m		x			
	Drainage system network	-		x			External source (Besos Tordera river basin Consortium)
	Land use:						
	infiltration rate	-		x			External source
	hydraulic roughness	-		x			
	cadastral data	-		x			
	Damage quantification of past events	-		x			
	Flow damage curves	-		x			
	Population:						
	density distribution	n. people/m^2		x			External source
	demographic data (influencing vulnerability maps)	-		x			External source; parcel of land granularity (asset, building...)
Output data	***Variables***	***Units***					
	Hazard profile (water depth, velocity)	m, m/s		x			
	Risk profile:						
	Risk maps	**-**		x			
	tangible damage	€		x			
	intangible damage (risk perception-related)	-		x			

Table 19 - Input and output variables for the SFINCS Domain Model and their availability for the different DEMO regions

SFINCS Responsible institution: VU **Category: Impact assessment model**			**Tallinn**	**Granollers**	**Naples**	**SWF**	**Comments**
DEMO regions involved					**x**		
Input data	***Variables***	***Units***					
	Meteorological data:						
	local precipitation	mm/h			x		**From WRF** (5km output)
	Other:						
	River discharge	m^3/s			x		External source (glofas), but it doesn't apply for Napoli
	Local sea level	m			x		External source (GTMS, Muis et al., 2020)
	Significant wave height	m			x		External source (ERA5)
	Elevation	m			x		External source, combined data set (local lidar high-res data (1 m) + FABDEM)
	Land use	categorical			x		External source (Cop_21_R - local Italian product (10m))
	infiltration rate	mm/hr			x		External source (gcn250 - global curve number dataset (Jaafar et al. 2019))
	hydraulic roughness	$s/m^{1/3}$			x		External source (Cop_21_R - manning coefficients based on land use)
Output data	***Variables***	***Units***					
	Flood maps (flooded areas and depth)	m^2, m			x		Raster cell (20m)

Table 20 - Input and output variables for the CLUMondo Domain Model and their availability for the different DEMO regions

CLUMondo Responsible institution: VU **Category: Sectoral model**			**Tallinn**	**Granollers**	**Naples**	**SWF**	**Comments**
DEMO regions involved						x	
Input data	***Variables***	***Units***					
	Tot. CO2/year	Mg C				x	External source
	monthly precipitation	mm				x	Using external but waiting for climate data from KNOWING partners
	total yearly precipitation	mm				x	
	evapotranspiration	-					
	Ta (Air Temperature)	K				x	Using external but waiting for climate data from KNOWING partners
	Slope	%				x	External source
	Soil texture (i.e., sand, silt, clay) and other soil properties (e.g., cation exchange capacity)	%				x	
	Soil depth	cm				x	
	CORINE Land cover	100m res				x	External source (CORINE land cover served as the base then certain covers were merged, or extended using additional data (such as forest species data))
	Current C flux	Mg C/ha/yr				x	External source
	Current C stock (above, below, organic layer, soil)	Mg C/ha				x	
	population density	pop/km2				x	
	pH	value/100m				x	
	Nitrogen	ratio/100m				x	
Output data	***Variables***	***Units***					
	Tot. CO2/year					x	
	land use shares (urban, cropland, forest land, others)	ha				x	
	biodiversity	indicator/ha				🟥	Attribute 'potential' biodiversity as a loose way to gauge those impacts
	crop production	tons/yr				x	
	wood yield/production	tons/yr				x	
	water runoff	m^3/yr				x	
	carbon sequestration rate	tC/yr				x	
	carbon sequestered (total)	tC				x	

Table 21 - Input and output variables for the Transport Domain Model and their availability for the different DEMO regions

MATSim & PTV Visum Responsible institution: AIT **Category: Sectoral model**			**Tallinn**	**Granollers**	**Naples**	**SWF**	**Comments**
DEMO regions involved			**x**		**x**	**x**	
Input data	***Variables***	***Units***					
	Road network	-	x		x	x	External source
	Public transport network & timetables	-	x		x	x	
	POIs (Points of Interests), activity-locations	-	x		x	x	
	Population data:						
	Composition and distribution	-	x		x	x	External source
	Employment rates	-	x		x	x	
	Car ownership rates	-	x		x	x	
	Home/work typology	-	x		x	x	
	Mobility surveys / Other transport related data:						All the data below are only available for the status quo
	origin-destination matrices	n. of person-trips, vehicles per OD-relation	x		?	x	if available for calibration … not mandatory
	mobility behaviour	-	x		x	x	External source
	socioeconomic indicators	-	x		x	x	
	Travel cost profile	€/transport mode	x		x	x	
	Emission factors per transport system	g/km	x		x	x	
	Private transport vehicle fleet composition	-	x		x	x	
	Traffic counts	n. of vehicles, passengers	x		x	x	
Output data	***Variables***	***Units***					
	Territorial road-based CO2	kt-CO2/d and yr	x		x	x	
	Tot. distance travelled per transport mode	km/transport mode/d and yr	x		x	x	
	Tot. time travelled per transport mode	h/transport mode/d and yr	x		x	x	
	Modal split	n. of trips per mode [%]	x		x	x	
	Network loads	n. of vehicles per link/d	x		x	x	

Table 22 - Input and output variables for the MAED-city Domain Model and their availability for the different DEMO regions

MAED-city Responsible institution: AIT **Category: Sectoral model**			**Tallinn**	**Granollers**	**Naples**	**SWF**	**Comments**
DEMO regions involved			**x**	**x**	**x**	**x**	
Input data	***Variables***	***Units***					
	Demography, social parameters						
	Total population	Million €t*km/yr	x	x	x	x	External source
	family size	person/dwelling	x	x	x	x	
	Tot. dwelling number	n. dwelling	x	x	x	x	
	Distribution of building stock by building type (houses)	%	x	x	x	x	
	potential and participating labour force	%	x	x	x	x	
	floor area per employee (service sector)	m^2/person	x	x	x	x	
	growth rate/year	%	x	x	x	x	
	labour force in the service sector	%	x	x	x	x	
	Technological parameters						
	Distribution of service sector by type of activities	%	x	x	x	x	External source
	Heating Degree Days (HDD)	°C day	x	x	x	x	**From WRF**
	Average dwelling floor area by building type	m^2	x	x	x	x	External source
	Heat loss rate per building type	W/m2*K	x	x	x	x	
	Annual useful energy demand for AC per building type	kWh/yr	x	x	x	x	
	Dwelling factors for cooking, hot water and appliances	kWh/dw/yr	x	x	x	x	
	Penetration rate of the energy carriers by end-use category of heating demand (building and industry sectors)	%	x	x	x	x	
	Energy efficiency by fuel type and by end-use category of heating demand (building and industry sectors)	%	x	x	x	x	
	Total freight-kilometres in terms of annual average distance per ton of good	tkm/yr	x	x	x	x	**From MATSim & PTV Visum**
	Vehicle load factor	person/vehicle	x	x	x	x	
	Modal split of freight transport	%	x	x	x	x	
	Average annual distance travelled (inter and intracity)	km/person/yr	x	x	x	x	External source
	Energy intensity by mode of passenger transport	kWh/100-km	x	x	x	x	
	Energy intensity by mode of freight transport	kWh/100-tkm	x	x	x	x	
	Economic Parameters						
	Annual useful energy intensity of industry subsector	kWh/€/yr	x	x	x	x	External source
	Tot. GDP annual average distance per mass	Million €t*km/yr	x	x	x	x	
	Tot. GDP	%	x	x	x	x	
	Tot. GDP growth rate/year	%	x	x	x	x	
	Sectoral GDP	%	x	x	x	x	

	Sectoral GDP growth rate/year	%	x	x	x	x	
Output data	***Variables***	***Units***					
	Tot. CO2/year	kt-CO2/yr					
	Sectorial CO2/year	kt-CO2/yr					
	Tot. final energy demand by fuel type/year	MWh/yr	x	x	x	x	
	Sectorial final energy demand by fuel type/year	MWh/yr	x	x	x	x	
	Sectorial useful energy demand by fuel type/year	MWh/yr					
	Sectorial useful energy demand by fuel type/year	MWh/yr					

Table 23 - Input and output variables for the IES-opt Domain Model and their availability for the different DEMO regions

IES-opt Responsible institution: AIT **Category: Sectoral model**			**Tallinn**	**Granollers**	**Naples**	**SWF**	**Comments**
DEMO regions involved			x	x	x	x	
Input data	***Variables***	***Units***					All variables are by 2050
	Transition network capacity (between DEMO reg. and outside)	MW	x	x	x	x	External source
	Transition network investment costs	€/MW	x	x	x	x	
	Annual electricity and district heating demand by sector (industry, residential and service) and end use (e.g.space heating, electric vehicles etc..)	MWh	x	x	x	x	**From MAED-City**
	Hydrogen demand by sector		x	x	x	x	
	Weather-dependent hourly time series of PV, wind, hydro generation	MWh	x	x	x	x	External source
	Electricity and heating/cooling demand profiles	-	x	x	x	x	
	Weather-dependent time variation of PV, wind, hydro generation	MW	x	x	x	x	
	Hourly time series of Direct Normal Irradiance (DNI) and Global Horizontal Irradiance (GHI)	W/m2	x	x	x	x	**From WRF**
	Hourly wind speed at 150 metres above ground level	m/s	x	x	x	x	
	hourly time series of air temperature at 2 m above ground level	°C	x	x	x	x	
	Hydro inflow (daily mean river discharge in m^3/s (weekly data)	m3/s				x	External source
	Max. realisable wind potential	MW	x	x	x	x	External source **SWF: From CLUMondo** (land use for wind)
	Max. realisable PV potential	MW	x	x	x	x	External source
	Max. realisable hydro potential	MW				x	
	Techno-economic parameters of the electricity, heating and storages technologies (e.g. CAPEX, OPEX, efficiency, lifetime...)	Different unit depending on the parameter	x	x	x	x	
	Fuel prices	€/MWh	x	x	x	x	
	Fuel availability	-	x	x	x	x	
	Taxes and subsidies	€/MW or €/MWh	x	x	x	x	
	CO2 prices	€/ton CO2	x	x	x	x	
Output data	***Variables***	***Units***					
	Investment costs for electricity and DH	€	x	x	x	x	
	Electricity and DH prices	€/MWh	x	x	x	x	
	Installed capacity by technology	MW	x	x	x	x	
	Power & DH production by technology	MWh	x	x	x	x	
	Fuel consumption for electricity and DH	MWh	x	x	x	x	
	Emissions for the electricity and DH	tons CO2	x	x	x	x	