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# *Report with recommendations of feasible combinations of regional mitigation measures for each NUTS3 region*

***D4.3***

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LOCALISED

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# Executive Summary

Deliverable 4.3, “Feasible combinations of mitigation measures”, suggests feasible combinations of regional emission reduction (mitigation) measures for all sectors for each NUTS3 region.

This version builds upon the preliminary release by resolving a number of significant issues previously present in the model ETHOS.MIDAS. ETHOS.MIDAS is a regional optimisation model for determining suitable measures for a given region to reach climate mitigation and climate adaptation goals. It uses the LOCALISED Data Sharing Platform (D3.4) to collect regional data and pathways and a large measure database (D4.1) of hundreds of individual measures to figure out pathways to net-zero and combinations of feasible mitigation and adaptation measures. In this version of the deliverable, major bugs have been addressed, improving the model's robustness and reliability. Additionally, key technical challenges have been overcome: data issues related to disaggregation have been mitigated, the stability of the genetic algorithm used for optimization has been substantially improved, and several aspects of the model’s calculation logic have been corrected. As a result, the entire toolchain is now functioning as intended, producing consistent and accurate results across all European regions.

This deliverable consists of this report and an Excel Table detailing the emission savings, the investment and the capacity factors for all measures for all regions. The Excel table contains the balanced scenario: It tries to balance costs and total emissions until 2050. This report itself shows a summary of the results for two example regions, one country and then all of the EU to give an impression of the current state of the measure recommendations.

The improvements also address previously identified disaggregation-related issues, which stemmed from:

- Incomplete regional constraint data due to limited availability of high-resolution datasets, which had constrained accurate implementation of some mitigation measures.
- Limited granularity in key variables, such as the inability to distinguish between residential and non-residential buildings.
- The inherent imprecision of disaggregation techniques relying on sparse open datasets at LAU and NUTS3 levels.

Ongoing efforts in Work Package 3 (WP3) have contributed significantly to resolving these challenges, including the integration of improved proxies and updated datasets. For more technical details, see Deliverables D3.1 and D3.3. The outputs of this deliverable are critical for Work Package 8 (WP8), where the CAST tool will utilize the optimization results. Furthermore, it informs subsequent WP4 tasks and deliverables, including T4.4 (The application programming interface) and D4.5 (Report of risk and vulnerability levels in each NUTS3 region).

# 1 Introduction

This deliverable is the outcome of Task T4.2 "Modelling, Regional Target Matching for mitigation, and Best Practice" of the LOCALISED project. The primary aim of this task is to support local and regional authorities in identifying feasible mitigation measures, customized to the unique socio-economic and environmental contexts of each region, while considering best practices from other regions and existing datasets.

A key element of Task 4.2 is the development of the modeling framework 'MIDAS' that translates mitigation targets (derived from WP3) into cross-sectoral combinations of suitable measures for each region and calculates costs and remaining emissions. 'MIDAS' uses a genetic algorithm to match measures to the pathways, which will help identify the most suitable set of measures by evaluating trade-offs between different mitigation options. This ensures that decision-makers have a clear understanding of the compromises involved, thus making these trade-offs transparent to end users. This process is supported by a comprehensive database of mitigation measures, defined in Task 4.1 (D4.1). Additionally, this approach provides local and regional authorities with a selection of best practices, shaped by ongoing feedback from Work Packages 5, 6, and 7, ensuring that the selected measures are based on the latest insights into climate impact and governance structures.

This deliverable utilizes the extensive database available in the Data Sharing Platform (DSP) from WP3, which brings together decarbonization pathways for all EU-27 member states (WP2) alongside a variety of regional datasets. By leveraging this information, the model allows regions to evaluate and select mitigation strategies that are not only feasible but also tailored to their specific needs and circumstances.

# 2 MIDAS

## *2.1 Goals of Midas*

MIDAS (Modular and Integrated Decarbonization and Adaptation Solver) is a regional climate policy optimization tool designed to operate at the NUTS-3 or LAU regional scale. It uses a genetic algorithm, allowing for the generation of solutions aimed at achieving decarbonization targets in line with EU27 climate legislation. These solutions are derived from downscaled decarbonization profiles and provide regions with actionable pathways to meet their climate goals.

The MIDAS model operates by optimizing several key objectives, including minimizing investment costs, reducing emissions, addressing climate vulnerability, and mitigating adverse social impacts. The model uses a diverse portfolio of mitigation measures and calculates thousands of combinations of measures with varying capacity factors to generate feasible and effective solutions for regional policymakers and stakeholders.

Since different users might have needs for different scenarios, one of the core ideas of MIDAS is not to generate a single solution, but to generate multiple solutions along a multi-dimensional pareto front and then offer the choice of the scenario to the user. This avoids the challenge of weighing costs, emissions, vulnerability and social impacts against each other, which can be highly controversial. The scenarios provided by MIDAS include economic, sustainable, equitable, resilient, trajectory following, and balanced approaches, each offering unique insights based on the particular optimization goal. Table 1 breaks down each scenario, highlighting the specific focus and goal for each approach within the MIDAS model.

Table 1: Overview of MIDAS Model Scenarios and their Objectives

| Scenario | Aim |
|---|---|
| Economic | Minimizes the overall investment cost required for the implementation of mitigation measures. It considers both capital and operational costs, scaled over the entire analysis period (2020–2050). |
| Sustainable | Focuses on minimizing emission production within the shortest possible time frame. The goal is to reduce the absolute number of emissions over time, ensuring rapid decarbonization. |
| Equitable | Prioritizes minimizing the social mal-effects of mitigation measures. It considers impacts on vulnerable communities, aiming for a fair and just transition, as defined by the LOCALISED social equity framework. |
| Resilient | Aims to minimize the anticipated risk of climate impacts by addressing vulnerabilities. It calculates the risk of adverse climate outcomes and adjusts mitigation measures accordingly. |
| Trajectory Following | Ensures the solution aligns closely with regional decarbonization pathways by minimizing deviations from the desired trajectory, using the Symmetric Mean Absolute Percentage Error (SMAPE). |
| Balanced | Seeks to provide an optimal combined solution by balancing all the objectives (investment cost, emissions reduction, social impact, and climate risk) to deliver a well-rounded result. |

One important detail about MIDAS is that it works in slices of five years, so it calculates the optimal measure calculation for 2025, 2030, 2035, 2040, 2045 and 2050. A time simulation inside a single year to calculate seasonal storage for example is not implemented though, since it’s assumed that energy storage is not going to be implemented on a regional level, but that for example seasonal hydrogen storage is going to be a national or even cross-european project.

The way MIDAS addresses local differences in costs is in two different ways: for generic measures, there is a purchasing power module that uses sector-specific purchasing power data to adjust costs. The second way is that the measure database supports sub-measures with geographic restrictions. For example, renovations measures for the main climate zones in Europe have been defined, since an energetic renovation in Norway has different requirements than in Spain.

Additionally, MIDAS has a secondary function in the background of CAST: if users modify a given measure set, add new measures or delete measures, it performs an analytical calculation of the changed measure set and the impacts of it.

## *2.2 Current Development Status*

As of this version, the core functionality of MIDAS is complete and production-ready. Major improvements have been implemented since the preliminary version, addressing previously identified issues in mitigation optimization, the measure database, and model stability. These enhancements significantly improve model robustness, computational efficiency, and output quality.

### *2.2.1 Mitigation Improvements*

The key improvements that have now been fully implemented include:

- **Optimization of the measure database**: In the earlier version, several emission-producing assets—particularly in the industry and buildings sectors—were not adequately addressed by mitigation measures. This gap in coverage led to an overreliance on Direct Air Capture (DAC) as a fallback to meet emission targets. To address this, new mitigation measures have been added to fill these sectoral gaps, allowing the model to pursue more realistic and diverse mitigation strategies. As a result, the reliance on DAC has significantly declined. In addition, the measure database has been streamlined by merging or clustering redundant or overlapping entries—especially in sectors like transport, where measures were previously too fine-grained. This reduction of the solution space improves computational efficiency without sacrificing model diversity. Where appropriate, soft constraints or penalties are used instead of hard exclusions, enabling the model to deprioritize, rather than eliminate, less suitable solutions (e.g., afforestation in water-scarce regions).

- **Calculation logic refinements**: Earlier issues where Direct Air Capture (DAC) was overly relied upon in certain regions have been corrected. Adjustments to optimization parameters and the measure set ensure that DAC is now treated as a last-resort option, aligning with realistic mitigation pathways.

- **Energy sector modeling enhancements**: The treatment of the energy sector has been significantly refined. The model now better accounts for cross-regional energy exchange, particularly in urban regions with limited local generation capacity. This makes the energy transition pathways more accurate and spatially realistic.

- **Stabilization of optimization results**: The genetic algorithm, while inherently heuristic, has been stabilized through improved parameter tuning and solution space management. Repeatability of results across multiple runs has increased, supporting more reliable scenario comparison and analysis.

- **Sensitivity analysis framework**: A structured approach to sensitivity analysis has been implemented. This allows a more thorough understanding of model behavior and helps prioritize high-impact parameters for future refinements.

These improvements have been applied and validated through extensive testing and systematic quality checks. With these corrections, the model is ready to support final deliverables and further applications across the project.

### *2.2.2 Further Development*

While MIDAS is now production-ready and fully supports mitigation modeling, some features planned for future deliverables are still under development:

- **Adaptation measures**: Core functionality for adaptation planning is mostly in place but requires further data integration and validation to become fully operational. These elements are targeted for future deliverables such as **D4.5**.

- **Social indicators**: Features related to equity, vulnerability, and other social indicators are planned but not yet implemented. These will be addressed in upcoming phases of the project.

## *2.3 Inputs to Midas*

MIDAS pulls from two main data sources: The LOCALISED Data Sharing Platform (DSP) of WP3 and the LOCALISED Measure Database (WP4). This section will briefly describe how the measure database is extended and how the DSP is used in MIDAS:

### *2.3.1 Measure Database*

In previous work in WP4, a comprehensive measure database that contains over 400 individual measures for mitigation and adaptation had been created. In T4.2, the relevant mitigation measures were quantified further, and additional conditions were defined. For example, for every measure one or more indicators were defined that limit the how much of the measure can be applied in a given region, which indicators are influenced by a measure by how much, which stakeholders have to pay how much, what the TRL level of the measure is, what SOIs are affected and much more. In Appendix 1 is a full measure definition supplied as an example in the JSON format as used in the model. Additionally sub-measures for specific countries or regions were defined and quantified as needed, to correctly model for example changing costs or different building stock situations in different regions of Europe.

### *2.3.2 LOCALISED Data Sharing Platform*

MIDAS draws regional data from the LOCALISED data sharing platform using REST calls. One call provides every single data point that MIDAS needs to perform the calculation. The database is described in more detail in D3.2 and D3.3. The exchange format for the data is JSON, which makes it convenient to reuse in other applications.

# 3 Modelling Principles of MIDAS

## *DSP-Measure Database-Model Relationship*

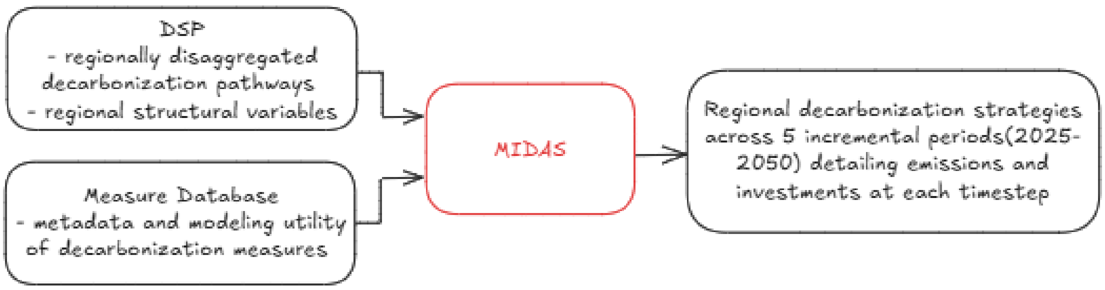


Fig.1: Overview of the relationship between the DSP data, the decarbonization Measure Database, and the MIDAS model

MIDAS is a data-driven, file-based optimization model designed to support regional decarbonization efforts by integrating information from two primary sources: the Measure Database and the Data Sharing Platform (DSP). The basic structure is showing in Fig. 1. These datasets provide the foundational input parameters necessary for MIDAS to model mitigation strategies and optimize the selection of feasible decarbonization measures for each region. It serves as a computational bridge between regional emission inventories (provided by the DSP) and feasible decarbonization measures (stored in the Measure Database), ensuring that each region receives tailored and implementable solutions that are both technically feasible and policy-compliant.

The DSP supplies key regional datasets, including:

- Baseline emissions for different sectors.
- Energy demand and resource availability for each region.
- Decarbonization targets aligned with the EU's climate policies.
- Disaggregated regional pathways derived from the EUCalc model, ensuring that the transition strategies align with high-level European decarbonization objectives.

The core function of MIDAS is to match the appropriate mitigation measures in the measure database to the relevant DSP data in order to identify optimal and regional specific decarbonization pathways. This process ensures that regional emissions can be progressively reduced from their current status quo to achieve net-zero emissions by

2050. However, this matching process is non-trivial because each measure must be correctly linked to the specific emission sources or energy assets it affects. The metadata and attributes of all measures, as outlined in Deliverable D4.1, play a crucial role in this alignment.

The primary objective of mitigation measures in MIDAS is to reduce sectoral emissions from baseline levels to net-zero by 2050. However, mitigation measures do not directly eliminate emissions; their effectiveness depends on the emission intensity of the energy asset they replace or influence. To account for this, MIDAS employs a systematic modeling approach that quantifies the emission impacts of each mitigation action by linking them to specific emitting assets.

Each mitigation measure is assigned an implementation impact on a designated energy asset, enabling the model to estimate emission reductions resulting from technology substitution. For example, a certain area of rooftop solar PV can generate 1 kWh of electricity under ideal conditions. If it replaces 1 kWh of electricity generated from fossil gas (represented as the variable "`elc_energy_production_fossil_gas`"), and that gas-based electricity production emits 180 g $CO_2$, then the substitution effectively eliminates 180 g $CO_2$ from the system.

This relationship is illustrated in Fig. 2. The figure shows how electricity production from fossil fuels (gas, oil, coal) contributes to sectoral $CO_2$ emissions through asset-specific emission intensities (e.g., `elc_emissions_CO2e_fossil_gas`). These emissions are then aggregated to compute total electricity-related $CO_2$ emissions (`elc_emissions_CO2e`). By capturing these interdependencies, MIDAS applies a normalization process to ensure consistent and accurate representation of emission reductions across various mitigation pathways. This structured framework supports scientifically rigorous and regionally relevant decarbonization planning.

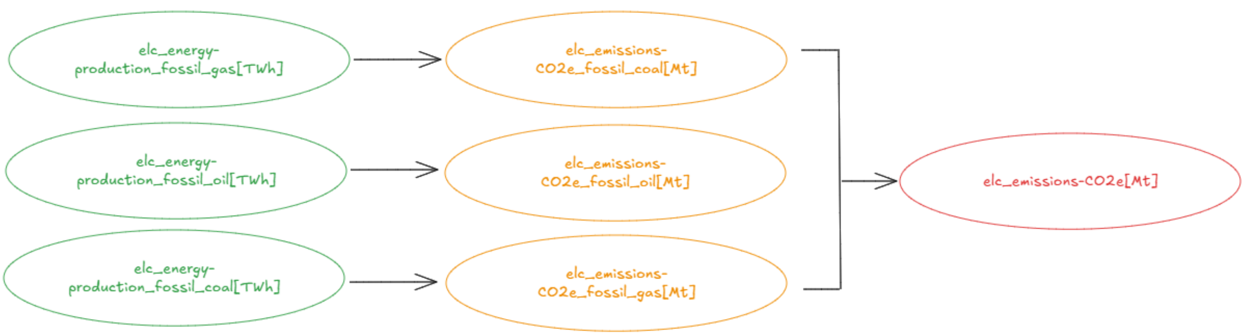


Fig. 2: Flow diagram illustrating how electricity production from fossil fuels (gas, oil, coal) contributes to sectoral $CO_2$ emissions within the MIDAS model.

To enable effective interaction between mitigation measures and the asset-level data within the DSP (Data and Scenario Platform), a new column titled 'Offset_KPIs' has been introduced in the measure database (Excel sheet). This column serves to establish explicit linkages between each measure and the specific assets—either physical (e.g., vehicles) or resource-based (e.g., electricity production)—that are associated with direct emissions. In some cases, the emission variable itself is listed directly. For instance, the measure with ID M153.0, which refers to the installation of Utility PV - Single Axis Tracking, mitigates emissions by displacing electricity generation from fossil-based sources such as coal, gas, and oil. These energy production assets are linked in the Offset_KPIs column, as they are directly responsible for $CO_2$ emissions. In other cases, such as direct air capture or efficiency improvement measures, the linkage is made directly to the emission nodes in DSP rather than through an intermediary asset. For these types of measures, the emission reduction occurs independently of a physical asset and is therefore recorded in Offset_KPIs as a direct emission variable.

The measure database is designed to be globally applicable and does not inherently distinguish between different regions. However, the implementation of any given mitigation measure is dependent on the availability of region-specific resources, which are provided by the DSP (Data and Scenario Platform). To ensure that the regional feasibility of measures is accurately modeled, the framework introduces two types of Key Performance Indicators (KPIs): Precondition_KPIs and Barrier_KPIs. Precondition_KPIs define the necessary conditions for a measure to be considered implementable in a region. If these conditions are not met, the measure cannot be deployed. In contrast, Barrier_KPIs set upper bounds on the extent to which a measure can be implemented, based on regional resource constraints. For example, consider the mitigation measure M154.0, which involves the installation of residential distributed rooftop PV. In this case, a region must have a non-zero number of buildings (Precondition_KPIs) for the measure to be feasible. Once this condition is met, the potential deployment capacity is further limited by the availability of rooftop area (Barrier_KPIs). These region-specific constraints are derived from the DSP and are essential for realistically modeling the spatial deployment of mitigation strategies. In addition, certain mitigation measures exhibit variation in investment costs across different member states. To account for this, such measures are represented by submeasures, each corresponding to a specific country where the investment cost is uniquely defined. The implementation of a submeasure is constrained by the country code for which the model is being executed, ensuring that cost assumptions remain regionally accurate.

The model also seeks to align with the regionally disaggregated decarbonization trajectories defined by EUCalc. For instance, if EUCalc specifies that a particular region should achieve 10 TWh of solar electricity production by 2050 as part of its pathway, MIDAS aims to track and validate its outputs against this target. To facilitate this alignment, a new column titled API_KPIs is introduced in the measure database. This column links each solar-related mitigation measure to the corresponding solar electricity production variable in the DSP, using consistent naming conventions. This linkage allows MIDAS to monitor the cumulative solar electricity output resulting from implemented measures and compare it against the EUCalc-defined targets.

These mechanisms facilitate effective communication between the measure database and the DSP, enabling integrated and coherent optimization. Crucially, the variable names used in both components must remain consistent to ensure proper linkage and functionality within the modeling framework.

## 3.1 Model Assumptions

Temporal Resolution: Electricity grids with transmission capacity, generation capacity and energy storage need to be designed on a national or continental level to be feasible and be calculated with a temporal resolution of at least 1h for the entire year.

The sizing and placement of energy storages for example strongly depends on both the distribution and amount of generation in the entire system and the transmission system. A system with a strong transmission grid for example needs considerably less energy storage than a system with a weak transmission grid. Optimizing local regions for energy independence by integrating sufficient energy storage for autarky can be an interesting academic exercise, but will most likely never be implemented, since it is significantly more expensive than building an integrated energy system.

Therefore the design decision for ETHOS.MIDAS was made to assume that the energy system design including generation, storage and transmission capacities is done on a national level and is already included in the plans that are input for ETHOS.MIDAS, since the foundation for ETHOS.MIDAS are the official national pathways.

The goal of ETHOS.MIDAS was not to replicate the work done on a national level, but to provide a comprehensive plan for the implementation of the created plans. The temporal modelling of energy generation, storage and energy consumption is therefore out of scope for ETHOS.MIDAS and energy storage is not considered further.

Fallback Option: The model includes Direct Air Capture (DAC) as a special mitigation measure, reflecting its emerging role in global decarbonization strategies. While DAC is recognized for its potential to directly remove $CO_2$ from the atmosphere, its deployment remains contentious due to high costs, significant energy requirements, and uncertainties regarding scalability. As such, the model treats DAC as a last-resort option, activated only when a region is unable to meet its emission reduction targets through other available measures. This situation may arise either due to insufficient linkage between mitigation measures and emission sources, or due to regional constraints that limit the deployment of those measures. To ensure DAC is only selected when strictly necessary, the model applies a penalty function to solutions that involve its implementation. This penalty reflects the boundary condition that DAC should not be a preferred solution and effectively deprioritizes it in favor of less controversial, more feasible mitigation options. Only in cases where no other viable pathway exists will DAC be selected as part of the optimal regional decarbonization strategy.

## 3.2 Optimization

The model operates on a region-specific basis, tailoring the optimization of decarbonization measures to the unique resource availability and constraints of each region. When an analysis is initiated for a given region (e.g., DE404), the model retrieves relevant regional data from the DSP, including key resource and infrastructure parameters. It then applies a filtering process, referred to as *Midas Filtering*, which evaluates each measure in the global measure database against regional Precondition_KPIs and Barrier_KPIs.

Only measures that satisfy these regional feasibility criteria are retained, resulting in a region-specific measure database. This filtered database, together with the corresponding regional DSP data, forms the complete input set for the MIDAS optimization engine. Figure 3 shows the region specific model optimization. The process ensures that all selected measures are implementable within the region's physical, technical, and socio-economic boundaries, thus supporting realistic and targeted decarbonization planning.


Fig. 3: Schematic overview of the data filtering and integration process for generating region-specific inputs to MIDAS

Once a region-specific set of mitigation measures has been defined, the model selects an optimal subset based on multiple competing objectives—such as minimizing emissions, reducing investment costs, and enhancing social acceptance. To achieve this, the model employs a genetic algorithm, a heuristic optimization technique inspired by the principles of natural selection.

Unlike traditional exact optimization methods that rely on fixed problem structures and deterministic search, genetic algorithms use probabilistic and evolutionary strategies to explore complex and high-dimensional solution spaces. Each potential solution—referred to as an individual—represents a unique combination of mitigation measures drawn from the filtered regional database. These individuals are grouped into populations that evolve over successive generations through genetic operations such as selection, crossover, and mutation. The fitness of each individual reflects how well it satisfies the defined objectives.

As the algorithm iterates, individuals with higher fitness values are promoted, leading to the emergence of a set of Pareto-optimal solutions, visualized in Figure 4. This Pareto front represents the trade-off surface across all objectives. Each red point on the plot corresponds to a non-dominated solution, meaning no other solution in the population performs better in all objectives simultaneously. The red point on the far left, for instance, illustrates a sustainability-focused scenario with maximum emissions reduction but higher investment. In contrast, solutions in the center of the Pareto front reflect balanced trade-offs between emissions and investment, offering more practical and cost-effective strategies.

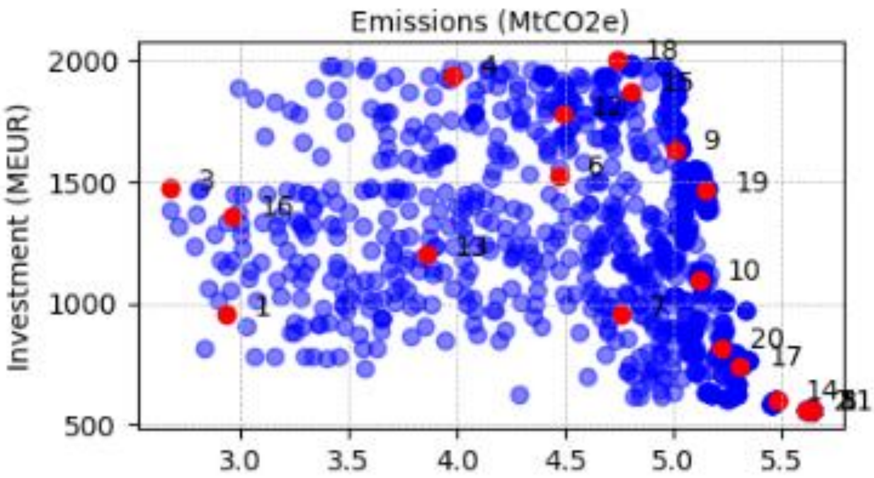


Fig. 4: Pareto front of MIDAS, illustrating the trade-off between emissions ($MtCO_2e$) and investment (MEUR). Blue points represent all evaluated scenarios, while red dots highlight selected optimal solutions balancing cost and emissions.

## *3.3 Mode of Operation*

The MIDAS model operates in two distinct modes: Optimization and Calculation.

The default mode is Optimization, where the model performs a stochastic search over the region-specific measure database using a genetic algorithm. This heuristic approach explores combinations of mitigation measures, guided by objective-specific fitness values, to identify Pareto-optimal solutions for emissions reduction, investment efficiency, and other criteria.

To enhance usability and flexibility, the model is also integrated with the CAST user interface via an API. This allows users to switch to the Calculation mode, where they can reassess the outcomes of a previously optimized solution by adjusting the capacity values of specific measures—based on their own local knowledge or updated data—without re-running the full optimization process.

This mode is particularly useful when users agree with the selected combination of mitigation measures but want to revise the scale of implementation. For instance, if the optimization suggests deploying 1 million battery electric vehicles in Berlin, but local planners determine that 2 million are feasible, the user can input this new capacity. The model then recalculates the fitness objectives (e.g., emissions reduction, investment) based on the updated values, producing revised regional outcomes.

For further information on the different modes of operation, please refer to Deliverable D4.2.

# 4 Outputs and Expected Users of Midas

MIDAS provides a large number of results, such as cumulative indicators, time series indicators, emission savings per measure, the indicators influenced by each measure, costs per measure, emissions and costs per sector, different rankings of measures and much more.

The output of MIDAS is again a JSON-file that is very easy to process in other software and can be used in the LOCALISED web frontend CAST.

The MIDAS model is designed to support a diverse range of users involved in regional and local climate action. Primary users include:

- Local citizens and communities, who can explore feasible mitigation actions at the individual or household level—such as building renovations or adopting clean technologies.

- Municipal and regional authorities, including city climate planning departments and state/provincial energy and environment agencies. These users can apply MIDAS to support policy development, climate target setting, and sustainable infrastructure planning, such as expanding public transportation networks.

- Stakeholders involved in climate financing, including public and private investors who need evidence-based insights for funding regional mitigation strategies.

- Climate policymakers, for evaluating decarbonization pathways aligned with national and regional goals.

- Private sector actors, such as energy-intensive industries and service providers, who can use the model to identify opportunities for emission reductions, cost savings, and regulatory compliance.

By addressing the needs of both public and private stakeholders, MIDAS serves as a versatile tool for supporting the design, implementation, and monitoring of regionally tailored climate strategies.

# 5 Feasible Mitigation Measures

This section aims to give an insight into the results of MIDAS by presenting selected results for:

- Two regions with measures per sector

- One country with measures per sector
- An overview of Europe

Additionally, the deliverable comes with an Excel sheet containing the full list of all emissions, all investments and all capacity factors for a single run of all of Europe. The chosen scenario is a balanced scenario with RCP8.5. From WP2 the national pathway variant is used instead of the behavioral pathway. The reason for this split approach is that it didn't seem useful to attach thousands of pages of report for individual regions as PDF, but the deliverable should show the results for all regions.

The link for the Excel-Sheet is:

Pflugradt, N., & Ghaddar, T. (2025). LOCALISED: Full European Measure Dataset for the Balanced Plan from 07.05.2025 [Data set]. Zenodo. https://doi.org/10.5281/zenodo.15462717

## 5.1 Regional Level

This section shows the measures for the individual sectors from two different regions to give an impression of the results.

### 5.1.1 DE125 (Heidelberg)

Heidelberg is an urban region with a high population density. The biggest employer is the local university. Therefore, there are few industrial measures, almost no agriculture and a lot of building measures. The detailed overview of the sectors and measures are shown in Fig. 5 to Fig. 12.

#### 5.1.1.1 General Overview

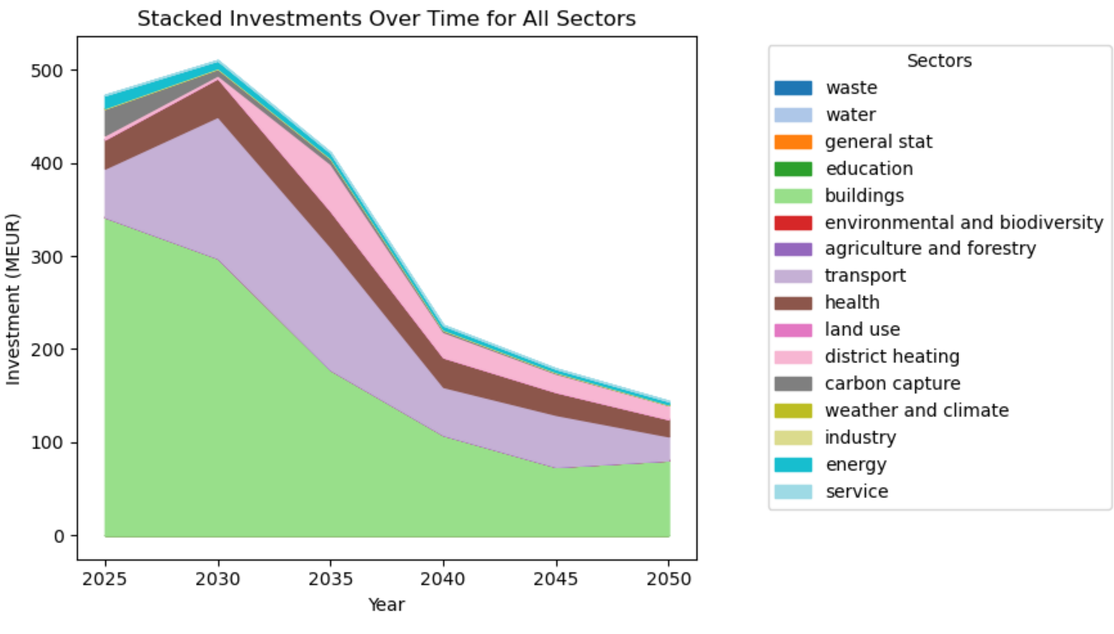


Fig. 5: The investment chart shows the region will have significant costs especially in the building sector over the next 25 years to reach net-zero.

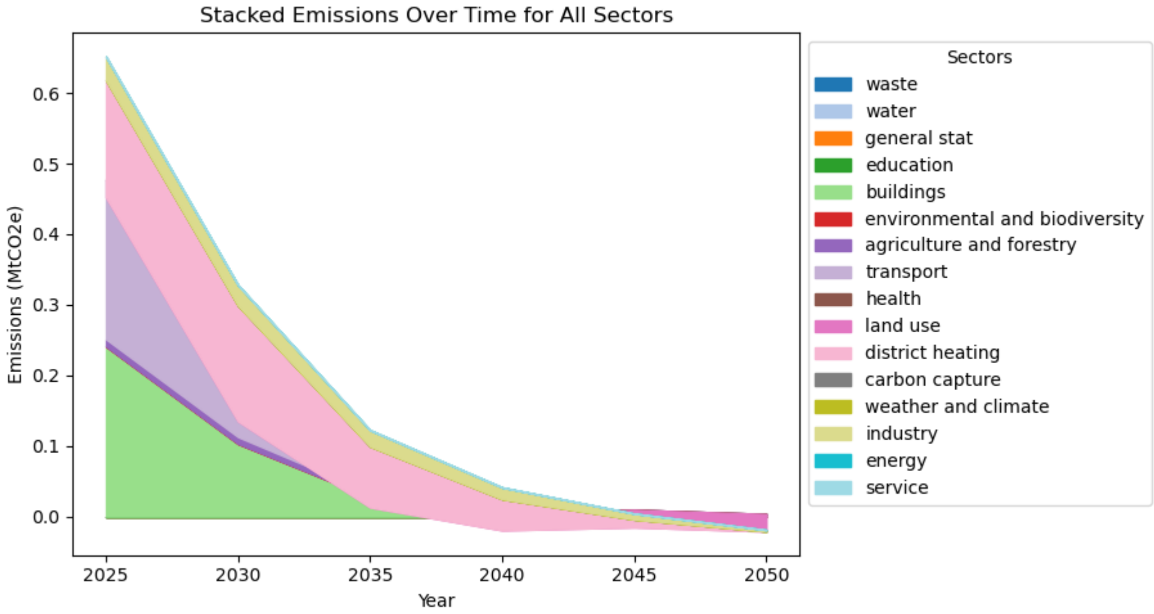


Fig. 6: The stacked emissions chart shows the remaining emissions in the region for each year. This shows that the region will reach net-zero and that the largest share of the emissions is coming from buildings.

#### *5.1.1.2 Agriculture*

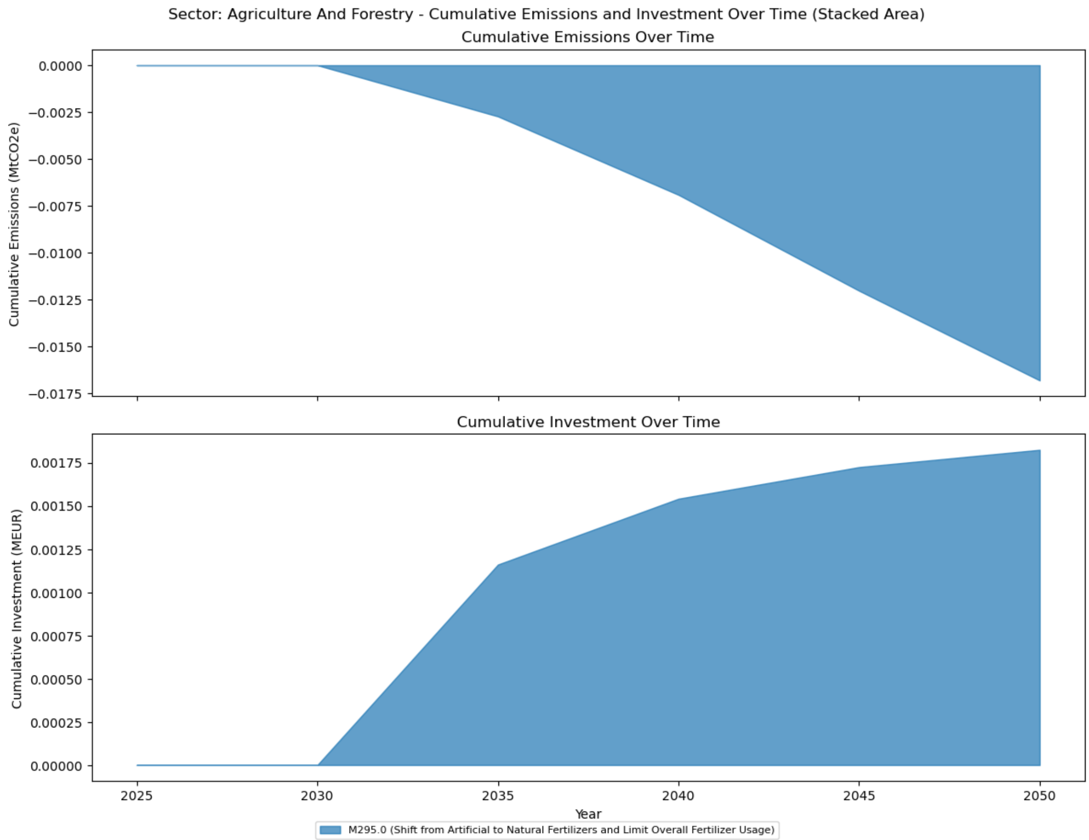


Fig. 7: The region has nearly no agricultural measures. This is expected since Heidelberg is a medium-sized city.

Table 2: List of measures for the agriculture sector

| Measure ID | Name |
|---|---|
| M295.0 | Shift from Artificial to Natural Fertilizers and limit overall fertilizer usage |

Table 3: Top 5 measures in Agriculture and Forestry Sector

| Measure | Investment (MEUR) | Emission Reduction (Mt CO2) |
|---|---|---|
| M295.0: Shift from artificial to natural fertilizers and limit overall fertilizer usage | 0,00182 | 0,07154 |

### *5.1.1.3 Buildings*

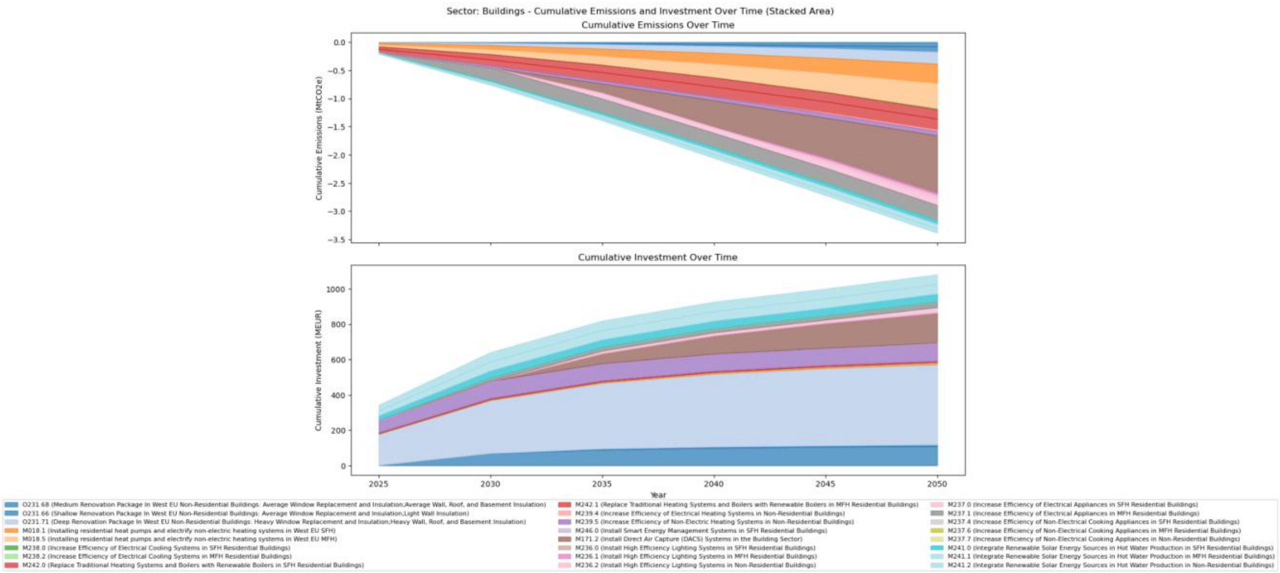


Fig. 8: The region has a large number of building measures, focused on increasing efficiency and replacing heating systems

Table 4: List of measures with the full measure name

| Measure ID | Name |
|---|---|
| O231.68 | Medium Renovation Package in West EU Non-Residential Buildings |
| O231.66 | Shallow Renovation Package in West EU Non-Residential Buildings |
| O231.71 | Deep Renovation Package in West EU Non-Residential Buildings |
| M018.1 | Installing residential heat pumps and electrify non-electric heating systems in West EU SFH |
| M018.5 | Installing residential heat pumps and electrify non-electric heating |

| | |
|---|---|
| | systems in West EU MFH |
| M238.0 | Increase Efficiency of Electrical Cooling Systems in SFH Residential Buildings |
| M238.2 | Increase Efficiency of Electrical Cooling Systems in MFH Residential Buildings |
| M242.0 | Replace Traditional Heating Systems and Boilers with Renewable Boilers in SFH Residential Buildings |
| M242.1 | Replace Traditional Heating Systems and Boilers with Renewable Boilers in MFH Residential Buildings |
| M239.4 | Increase Efficiency of Electrical Heating Systems in Non-Residential Buildings |
| M239.5 | Increase Efficiency of Non-Electric Heating Systems in Non-Residential Buildings |
| M240.6 | Install Smart Energy Management Systems in SFH Residential Buildings |
| M171.2 | Install Direct Air Capture (DACS) Systems in the Building Sector |
| M236.0 | Install High Efficiency Lighting Systems in SFH Residential Buildings |
| M236.1 | Install High Efficiency Lighting Systems in MFH Residential Buildings |
| M236.2 | Install High Efficiency Lighting Systems in Non-Residential Buildings |
| M237.0 | Increase Efficiency of Electrical Appliances in SFH Residential Buildings |
| M237.1 | Increase Efficiency of Electrical Appliances in MFH Residential Buildings |
| M237.4 | Increase Efficiency of Non-Electrical Cooking Appliances in SFH Residential Buildings |
| M237.6 | Increase Efficiency of Non-Electrical Cooking Appliances in MFH Residential Buildings |
| M237.7 | Increase Efficiency of Non-Electrical Cooking Appliances in Non-Residential Buildings |
| M241.0 | Integrate Renewable Solar Energy Sources in Hot Water Production in SFH Residential Buildings |
| M241.1 | Integrate Renewable Solar Energy Sources in Hot Water Production in MFH Residential Buildings |
| M241.2 | Integrate Renewable Solar Energy Sources in Hot Water Production in Non-Residential Buildings |

Table 5: Top 5 measures in the Buildings Sector

| Measure | Investment (MEUR) | Emission Reduction (Mt CO2) |
|---|---|---|
| O231.71: Deep Renovation Package in non-residential buildings | 455.7 | 0.926 |
| M018.5: Installing residential heat pumps in multi family homes | 6.033 | 1.904 |
| O231.68: medium renovation package in non-residential buildings | 108.82 | 0.343 |
| M018.1: installing residential heat pumps in SFH | 4.575 | 1.444 |
| O231.66: Shallow renovation package in non-residential buildings | 8.596 | 0.348 |

#### *5.1.1.4 Carbon Capture*

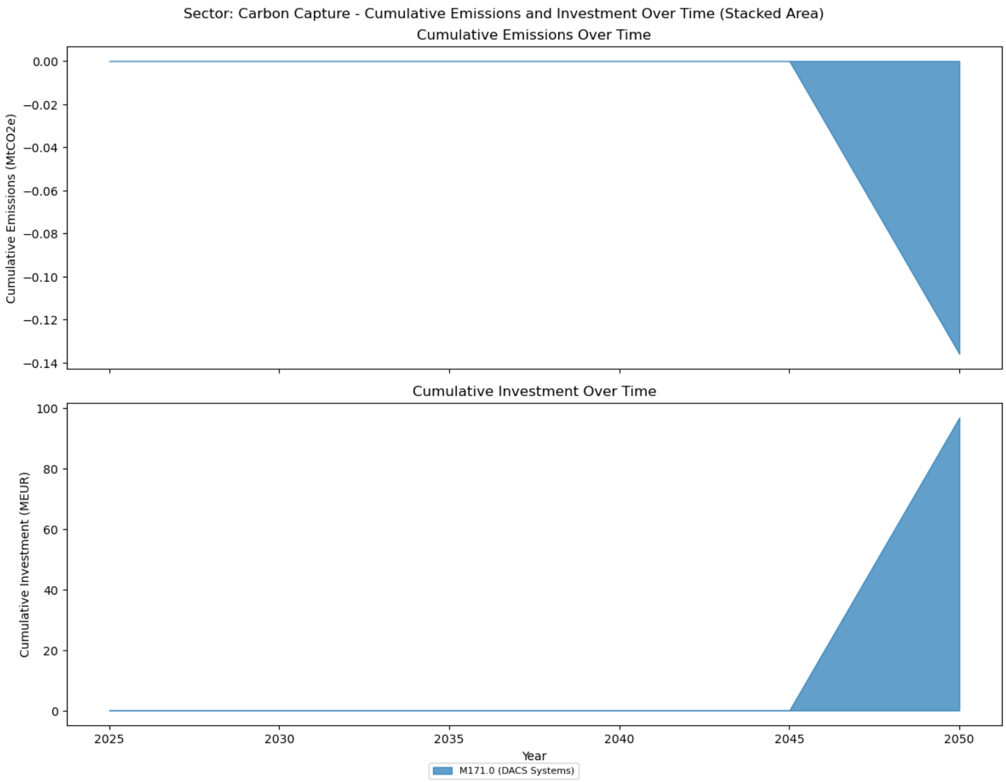


Fig. 9: Towards 2050, the region needs to install a small amount of direct air capture to reach net-zero.

#### *5.1.1.5 Energy Sector*

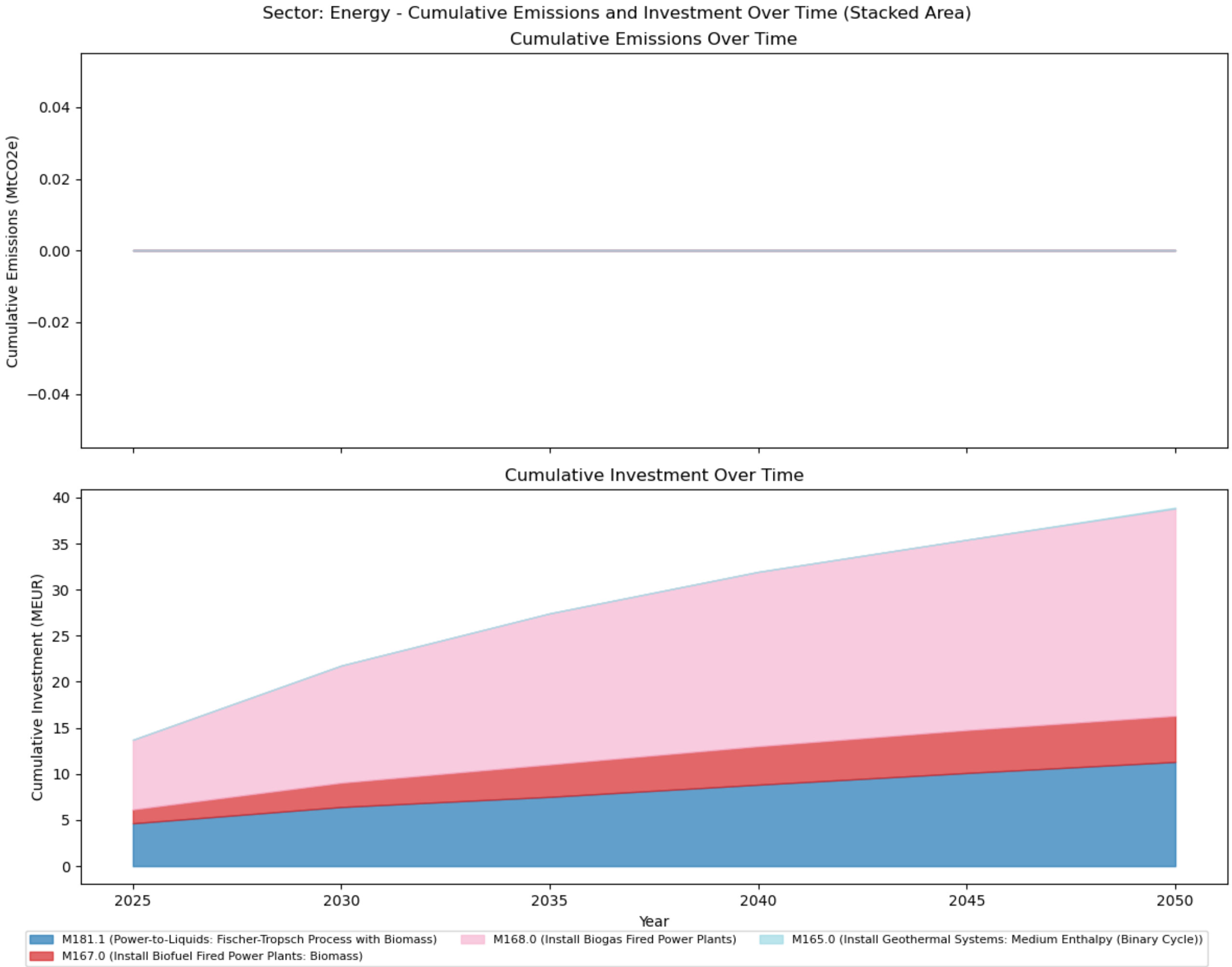


Fig. 10: The energy sector shows that towards 2050 the region installs a lot of biogas fired power plants. There are no emission reductions in the energy sector because Heidelberg does not have significant initial emissions in this sector; however, measures are still installed because the model aims to align with the EUCalc trajectory, which indicates that Heidelberg should implement these measures by 2050

Table 6: List of measures with the full measure name

| Measure ID | Name |
|---|---|
| M181.1 | Power-to-Liquids: Fischer-Tropsch Process with Biomass |
| M167.0 | Install Biofuel Fired Power Plants: Biomass |
| M168.0 | Install Biogas Fired Power Plants |
| M165.0 | Install Geothermal Systems: Medium Enthalpy |

Table 7: Top 5 measures in the Energy Sector

| Measure | Investment (MEUR) | Emission Reduction (Mt CO2) |
|---|---|---|
| M168.0: Install Biogas Fired power plants | 22.5 | 0 |
| M181.1: Power-to-liquids: Fischer-Tropsch Process with Biomass | 11.31 | 0 |
| M167.0: Install biofuel fired power plants with Biomass | 4.997 | 0 |
| M165.0: install geothermal systems (Medium enthalpy) | 0.0927 | 0 |

#### *5.1.1.6 Industry*

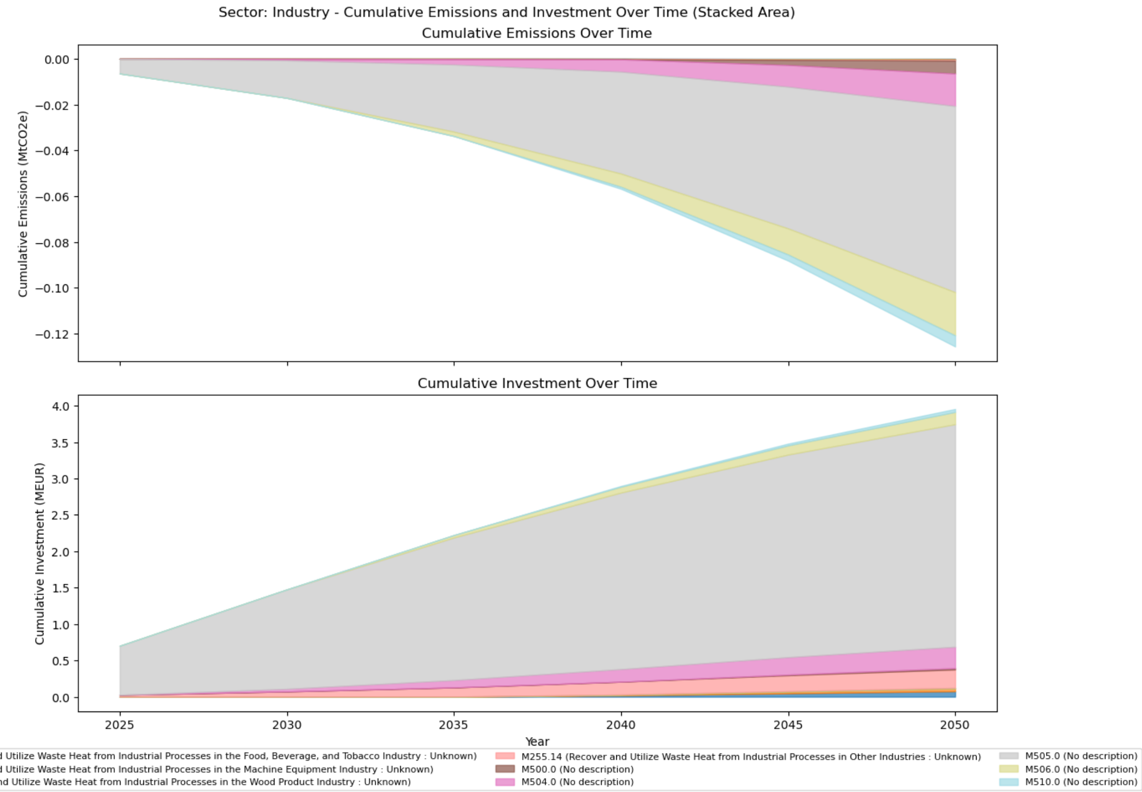


Fig. 11: The industry sector in the town is comparatively small and the measures focus on utilizing waste heat.

Table 8: List of measures with the full measure name

| Measure ID | Name |
|---|---|
| M255.5 | Recover and Utilize Waste Heat from Industrial Processes in the Food, Beverage, and Tobacco Industry |
| M255.7 | Recover and Utilize Waste Heat from Industrial Processes in the |

| | |
|---|---|
| | Machine Equipment Industry |
| M255.11 | Recover and Utilize Waste Heat from Industrial Processes in the Wood Product Industry |
| M255.14 | Recover and Utilize Waste Heat from Industrial Processes in Other Industries |
| M504.0 | Industrial electrification in the Food, Beverage, and Tobacco Industry |
| M505.0 | Industrial electrification in Other Industries |
| M506.0 | Industrial electrification in the Machine Equipment Industry |
| M510.0 | Industrial electrification in the Wood Product Industry |

Table 9: Top 5 measures in the Industry Sector

| Measure | Investment (MEUR) | Emission Reduction (Mt CO2) |
|---|---|---|
| M255.5: Recover and utilize waste heat from industrial processes in the food, beverage, and tobacco industry | 0.0743 | 0.00078 |
| M255.7: recover and utilize waste heat from industrial processes in the wood product industry | 0.039 | 0.00082 |
| M255.11: recover and utilize waste heat from industrial processes in the machine equipment | 0.008 | 0.00015 |
| M255.14: recover and utilize waste heat from industrial processes in other industries | 0.252 | 0.0016 |
| M500.0: industrial electrification of fossil fuel based processes | 0.0187 | 0.02 |

#### *5.1.1.7 Transport*

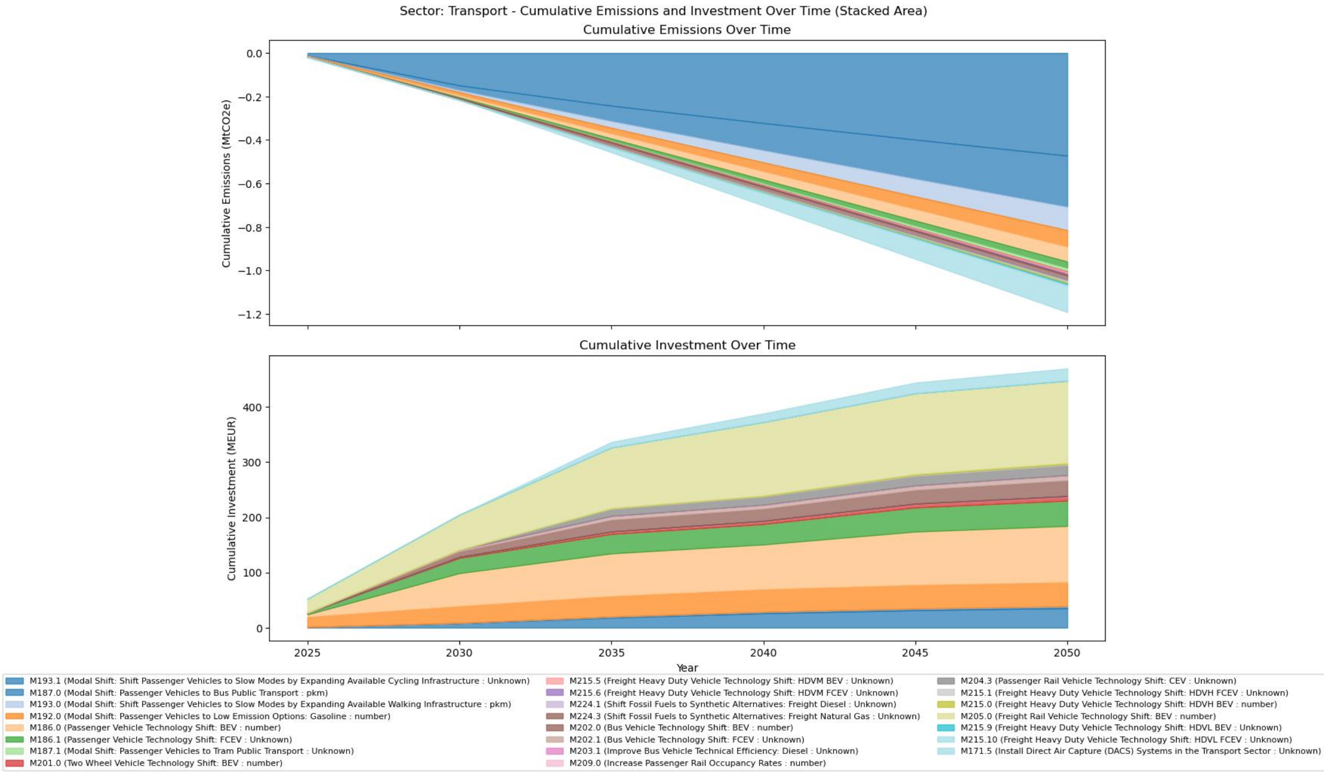


Fig. 12: The transport sector measures focus on modal shift towards public transport and electrification of the transport sector. This sector is one of the most fine-grained ones.

Table 10: List of measures with the full measure name

| Measure ID | Name |
|---|---|
| M193.1 | Modal Shift: Shift Passenger Vehicles to Slow Modes by Expanding Available Cycling Infrastructure |
| M187.0 | Modal Shift: Passenger Vehicles to Bus Public Transport (pkm) |
| M193.0 | Modal Shift: Shift Passenger Vehicles to Slow Modes by Expanding Available Walking Infrastructure (pkm) |
| M192.0 | Modal Shift: Passenger Vehicles to Low Emission Options: Gasoline |
| M186.0 | Passenger Vehicle Technology Shift: BEV |
| M186.1 | Passenger Vehicle Technology Shift: FCEV |
| M187.1 | Modal Shift: Passenger Vehicles to Tram Public Transport |
| M201.0 | Two Wheel Vehicle Technology Shift: BEV |
| M215.5 | Freight Heavy Duty Vehicle Technology Shift: HDVM BEV |
| M215.6 | Freight Heavy Duty Vehicle Technology Shift: HDVM FCEV |

| | |
|---|---|
| M224.1 | Shift Fossil Fuels to Synthetic Alternatives: Freight Diesel |
| M224.3 | Shift Fossil Fuels to Synthetic Alternatives: Freight Natural Gas |
| M220.0 | Bus Vehicle Technology Shift: BEV |
| M220.1 | Bus Vehicle Technology Shift: FCEV |
| M203.1 | Improve Bus Vehicle Technical Efficiency: Diesel |
| M209.0 | Increase Passenger Rail Occupancy Rates |
| M204.3 | Passenger Rail Vehicle Technology Shift: CEV |
| M215.1 | Freight Heavy Duty Vehicle Technology Shift: HDVH FCEV |
| M215.0 | Freight Heavy Duty Vehicle Technology Shift: HDVH BEV |
| M205.0 | Freight Rail Vehicle Technology Shift: BEV Freight Rail Vehicle Technology Shift: BEV |
| M215.9 | Freight Heavy Duty Vehicle Technology Shift: HDVL BEV |
| M215.10 | Freight Heavy Duty Vehicle Technology Shift: HDVL FCEV |
| M171.5 | Install Direct Air Capture (DACS) Systems in the Transport Sector |

Table 11: Top 5 measures in the Transport Sector

| Measure | Investment (MEUR) | Emission Reduction (Mt CO2) |
|---|---|---|
| M193.1: Modal shift: shift passenger vehicles to slow modes by expanding available cycling infrastructure | 35.27 | 2.103 |
| M187.0: Modal shift: passenger vehicles to bus public transport | 2.8 | 1.019 |
| M186.0: Passenger vehicle technology shift: BEV | 101.89 | 0.29 |
| M205.0: freight rail vehicle technology shift: HDVL BEV | 149.1 | 0 |

#### ***5.1.1.6*** **Summary**

This example for DE125 shows that the modeling approach yields usable pathways for individual regions, but that some work remains to be done to improve the result quality. Especially the industry sector and the energy sector needs further refinement, while the other sectors need calibration and finetuning.

### 5.1.2 ES424 (Guadalajara)

Guadalajara is a thinly populated province in Spain with a population density of only 22 citizens / km2. The agriculture sector causes a significant part of the region's emissions.

#### 5.1.2.1 Overview

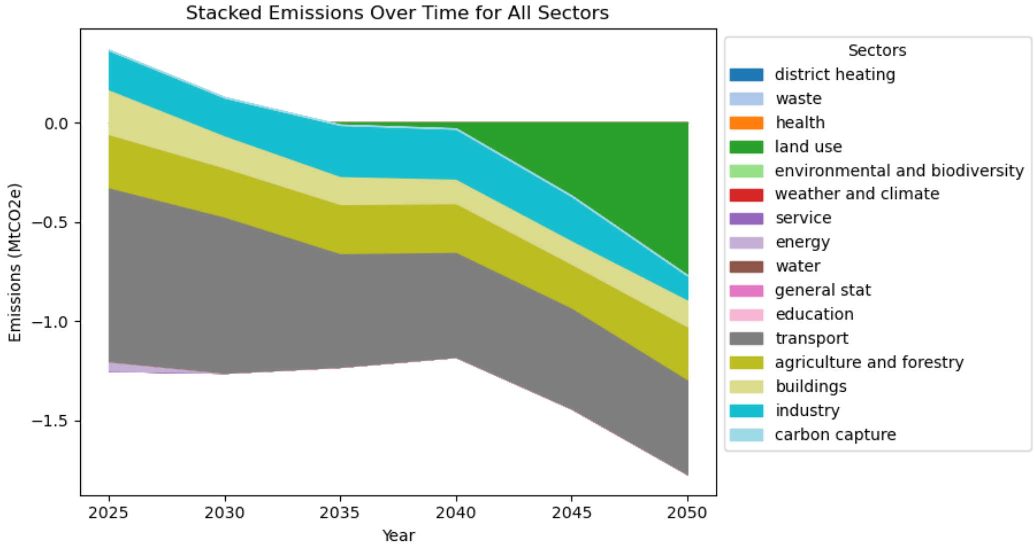


Fig. 13: Currently MIDAS suggests significant afforestation for the region to create negative emissions. These measures probably need further constraints with water availability.

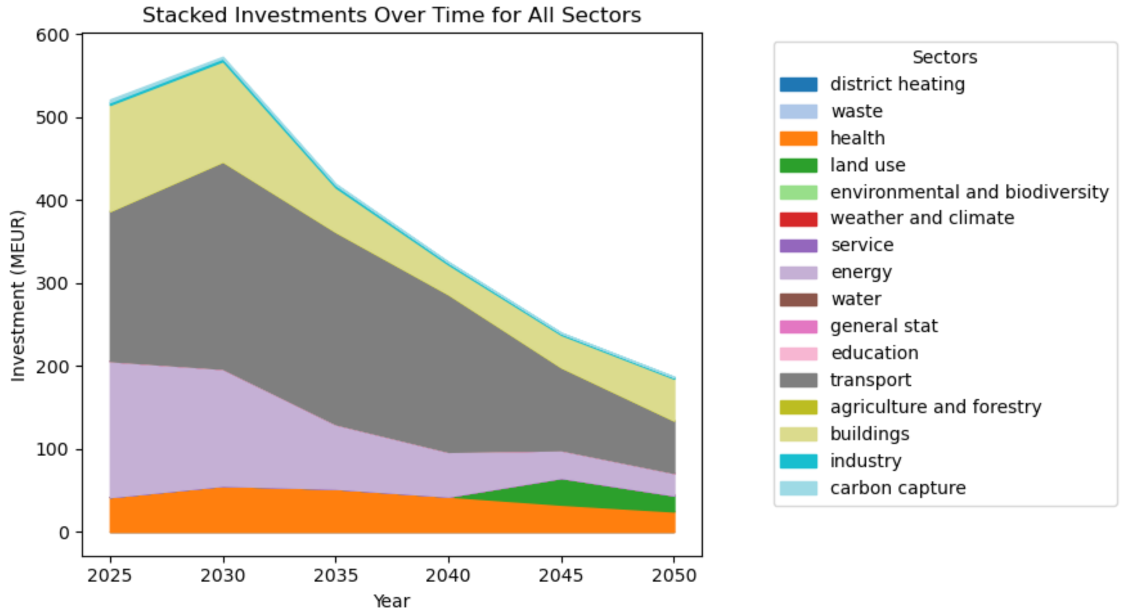


Fig. 14: The investment in the region is primarily in the transport sector, with some costs in the land use and energy sector.

#### *5.1.2.2 Agriculture*

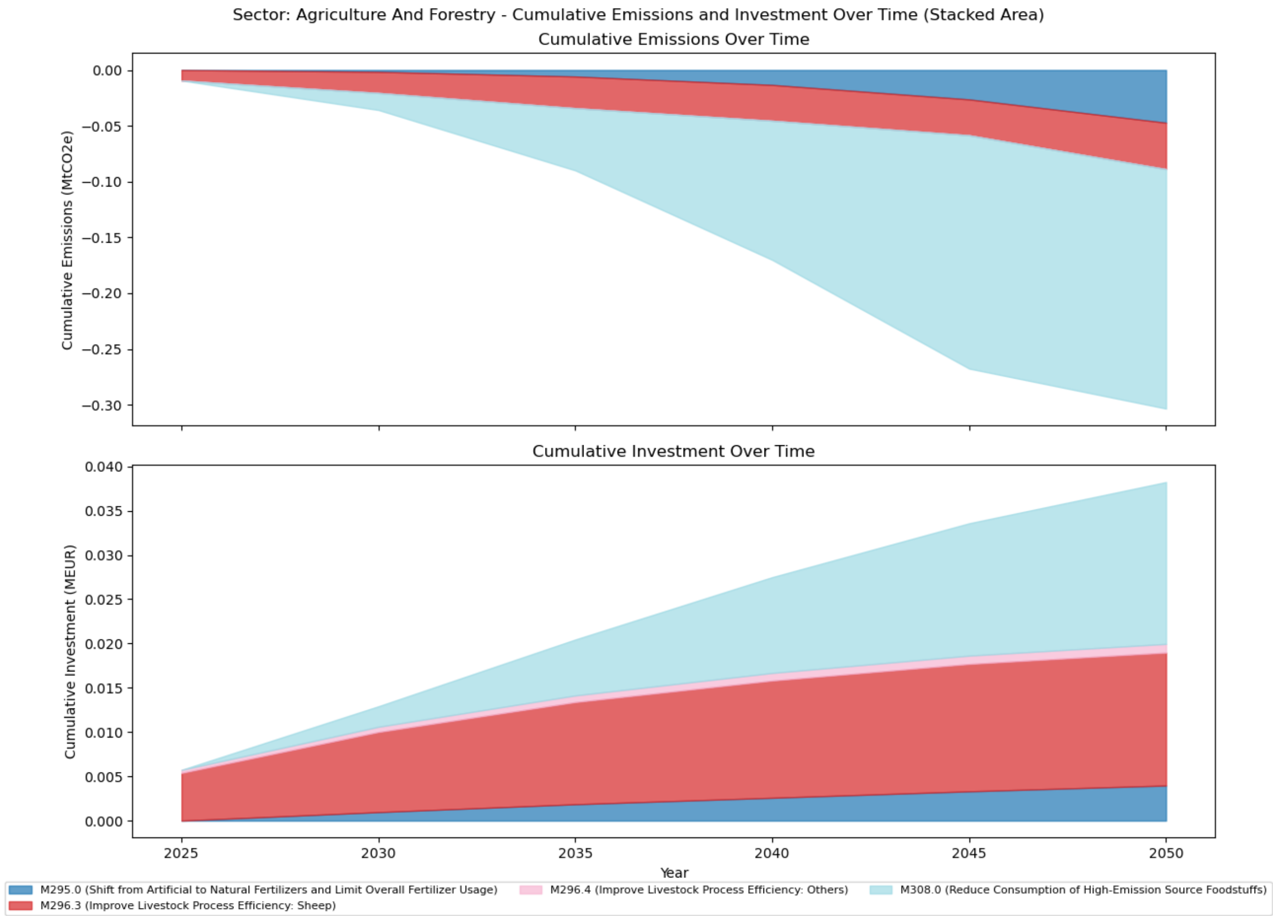


Fig. 15: The agriculture sector has only moderate costs, but contributes significantly to the emission reductions.

Table 12: Top 5 measures in Agriculture and Forestry Sector

| Measure | Investment (MEUR) | Emission Reduction (Mt CO2) |
|---|---|---|
| M295.0: Shift from artificial to natural fertilizers and limit overall fertilizer usage | 0.004 | 0.187 |
| M296.3: improve livestock process efficiency: sheep | 0.015 | 0.163 |
| M296.4: improve livestock process efficiency | 0.0009 | 0 |
| M308.0: reduce consumption of high-emission source foodstuffs | 0.018 | 1.017 |

#### *5.1.2.3 Buildings*

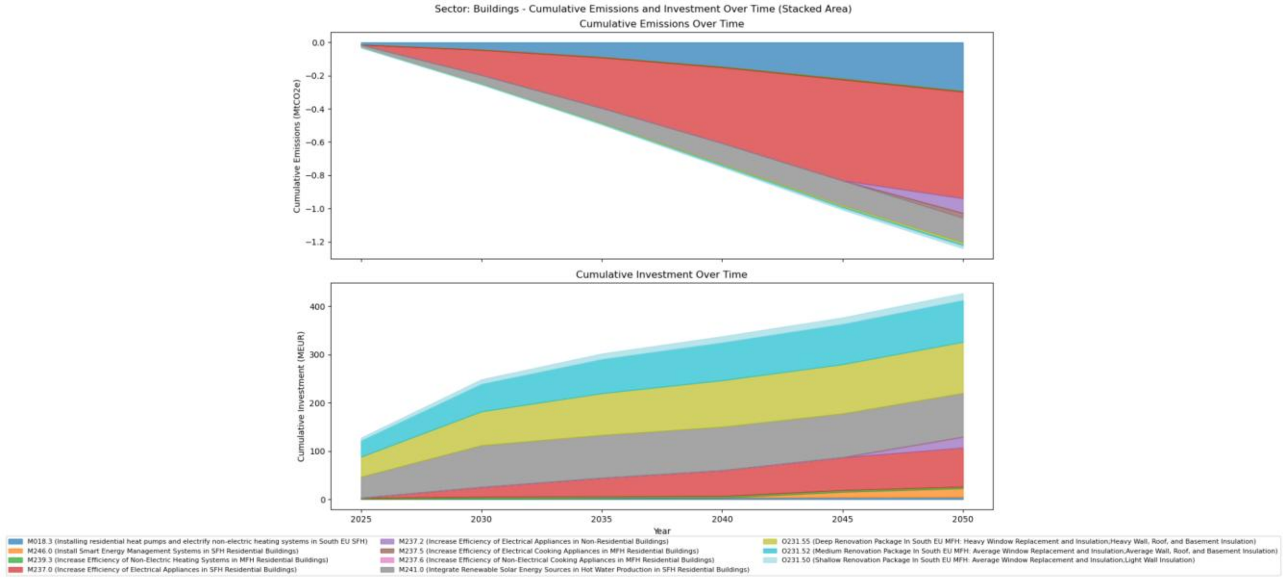


Fig. 16: The building sector has significant costs but significantly lower emission reductions. The measure focus on domestic hot water and heating systems.

Table 13: List of measures with the full measure name

| Measure ID | Name |
|---|---|
| M018.3 | Installing residential heat pumps and electrify non-electric heating systems in South EU SFH |
| M246.0 | Install Smart Energy Management Systems in SFH Residential Buildings |
| M239.3 | Increase Efficiency of Non-Electric Heating Systems in MFH Residential Buildings |
| M237.0 | Increase Efficiency of Electrical Appliances in SFH Residential Buildings |
| M237.2 | Increase Efficiency of Electrical Appliances in Non-Residential Buildings |
| M237.5 | Increase Efficiency of Electrical Cooking Appliances in MFH Residential Buildings |
| M237.6 | Increase Efficiency of Non-Electrical Cooking Appliances in MFH Residential Buildings |
| M241.0 | Integrate Renewable Solar Energy Sources in Hot Water Production in SFH Residential Buildings |
| O231.55 | Deep Renovation Package in South EU MFH: Heavy Window Replacement and Insulation; Heavy Wall, Roof, and Basement Insulation |

| | |
|---|---|
| O231.52 | Medium Renovation Package in South EU MFH: Average Window Replacement and Insulation; Average Wall, Roof, and Basement Insulation |
| O231.50 | Shallow Renovation Package in South EU MFH: Average Window Replacement and Insulation; Light Wall Insulation |

Table 14: Top 5 measures in the Buildings Sector

| Measure | Investment (MEUR) | Emission Reduction (Mt CO2) |
|---|---|---|
| M237.0: increase efficiency of electrical appliances in SFH residential buildings | 81 | 3.013 |
| M239.3: increase efficiency of non-electric heating systems in MFH residential buildings | 3.49 | 0.02 |
| M018.3: installing residential heat pumps and electrify non-electric heating systems in SFH | 4.41 | 1.23 |
| M246.0: install smart energy management systems in SFH residential buildings | 18.16 | 0.00022 |
| M237.2: increase efficiency of electrical appliances in non-residential buildings | 22 | 0.257 |

### *5.1.2.4 Energy*

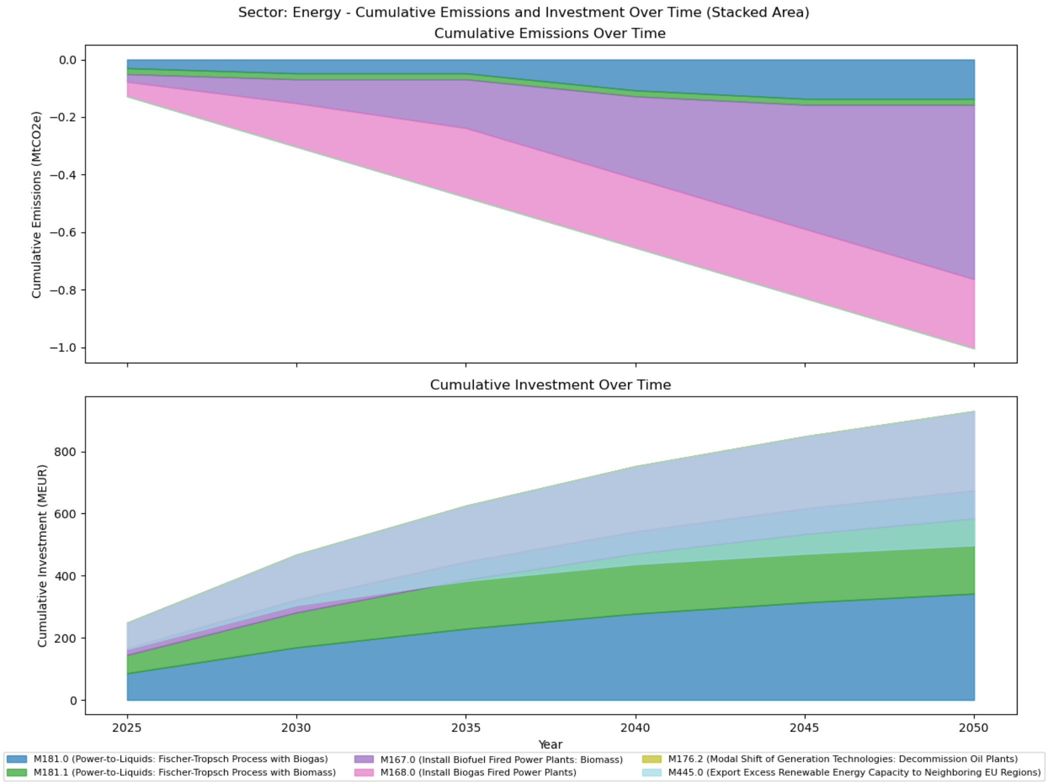


Fig. 17: The energy sector revolves around operating power-to-liquids and biomass/biogas power plants, which seems reasonable due to the high share of agriculture in the region.

Table 15: List of measures with the full measure name

| Measure ID | Name |
|---|---|
| M181.0 | Power-to-Liquids: Fischer-Tropsch Process with Biogas |
| M181.1 | Power-to-liquids: Fischer-Tropsch Process with Biomass |
| M167.0 | Install Biofuel Fired Power Plants: Biomass |
| M168.0 | Install Biogas Fired Power Plants |
| M176.2 | Modal Shift of generation technologies: decommission oil plants |
| M445.0 | Export Excess Renewable Energy Capacity to Neighboring EU Regions |

Table 16: Top 5 measures in the Energy Sector

| Measure | Investment (MEUR) | Emission Reduction (Mt CO2) |
|---|---|---|
| M181.0: Power-to-liquids: Fischer Tropsch Process with Biogas | 342.2 | 0.597 |
| M181.1: Power-to-liquids: Fischer Tropsch Process with Biomass | 241.7 | 0.06 |
| M445.0: Export excess renewable energy capacity to neighboring EU regions | 432.4 | 0 |

| | | |
|---|---|---|
| M176.2: modal shift of generation technologies: decommission oil plants | 0.004 | 0 |
| M167.0: install biofuel fired power plants | 90.5 | 2.52 |

#### *5.1.2.5 Industry*

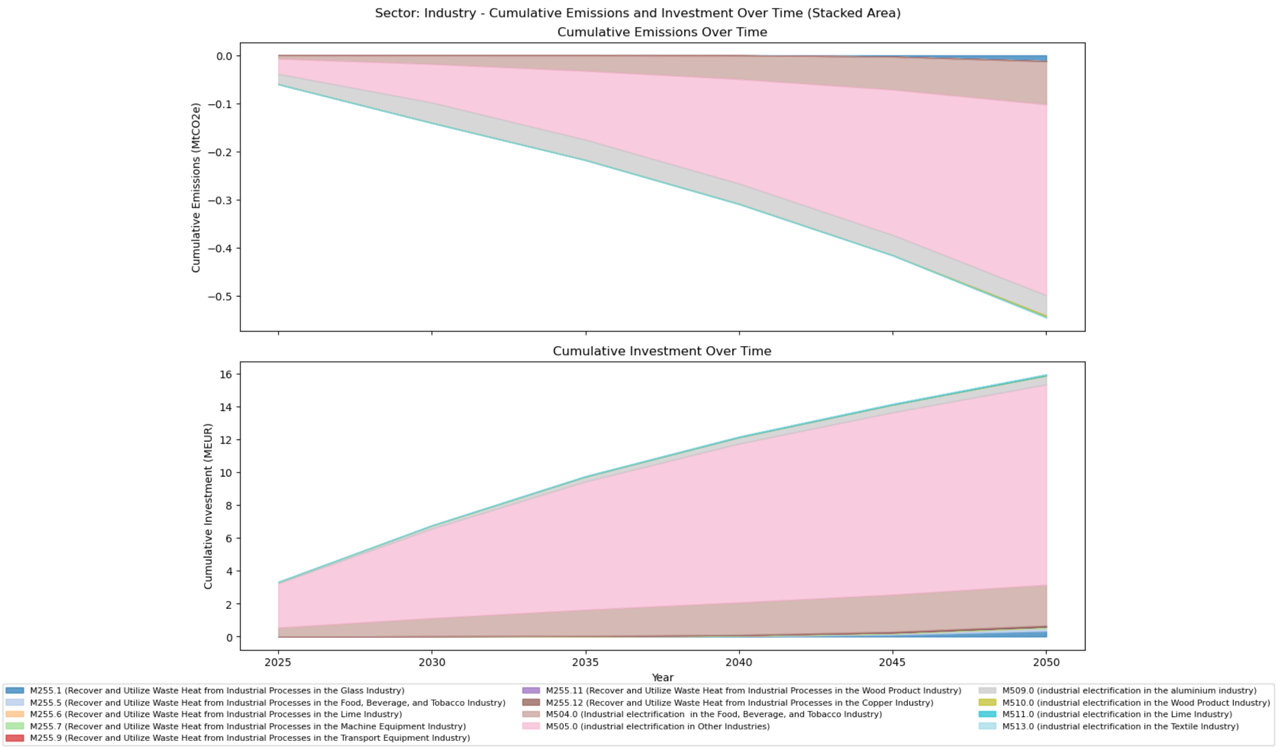


Fig. 18: The industry sector focuses on electrification, which currently in the model has very high costs. The rest of the costs go towards implementing waste heat reuses processes. This needs further refinement, and some constraints are required to limit the amount of waste reuse.

Table 17: List of measures with the full measure name

| Measure ID | Name |
|---|---|
| M255.1 | Recover and Utilize Waste Heat from Industrial Processes in the Glass Industry |
| M255.5 | Recover and Utilize Waste Heat from Industrial Processes in the Food, Beverage, and Tobacco Industry |
| M255.6 | Recover and Utilize Waste Heat from Industrial Processes in the Lime Industry |
| M255.7 | Recover and Utilize Waste Heat from Industrial Processes in the Machine Equipment Industry |
| M255.9 | Recover and Utilize Waste Heat from Industrial Processes in the Transport Equipment Industry |

| | |
|---|---|
| M255.11 | Recover and Utilize Waste Heat from Industrial Processes in the Wood Product Industry |
| M255.12 | Recover and Utilize Waste Heat from Industrial Processes in the Copper Industry |
| M504.0 | Industrial electrification in the Food, Beverage, and Tobacco Industry |
| M505.0 | Industrial electrification in Other Industries |
| M509.0 | Industrial electrification in the aluminium industry |
| M510.0 | Industrial electrification in the Wood Product Industry |
| M511.0 | Industrial electrification in the Lime Industry |
| M513.0 | Industrial electrification in the Textile Industry |

Table 18: Top 5 measures in the Industry Sector

| Measure | Investment (MEUR) | Emission Reduction (Mt CO2) |
|---|---|---|
| M505.0: industrial electrification | 12.19 | 1.66 |
| M255.12: recover and utilize waste heat from industrial processes in the copper industry | 0.064 | 0.0019 |
| M255.5: Recover and Utilize Waste Heat from Food, Beverage, and Tobacco Industry | 0.2 | 0.0023 |
| M255.1: Recover and Utilize Waste Heat in the Glass Industry | 0.0012 | 0.00003 |
| M255.7: Recover and Utilize Waste Heat from Machine equipment industry | 0.074 | 0.0012 |

### *5.1.2.6 Land Use*

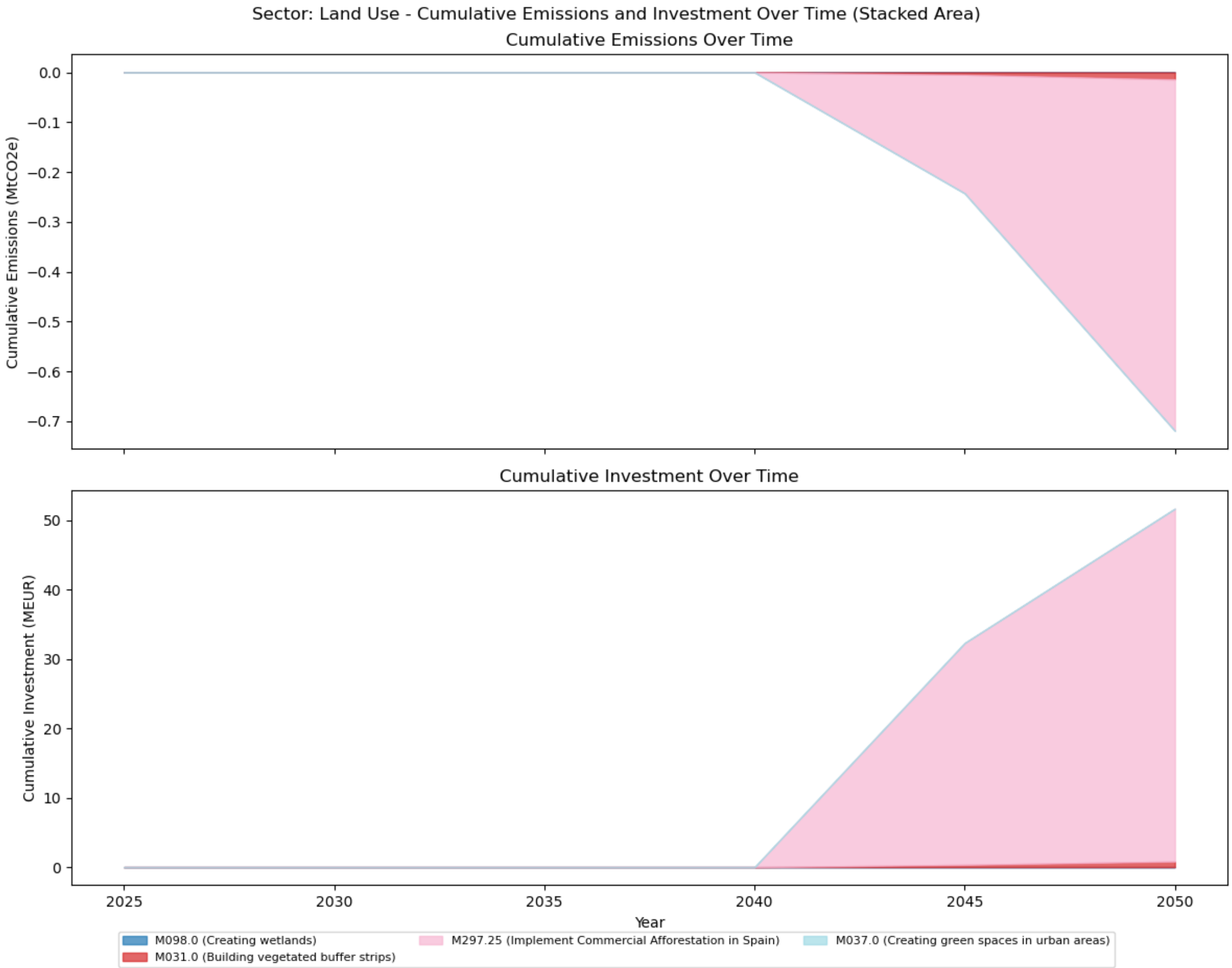


Fig. 19: The land use sector focuses on afforestation for negative CO2 emissions. This shows that the measure probably needs additional constraints regarding water availability.

Table 19: Top 5 measures in the Land Use Sector

| Measure | Investment (MEUR) | Emission Reduction (Mt CO2) |
|---|---|---|
| M297.25: Implement Commercial Afforestation | 50.9 | 2.5 |
| M098.0: Creating wetlands | 0.0002 | 0.00002 |
| M031.0: Building vegetated buffer strips | 0.809 | 0.05 |
| M037.0: Creating green spaces in urban areas | 0.0003 | 0 |

### *5.1.2.7 Transport*

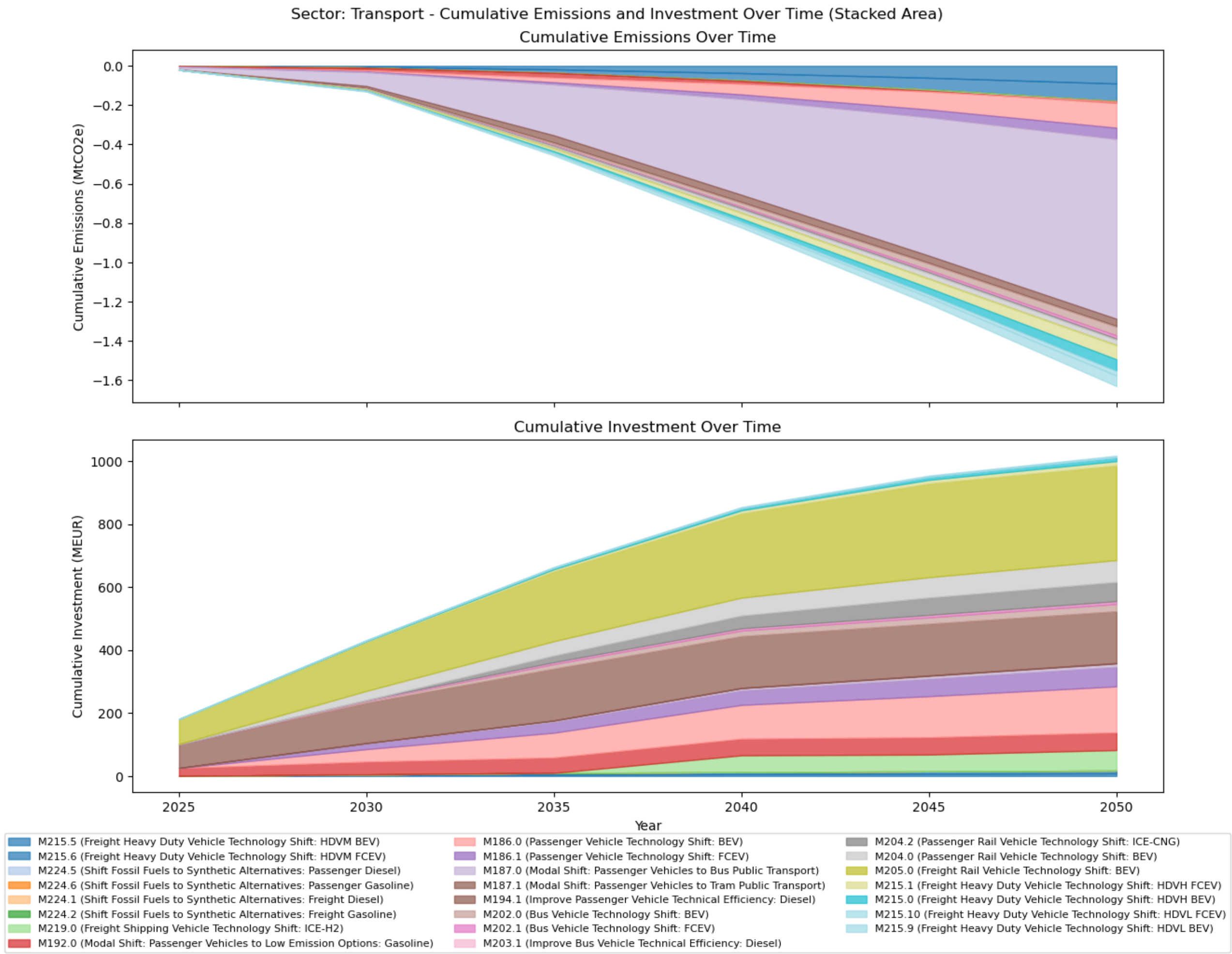


Fig. 20: The transport sector measures again consist of a mixture of modal shift towards public transport and an electrification of the transport sector.

Table 20: List of measures with the full measure name

| Measure ID | Name |
|---|---|
| M215.5 | Freight Heavy Duty Vehicle Technology Shift: HDVM BEV |
| M215.6 | Freight Heavy Duty Vehicle Technology Shift: HDVM FCEV |
| M224.5 | Shift Fossil Fuels to Synthetic Alternatives: Passenger Diesel |
| M224.6 | Shift Fossil Fuels to Synthetic Alternatives: Passenger Gasoline |
| M224.1 | Shift Fossil Fuels to Synthetic Alternatives: Freight Diesel |
| M224.2 | Shift Fossil Fuels to Synthetic Alternatives: Freight Gasoline |
| M219.0 | Freight Shipping Vehicle Technology Shift: ICE-H2 |
| M192.0 | Modal Shift: Passenger Vehicles to Low Emission Options: Gasoline |

| | |
|---|---|
| M186.0 | Passenger Vehicle Technology Shift: BEV |
| M186.1 | Passenger Vehicle Technology Shift: FCEV |
| M187.0 | Modal Shift: Passenger Vehicles to Bus Public Transport |
| M187.1 | Modal Shift: Passenger Vehicles to Tram Public Transport |
| M194.1 | Improve Passenger Vehicle Technical Efficiency: Diesel |
| M202.0 | Bus Vehicle Technology Shift: BEV |
| M202.1 | Bus Vehicle Technology Shift: FCEV |
| M203.1 | Improve Bus Vehicle Technical Efficiency: Diesel |
| M204.2 | Passenger Rail Vehicle Technology Shift: ICE-CNG |
| M204.0 | Passenger Rail Vehicle Technology Shift: BEV |
| M205.0 | Freight Rail Vehicle Technology Shift: BEV |
| M215.1 | Freight Heavy Duty Vehicle Technology Shift: HDVH FCEV |
| M215.0 | Freight Heavy Duty Vehicle Technology Shift: HDVH BEV |
| M215.10 | Freight Heavy Duty Vehicle Technology Shift: HDVL FCEV |
| M215.9 | Freight Heavy Duty Vehicle Technology Shift: HDVL BEV |

Table 11: Top 5 measures in the Transport Sector

| Measure | Investment (MEUR) | Emission Reduction (Mt CO2) |
|---|---|---|
| M205.0: Freight Rail Vehicle Technology Shift: BEV | 300.52 | 0 |
| M224.5: Shift Fossil Fuels to Synthetic Alternatives: Passenger Diesel | 0.0002 | 0.0002 |
| M224.6: Shift Fossil Fuels to Synthetic Alternatives: Passenger Gasoline | 0.00013 | 0 |
| M224.1: Shift Fossil Fuels to Synthetic Alternatives: Freight Diesel | 0.00052 | 0 |
| M215.5: Freight Heavy Duty Vehicle Technology Shift: HDVM BEV | 8.33 | 0.37 |

#### *5.1.2.8 Conclusion for region ES424*

The results show again that MIDAS provides plausible measure suggestions, but still needs refinement in certain aspects. Especially the land use and the industrial waste reuse needs further work.

## *5.2 Country level: Poland*

To provide more insight into the situation on a country-level, this section provides an insight into the aggregated situation for Poland as an example.

### *5.2.1 Overview*

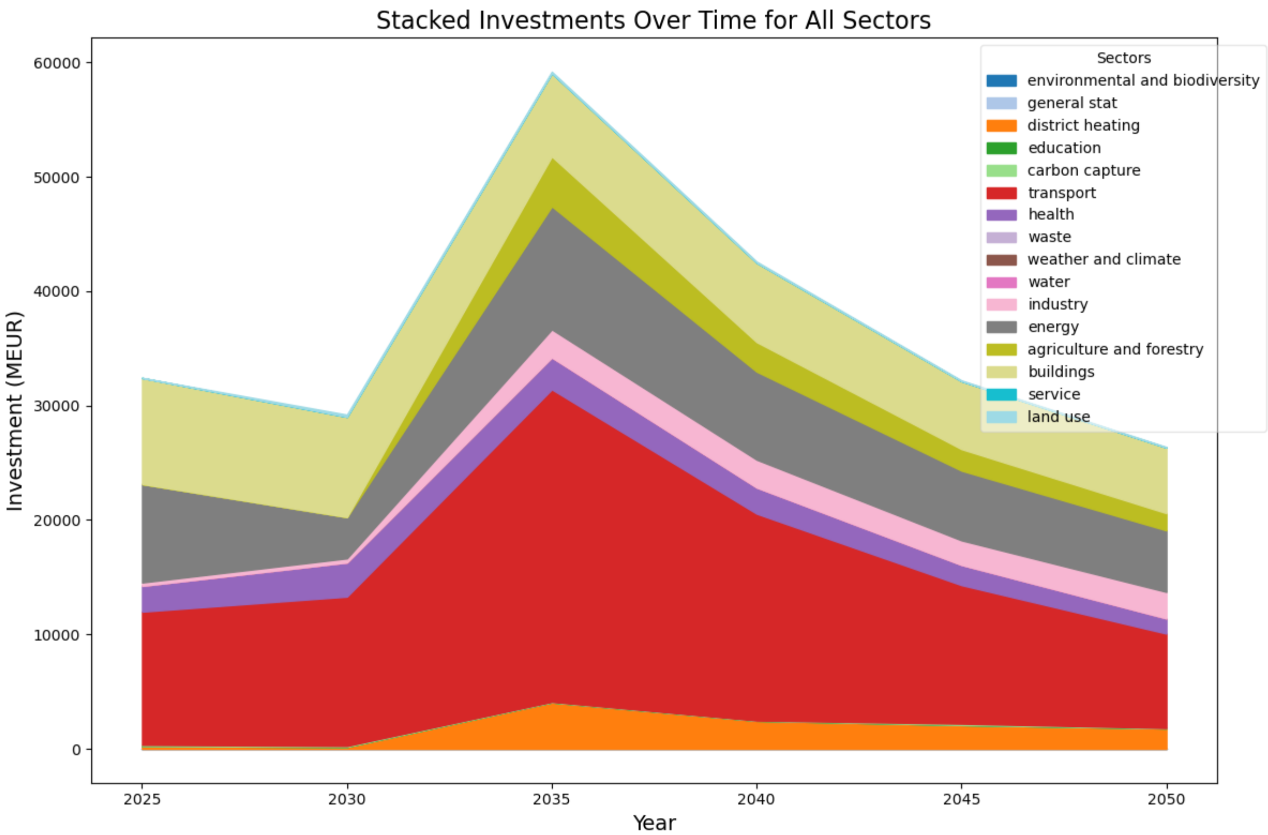


Fig. 21: The investment for measures in Poland is dominated by transport and buildings.

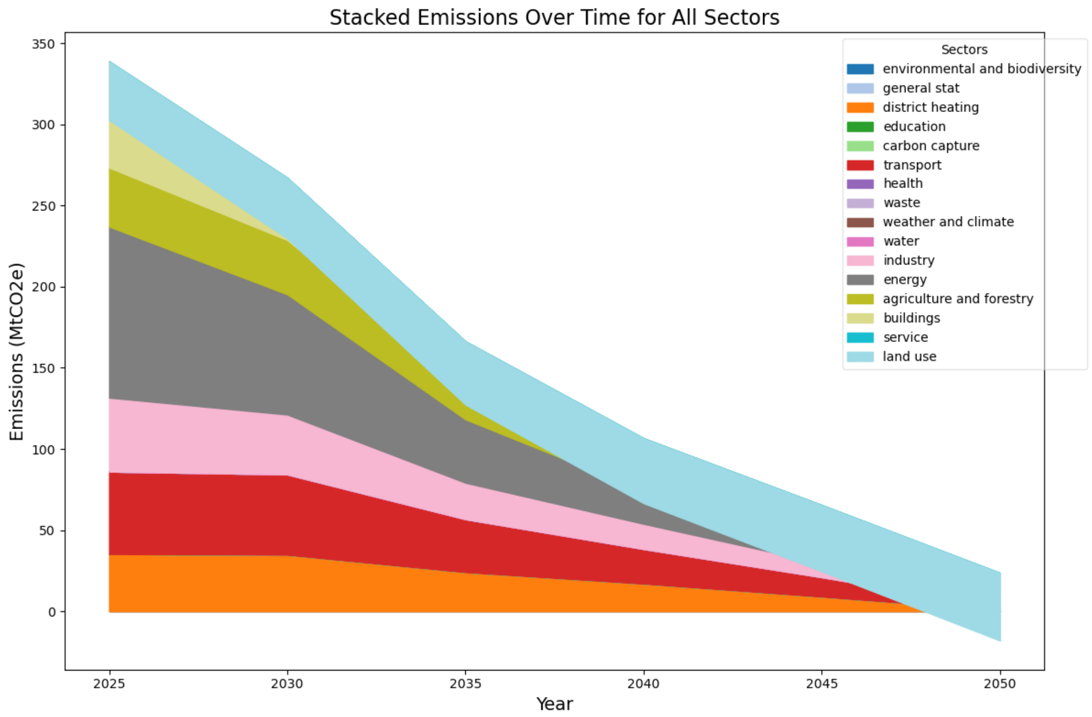


Fig. 22: The emissions in the country are dominated by energy, buildings and industry.

### *5.2.2 Agriculture*

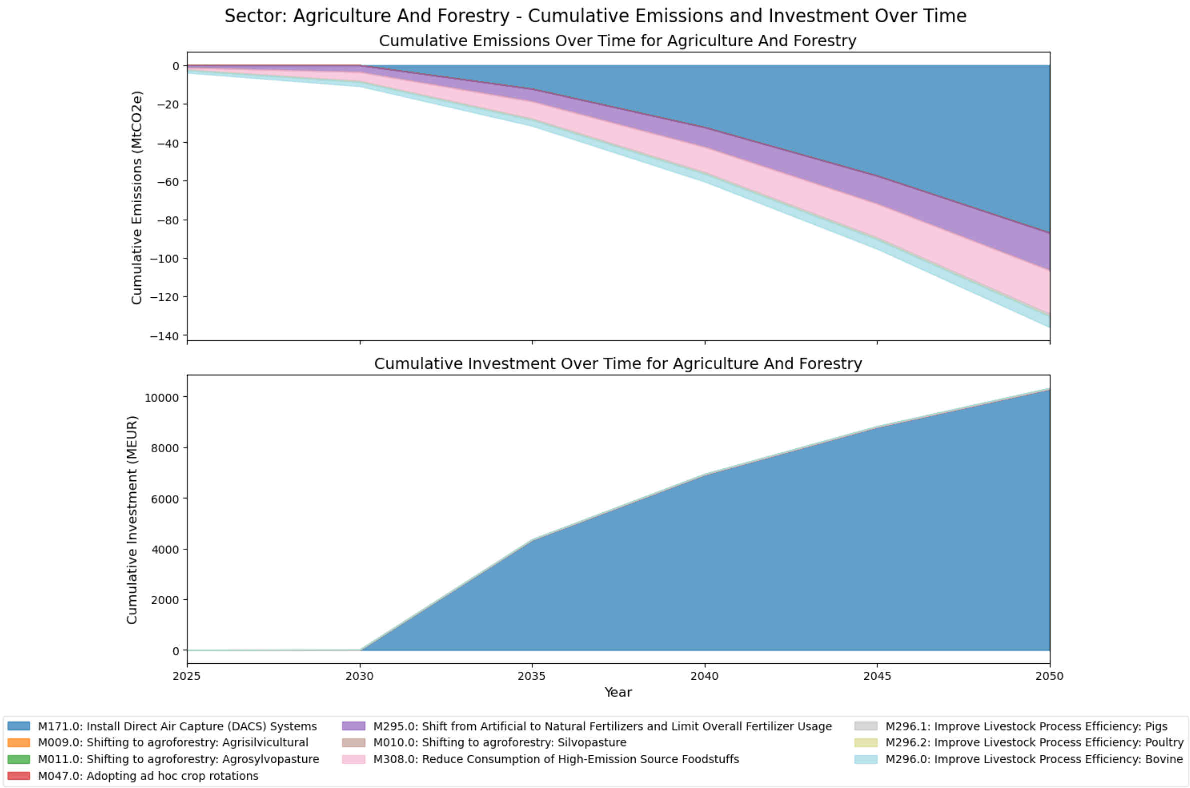


Fig. 23: The measures for the country are centered on reducing fertilizers and reducing high-emission foodstuffs.

Table 21: List of measures with the full measure name

| Measure ID | Name |
|---|---|
| M171.0 | Install Direct Air Capture (DACS) Systems |
| M009.0 | Shifting to agroforestry: Agrisilvicultural |
| M011.0 | Shifting to agroforestry: Agrosylvopasture |
| M010.0 | Shifting to agroforestry: Silvopasture |
| M047.0 | Adopting ad hoc crop rotations |
| M295.0 | Shift from Artificial to Natural Fertilizers and Limit Overall Fertilizer Usage |
| M308.0 | Reduce Consumption of High-Emission Source Foodstuffs |
| M296.1 | Improve Livestock Process Efficiency: Pigs |
| M296.2 | Improve Livestock Process Efficiency: Poultry |
| M296.0 | Improve Livestock Process Efficiency: Bovine |

### 5.2.3 Buildings

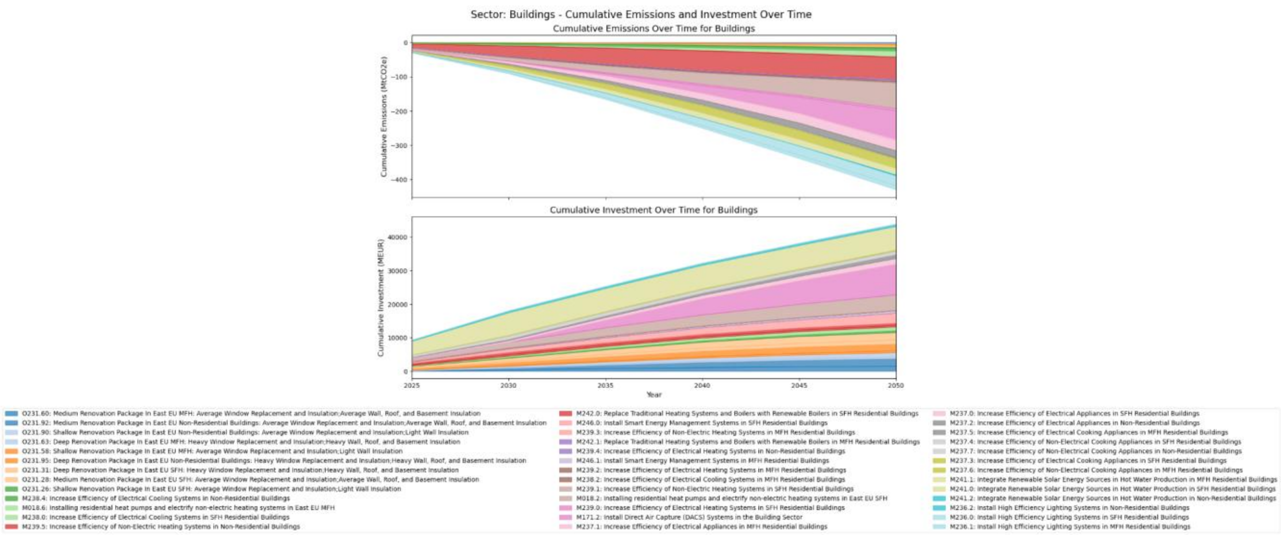


Fig. 24: The building measures are a combination of all building renovation measures, installation of heat pumps and increasing the efficiency of appliances. This seems reasonable.

Table 22: List of measures with the full measure name

| Measure ID | Name |
|---|---|
| O231.60 | Medium Renovation Package in East EU MFH: Average Window Replacement and Insulation; Average Wall, Roof, and Basement |

| | |
|---|---|
| | Insulation |
| O231.92 | Medium Renovation Package in East EU Non-Residential Buildings: Average Window Replacement and Insulation; Average Wall, Roof, and Basement Insulation |
| O231.90 | Shallow Renovation Package in East EU Non-Residential Buildings: Light Wall Insulation |
| O231.63 | Deep Renovation Package in East EU MFH: Heavy Window Replacement and Insulation; Heavy Wall, Roof, and Basement Insulation |
| O231.58 | Shallow Renovation Package in East EU MFH: Light Wall Insulation |
| O231.95 | Deep Renovation Package in East EU Non-Residential Buildings: Heavy Wall, Roof, and Basement Insulation |
| O231.31 | Deep Renovation Package in East EU SFH: Heavy Window Replacement and Insulation; Heavy Wall, Roof, and Basement Insulation |
| O231.82 | Medium Renovation Package in East EU SFH: Average Wall, Roof, and Basement Insulation |
| O231.86 | Shallow Renovation Package in East EU SFH: Light Wall Insulation |
| M238.4 | Increase Efficiency of Electrical Cooling Systems in Non-Residential Buildings |
| M018.6 | Installing residential heat pumps and electrify non-electric heating systems in East EU MFH |
| M238.0 | Increase Efficiency of Electrical Cooling Systems in SFH Residential Buildings |
| M239.5 | Increase Efficiency of Non-Electric Heating Systems in Non-Residential Buildings |
| M242.0 | Replace Traditional Heating Systems and Boilers with Renewable Boilers in SFH Residential Buildings |
| M246.0 | Install Smart Energy Management Systems in SFH Residential Buildings |
| M239.3 | Increase Efficiency of Non-Electric Heating Systems in MFH Residential Buildings |
| M242.1 | Replace Traditional Heating Systems and Boilers with Renewable Boilers in MFH Residential Buildings |
| M239.4 | Increase Efficiency of Electrical Heating Systems in Non-Residential Buildings |

| | |
|---|---|
| M246.1 | Install Smart Energy Management Systems in MFH Residential Buildings |
| M239.2 | Increase Efficiency of Electrical Heating Systems in MFH Residential Buildings |
| M238.2 | Increase Efficiency of Electrical Cooling Systems in MFH Residential Buildings |
| M239.1 | Increase Efficiency of Non-Electric Heating Systems in SFH Residential Buildings |
| M018.2 | Installing residential heat pumps and electrify non-electric heating systems in East EU SFH |
| M239.0 | Increase Efficiency of Electrical Heating Systems in SFH Residential Buildings |
| M171.2 | Install Direct Air Capture (DACS) Systems in the Building Sector |
| M237.1 | Increase Efficiency of Electrical Appliances in MFH Residential Buildings |
| M237.0 | Increase Efficiency of Electrical Appliances in SFH Residential Buildings |
| M237.2 | Increase Efficiency of Electrical Appliances in Non-Residential Buildings |
| M237.5 | Increase Efficiency of Electrical Cooking Appliances in MFH Residential Buildings |
| M237.4 | Increase Efficiency of Non-Electrical Cooking Appliances in SFH Residential Buildings |
| M237.7 | Increase Efficiency of Non-Electrical Cooking Appliances in Non-Residential Buildings |
| M237.3 | Increase Efficiency of Electrical Cooking Appliances in SFH Residential Buildings |
| M237.6 | Increase Efficiency of Non-Electrical Cooking Appliances in MFH Residential Buildings |
| M241.1 | Integrate Renewable Solar Energy Sources in Hot Water Production in MFH Residential Buildings |
| M241.0 | Integrate Renewable Solar Energy Sources in Hot Water Production in SFH Residential Buildings |
| M241.2 | Integrate Renewable Solar Energy Sources in Hot Water Production in Non-Residential Buildings |
| M236.2 | Install High Efficiency Lighting Systems in Non-Residential Buildings |
| M236.0 | Install High Efficiency Lighting Systems in SFH Residential Buildings |

| | |
|---|---|
| M236.1 | Install High Efficiency Lighting Systems in MFH Residential Buildings |

### 5.2.4 Carbon Capture

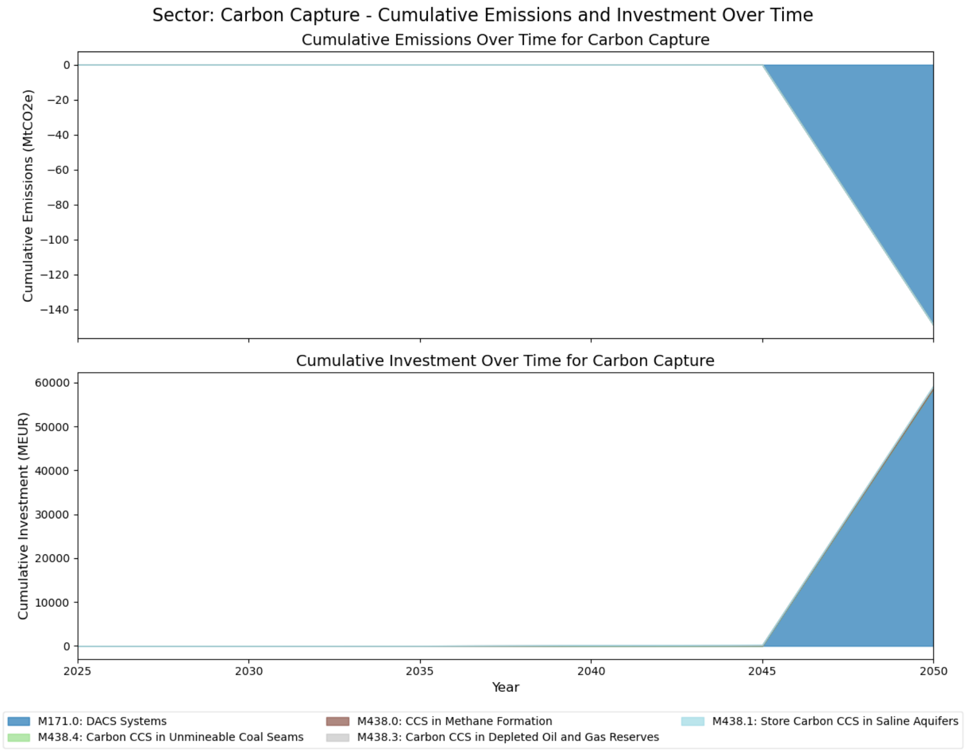


Fig. 25: Carbon capture only really appears after 2025 in most regions and is used to reduce emissions where no other measures are available.

Table 23: List of measures with the full measure name

| Measure ID | Name |
|---|---|
| M171.0 | DACS Systems |
| M438.4 | Carbon CCS in Unmineable Coal Seams |
| M438.0 | CCS in Methane Formation |
| M438.3 | Carbon CCS in Depleted Oil and gas reserves |
| M438.1 | Store carbon CCS in Saline Aquifers |

### *5.2.5 Energy*

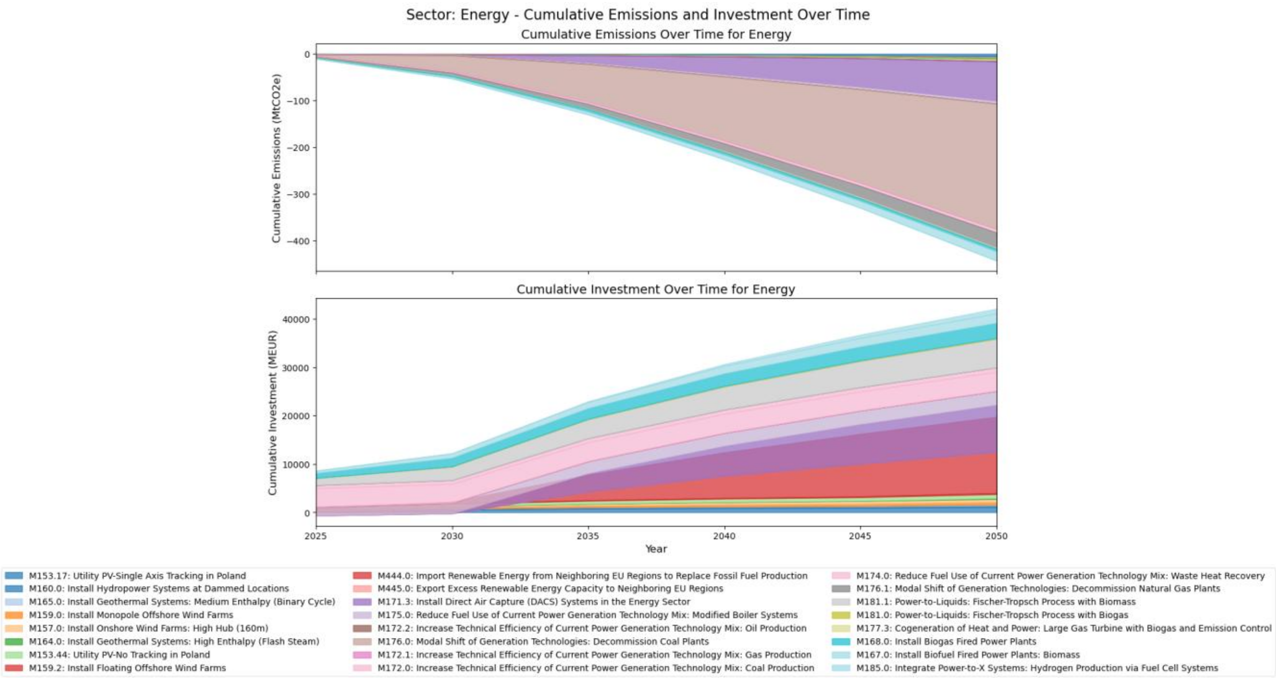


Fig. 26: The energy sector shows a plausible mix of measures of all types, with wind, PV, decarbonisation and hydrogen measures all on display.

Table 24: List of measures with the full measure name

| Measure ID | Name |
|---|---|
| M153.17 | Utility PV: Single Axis Tracking in Poland |
| M160.0 | Install Hydropower Systems at Dammed Locations |
| M165.0 | Install Geothermal Systems: Medium Enthalpy (Binary Cycle) |
| M159.0 | Install Monopile Offshore Wind Farms |
| M157.0 | Install Onshore Wind Farms: High Hub (160m) |
| M164.0 | Install Geothermal Systems: High Enthalpy (Flash Steam) |
| M153.4 | Utility PV: No Tracking in Poland |
| M159.2 | Install Floating Offshore Wind Farms |
| M444.0 | Import Renewable Energy from Neighboring EU Regions to Replace Fossil Fuel Production |
| M445.0 | Export Excess Renewable Energy Capacity to Neighboring EU Regions |
| M171.3 | Install Direct Air Capture (DACS) Systems in the Energy Sector |
| M175.0 | Reduce Fuel Use of Current Power Generation Technology Mix: |

| | |
|---|---|
| | Modified Boiler Systems |
| M172.2 | Increase Technical Efficiency of Power Generation Mix: Oil Production |
| M172.1 | Increase Technical Efficiency of Power Generation Mix: Gas Production |
| M172.0 | Increase Technical Efficiency of Power Generation Mix: Coal Production |
| M174.0 | Reduce Fuel Use of Power Generation Mix: Waste Heat Recovery |
| M176.0 | Modal Shift of Generation Technologies: Decommission Coal Plants |
| M176.1 | Modal Shift of Generation Technologies: Decommission Natural Gas Plants |
| M181.0 | Power-to-Liquids: Fischer-Tropsch Process with Biomass |
| M177.3 | Cogeneration of Heat and Power: Large Gas Turbine with Biogas and Emission Control |
| M168.0 | Install Biogas Fired Power Plants |
| M167.0 | Install Biofuel Fired Power Plants: Biomass |
| M185.0 | Integrate Power-to-X Systems: Hydrogen Production via Fuel Cell Systems |

### 5.2.6 Transport

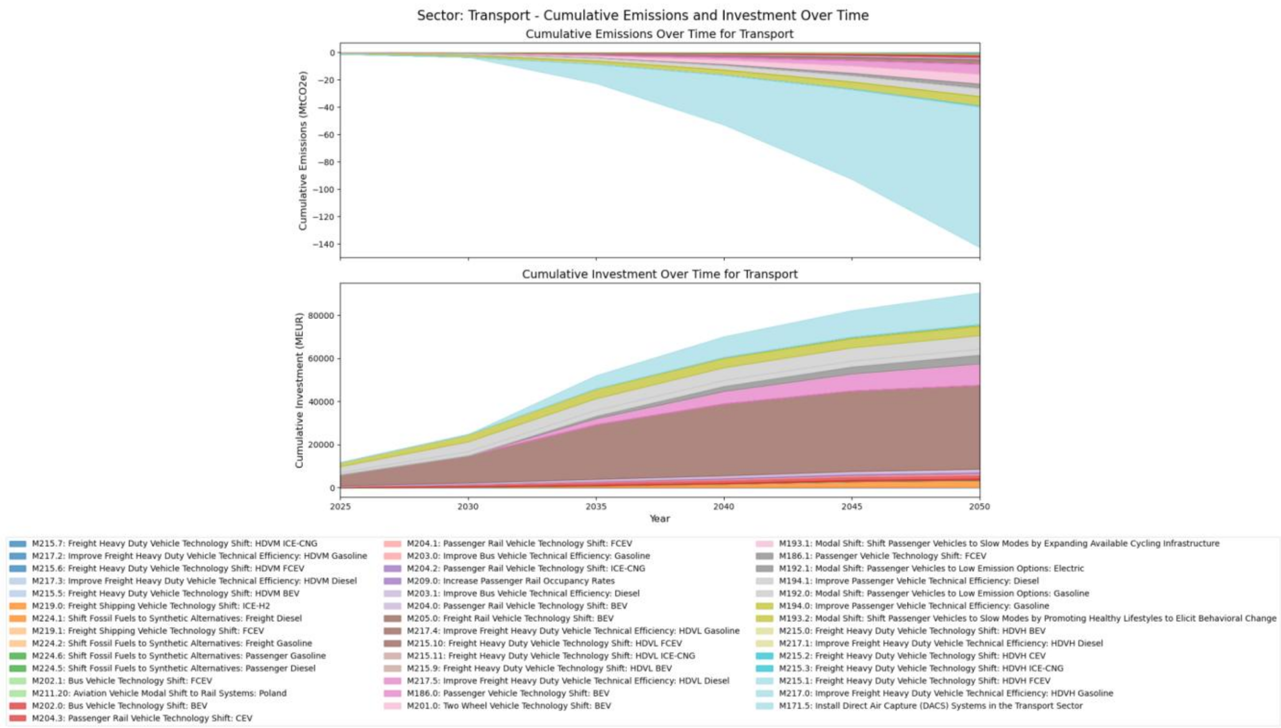


Fig. 27: The transport sector also shows a plausible spread of measures of all types.

Table 25: List of measures with the full measure name

| Measure ID | Name |
|---|---|
| M215.7 | Freight Heavy Duty Vehicle Technology Shift: HDVM ICE-CNG |
| M217.2 | Improve Freight Heavy Duty Vehicle Technical Efficiency: HDVM Gasoline |
| M215.6 | Freight Heavy Duty Vehicle Technology Shift: HDVM FCEV |
| M217.3 | Improve Freight Heavy Duty Vehicle Technical Efficiency: HDVM Diesel |
| M215.5 | Freight Heavy Duty Vehicle Technology Shift: HDVM BEV |
| M219.0 | Freight Shipping Vehicle Technology Shift: ICE-H2 |
| M224.1 | Shift Fossil Fuels to Synthetic Alternatives: Freight Diesel |
| M224.2 | Shift Fossil Fuels to Synthetic Alternatives: Freight Gasoline |
| M224.6 | Shift Fossil Fuels to Synthetic Alternatives: Passenger Gasoline |
| M224.5 | Shift Fossil Fuels to Synthetic Alternatives: Passenger Diesel |
| M211.0 | Aviation Vehicle Modal Shift to Rail Systems: Poland |
| M204.3 | Passenger Rail Vehicle Technology Shift: CEV |
| M204.1 | Passenger Rail Vehicle Technology Shift: FCEV |
| M203.0 | Improve Bus Vehicle Technical Efficiency: Gasoline |
| M204.6 | Freight Rail Vehicle Technology Shift: BEV |
| M202.0 | Bus Vehicle Technology Shift: BEV |
| M202.1 | Bus Vehicle Technology Shift: FCEV |
| M215.10 | Freight Heavy Duty Vehicle Technology Shift: HDVL Gasoline |
| M215.0 | Freight Heavy Duty Vehicle Technology Shift: HDVH FCEV |
| M215.1 | Freight Heavy Duty Vehicle Technology Shift: HDVH ICE-CNG |
| M215.9 | Freight Heavy Duty Vehicle Technology Shift: HDVL BEV |
| M217.5 | Improve Freight Heavy Duty Vehicle Technical Efficiency: HDVH Diesel |
| M186.0 | Passenger Vehicle Technology Shift: BEV |
| M193.1 | Modal Shift: Passenger Vehicles to Slow Modes by Expanding Available Cycling Infrastructure |
| M192.1 | Modal Shift: Passenger Vehicles to Low Emission Options: Electric |

| | |
|---|---|
| M192.0 | Modal Shift: Passenger Vehicles to Low Emission Options: Gasoline |
| M193.4 | Modal Shift: Shift Passenger Vehicles to Slow Modes by Promoting Healthy Lifestyles to Elicit Behavioral Change |
| M171.5 | Install Direct Air Capture (DACS) Systems in the Transport Sector |

### *5.2.7 Industry*

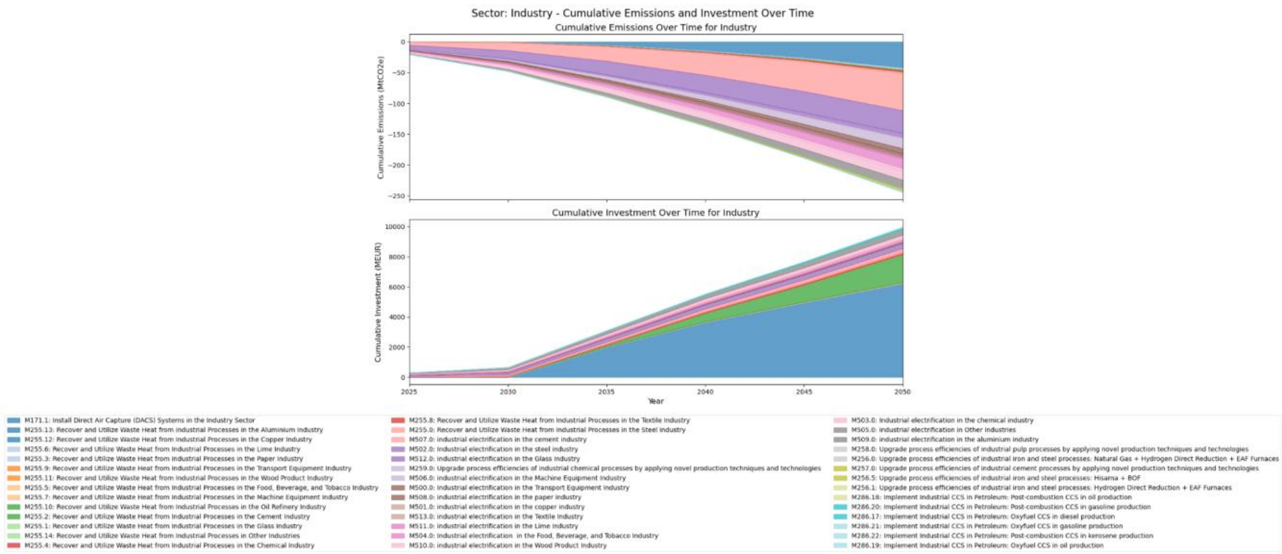


Fig. 28: The industry sector needs further refinement. The cost assumptions about waste heat reuse and the maximum potential are only a first approximation currently based on the sources in the literature mentioned in the measure database.

Table 26: List of measures with the full measure name

| Measure ID | Name |
|---|---|
| M255.0 | Recover and Utilize Waste Heat from Industrial Processes in the Steel Industry |
| M255.1 | Recover and Utilize Waste Heat from Industrial Processes in the Glass Industry |
| M255.2 | Recover and Utilize Waste Heat from Industrial Processes in the Cement Industry |
| M255.3 | Recover and Utilize Waste Heat from Industrial Processes in the Paper Industry |
| M255.4 | Recover and Utilize Waste Heat from Industrial Processes in the Chemical Industry |
| M255.5 | Recover and Utilize Waste Heat from Industrial Processes in the Food, Beverage, and Tobacco Industry |

| | |
|---|---|
| M255.6 | Recover and Utilize Waste Heat from Industrial Processes in the Lime Industry |
| M255.7 | Recover and Utilize Waste Heat from Industrial Processes in the Machine Equipment Industry |
| M255.8 | Recover and Utilize Waste Heat from Industrial Processes in the Textile Industry |
| M255.9 | Recover and Utilize Waste Heat from Industrial Processes in the Transport Equipment Industry |
| M255.10 | Recover and Utilize Waste Heat from Industrial Processes in the Oil Refinery Industry |
| M255.11 | Recover and Utilize Waste Heat from Industrial Processes in the Wood Product Industry |
| M255.12 | Recover and Utilize Waste Heat from Industrial Processes in the Copper Industry |
| M255.13 | Recover and Utilize Waste Heat from Industrial Processes in the Aluminium Industry |
| M255.14 | Recover and Utilize Waste Heat from Industrial Processes in Other Industries |
| M501.0 | Industrial Electrification in the Copper Industry |
| M502.0 | Industrial Electrification in the Steel Industry |
| M503.0 | Industrial Electrification in the Chemical Industry |
| M504.0 | Industrial Electrification in the Food, Beverage, and Tobacco Industry |
| M505.0 | Industrial Electrification in Other Industries |
| M507.0 | Industrial Electrification in the Cement Industry |
| M508.0 | Industrial Electrification in the Transport Equipment Industry |
| M509.0 | Industrial Electrification in the Aluminium Industry |
| M510.0 | Industrial Electrification in the Wood Product Industry |
| M511.0 | Industrial Electrification in the Lime Industry |
| M512.0 | Industrial Electrification in the Glass Industry |
| M513.0 | Industrial Electrification in the Textile Industry |
| M256.1 | Upgrade Process Efficiencies of Industrial Iron and Steel Processes: Hydrogen Direct Reduction + EAF Furnaces |
| M256.5 | Upgrade Process Efficiencies of Industrial Iron and Steel Processes: |

| | |
|---|---|
| | HIsarna + BOF |
| M257.0 | Upgrade Process Efficiencies of Industrial Cement Processes by Applying Novel Production Techniques and Technologies |
| M258.0 | Upgrade Process Efficiencies of Industrial Iron and Steel Processes: Natural Gas + Hydrogen Direct Reduction + EAF Furnaces |
| M258.1 | Upgrade Process Efficiencies of Industrial Pulp Processes by Applying Novel Production Techniques and Technologies |
| M259.0 | Upgrade Process Efficiencies of Industrial Chemical Processes by Applying Novel Production Techniques and Technologies |
| M286.17 | Implement Industrial CCS in Petroleum: Oxyfuel CCS in Diesel Production |
| M286.18 | Implement Industrial CCS in Petroleum: Post-Combustion CCS in Oil Production |
| M286.19 | Implement Industrial CCS in Petroleum: Oxyfuel CCS in Oil Production |
| M286.20 | Implement Industrial CCS in Petroleum: Post-Combustion CCS in Gasoline Production |
| M286.21 | Implement Industrial CCS in Petroleum: Oxyfuel CCS in Gasoline Production |
| M286.22 | Implement Industrial CCS in Petroleum: Post-Combustion CCS in Kerosene Production |
| M171.1 | Install Direct Air Capture (DACS) Systems in the Industry Sector |

### *5.2.8 Conclusion*

The results show that the modeling approach is basically sound, and some sectors yield very decent results already, but further refinement is needed in the next few months.

## *5.3 EU Level*

To give an impression of the overall results, this section contains the aggregated measures for all of Europe.

### 5.3.1 Overview

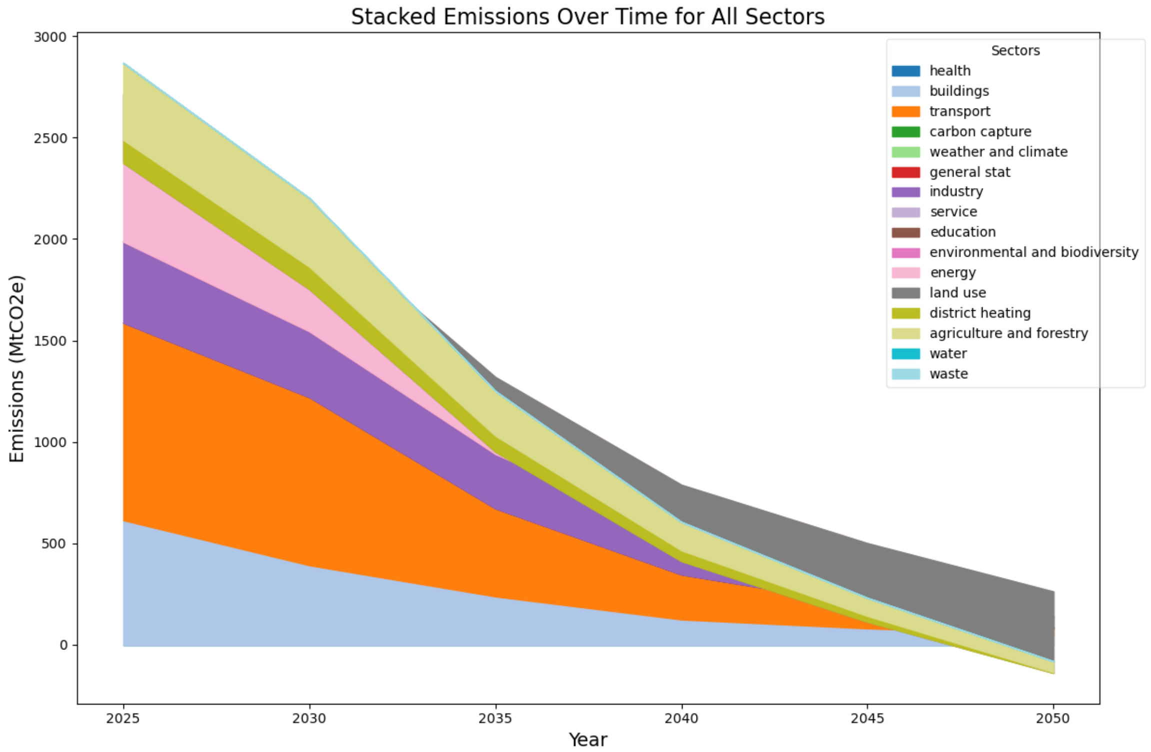


Fig. 29: The total emissions breakdown looks plausible and is even trending very slightly negative towards 2050.

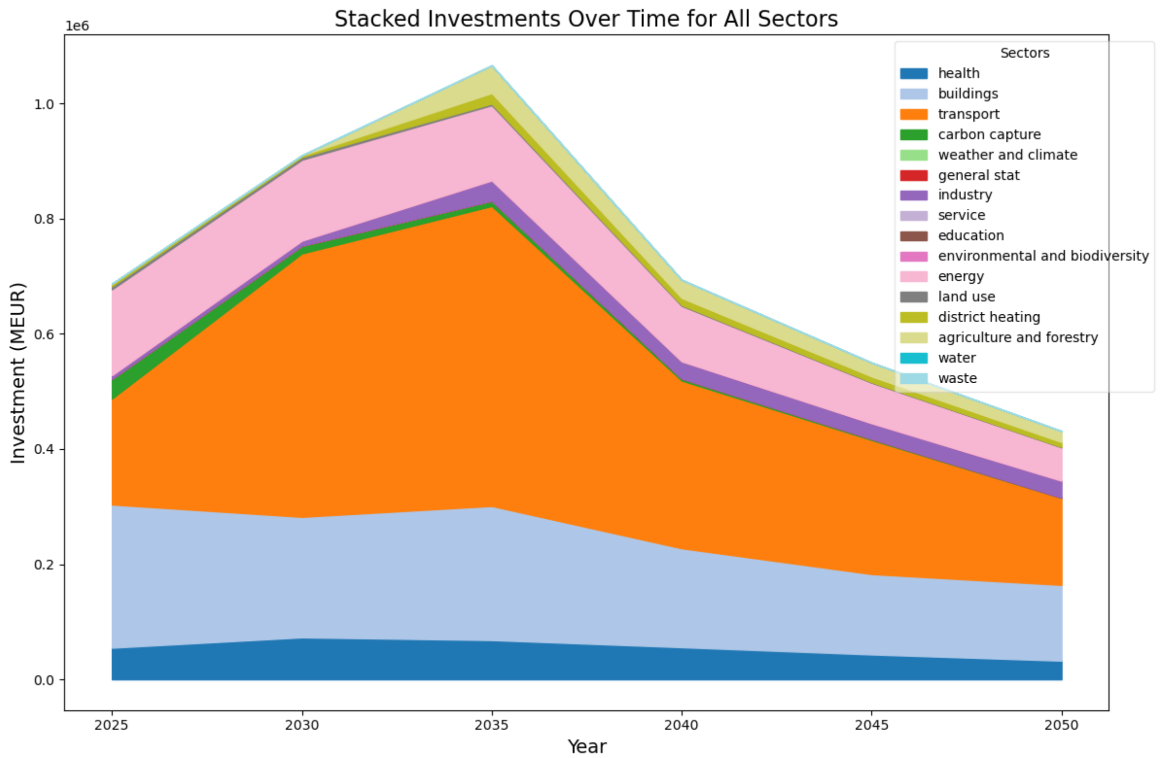


Fig. 30: The stacked investment for the EU shows that especially the transport sector will require major investments in the next 10 years to invest in public transport.

### *5.3.2 Buildings*

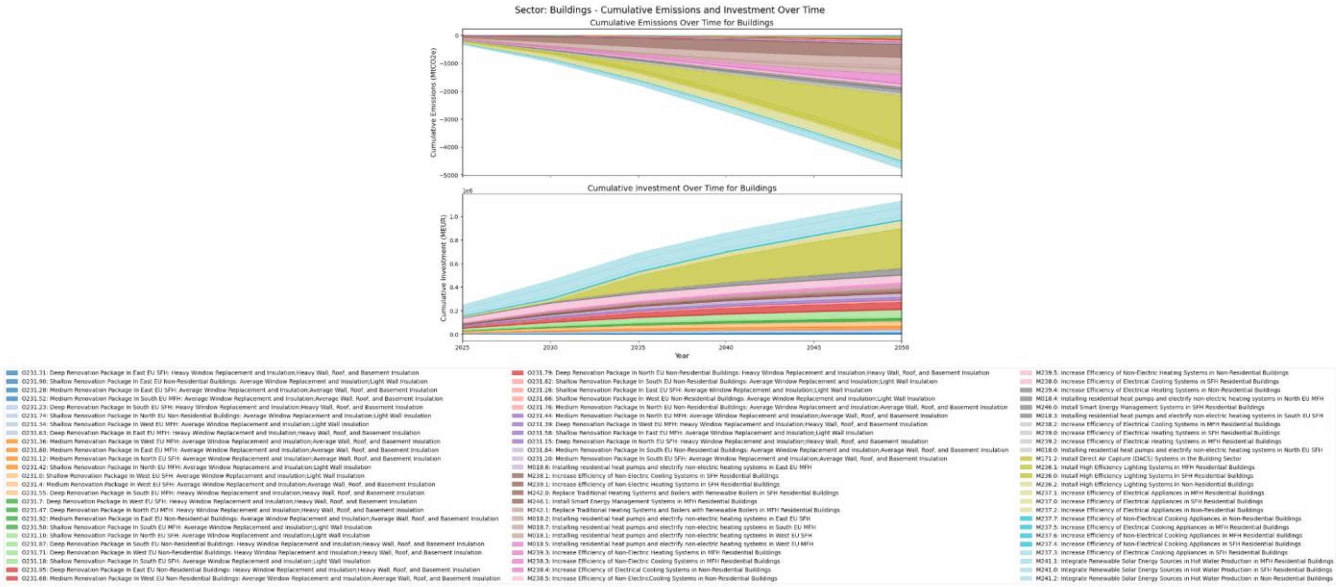


Fig. 31: The building sector shows a good spread of measures. The reason for the many different renovation measures is that renovations heavily depend on the local building stock and therefore need different measures.

### *5.3.3 Agriculture*

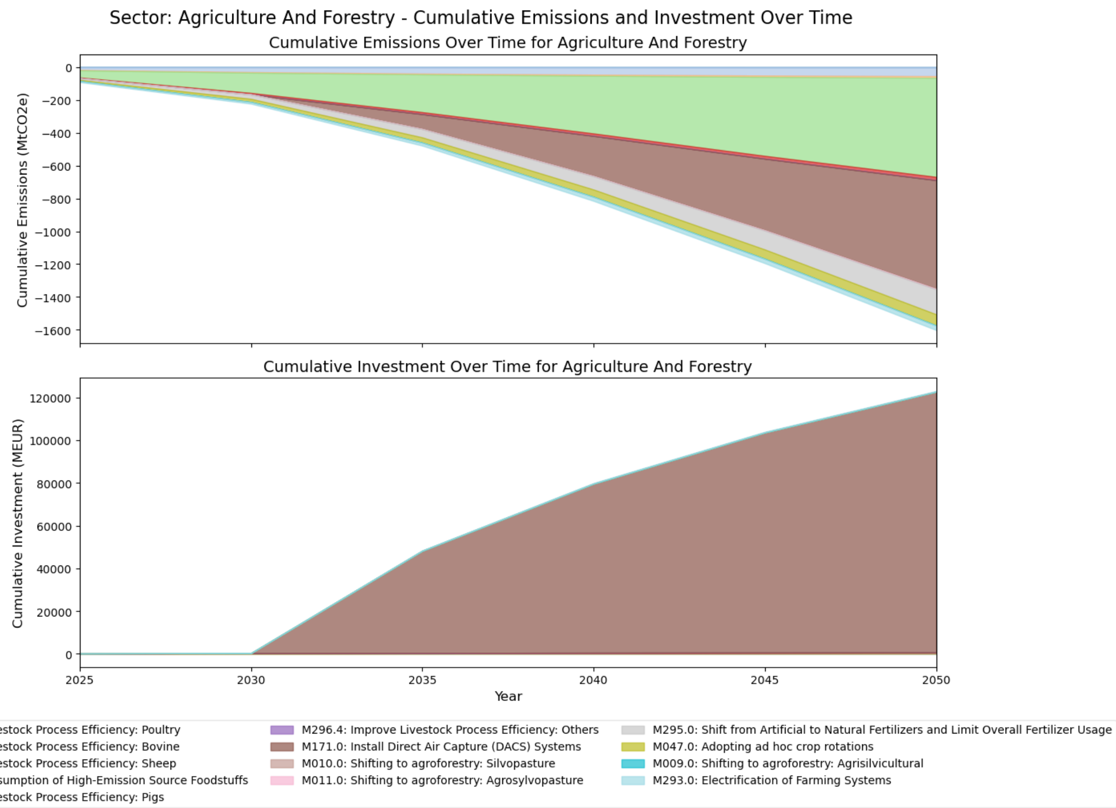


Fig. 32: The European forestry sector will need further refining. The main measures are electrification, fertilizer replacement and efficiency increases.

### *5.3.4 Carbon Capture*

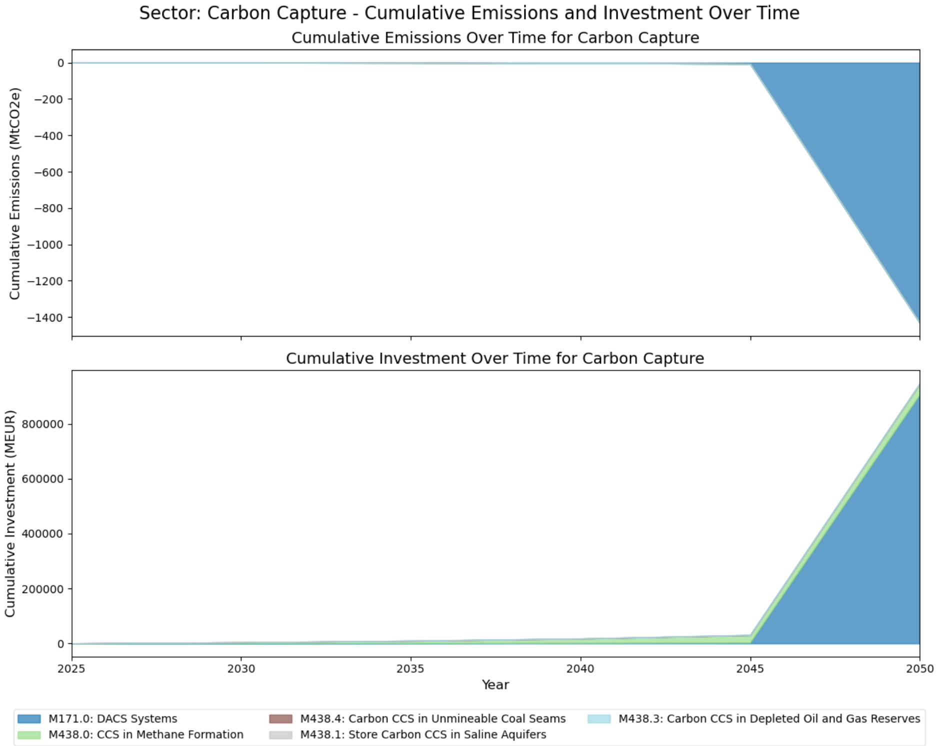


Fig. 33: Carbon capture shows a realistic profile: It’s only used as measure of last resort towards 2050. The absolute numbers will still be corrected, since it’s used to reach net-zero for any emissions that are not yet resolved with measures.

### *5.3.5 Energy*

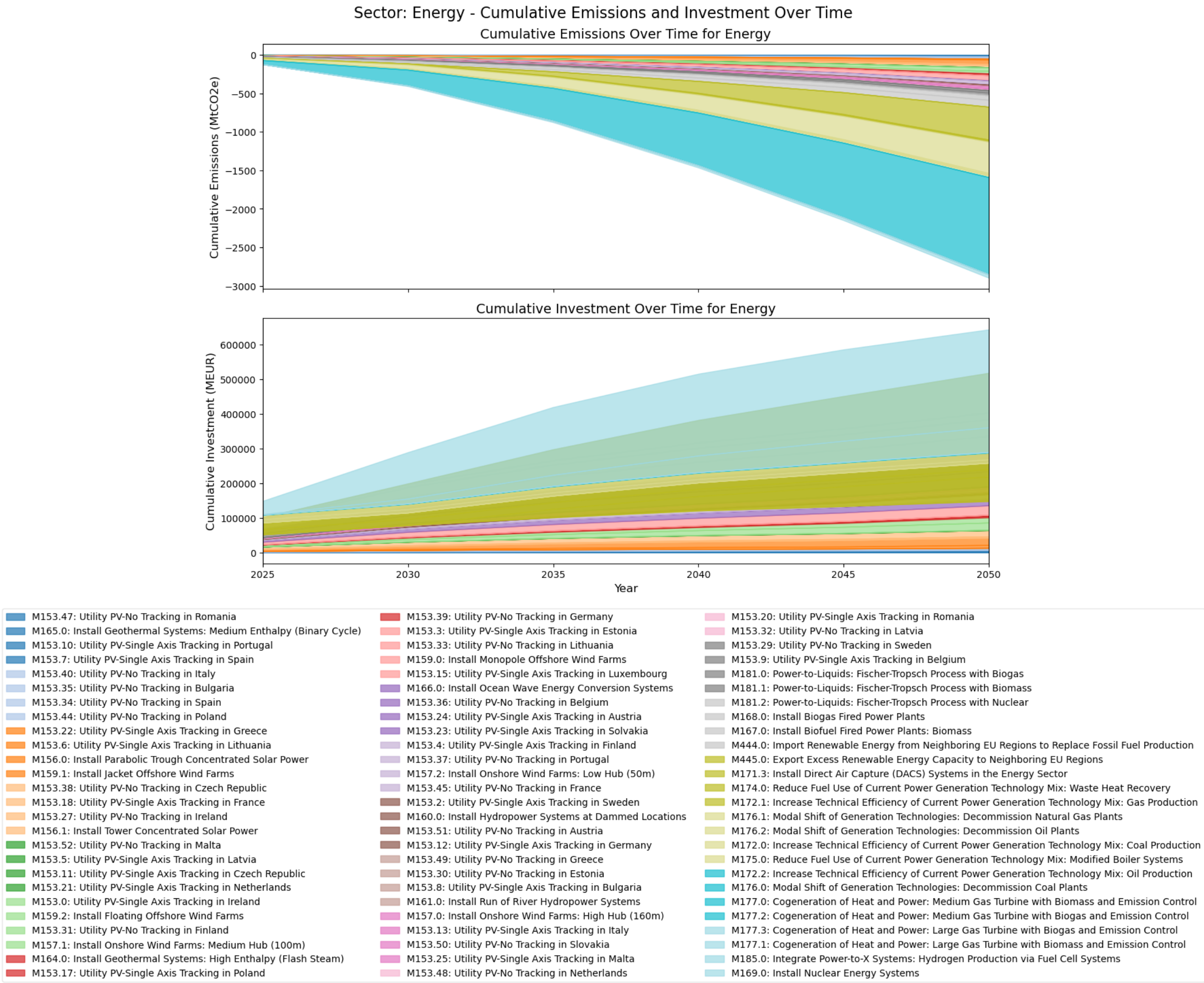


Fig. 34: The energy sector in Europe also shows a good spread across measures. Since costs and energy generation vary wildly across countries for e.g. photovoltaics, there's individual measures for different regions.

### 5.3.6 Transport

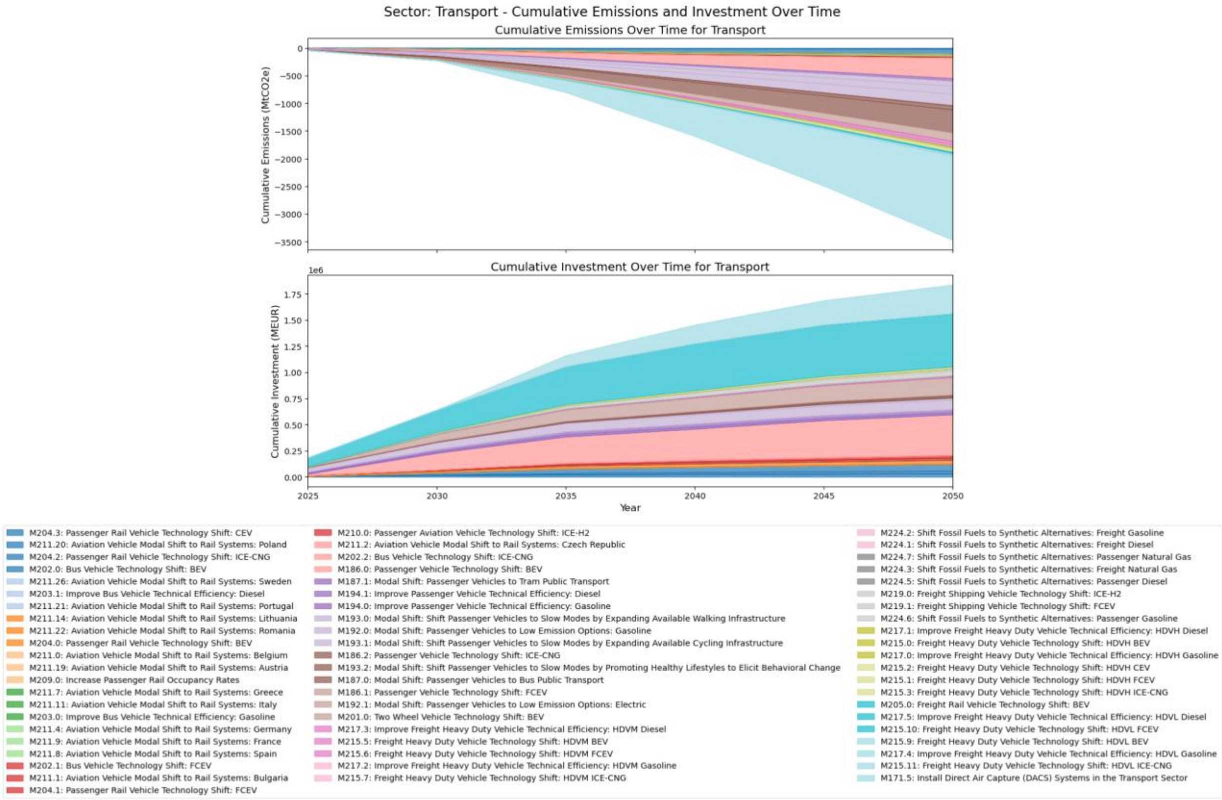


Fig. 35: The transport sector also shows a good spread of measures across Europe. Some of the measures still need further refinement though. It is noteworthy that these pathways are based on the EUCalc projections, and thus the fuel cell vehicle projection is high compared with more recent pathways.

### 5.3.7 Industry

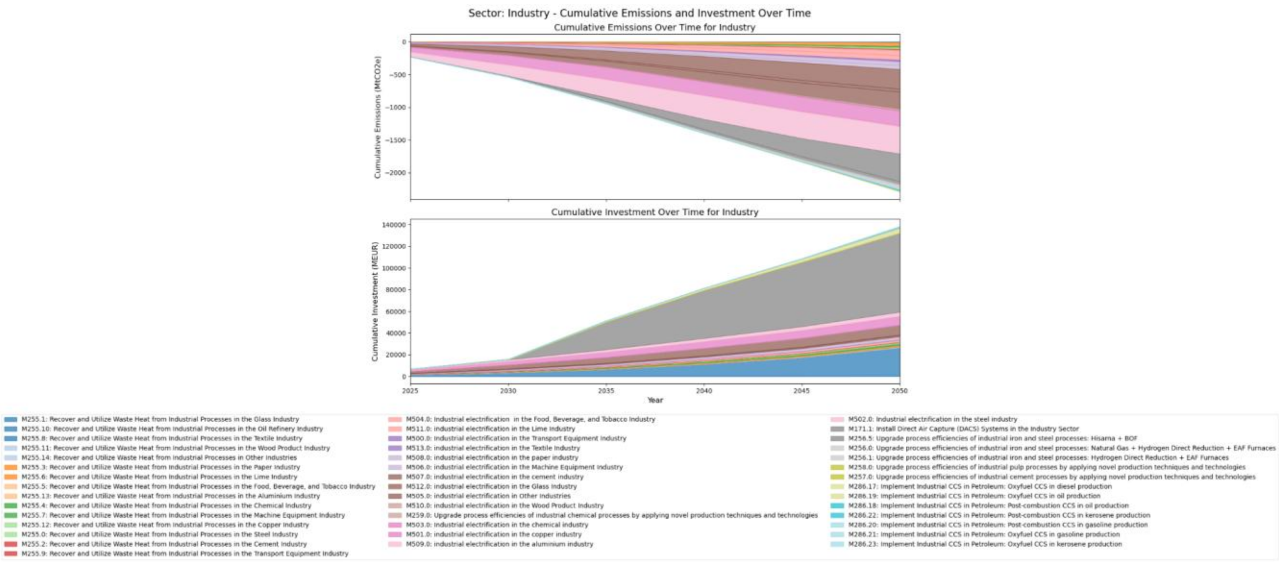


Fig. 36: The industry sector needs further refinement, since it still needs additional measures and constrains.

### 5.3.8 Land Use

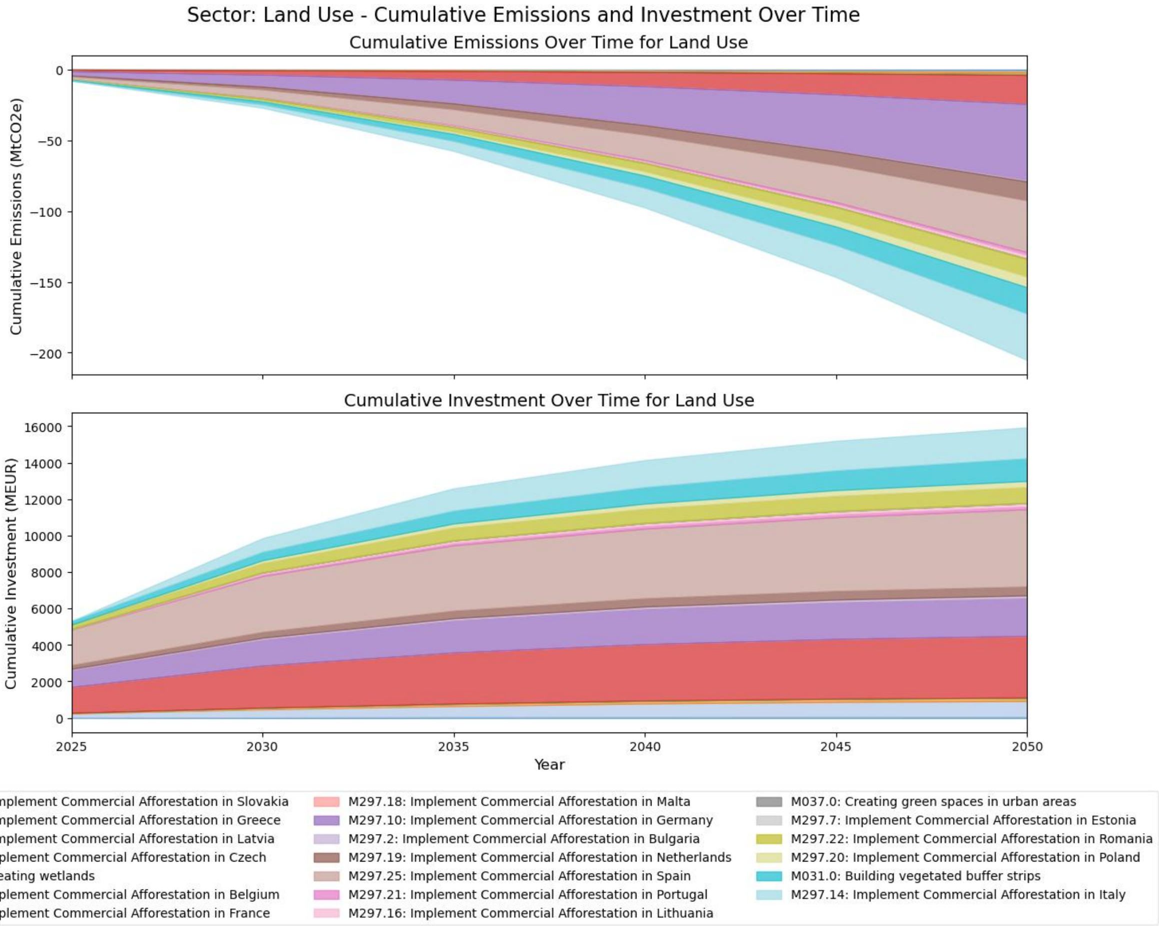


Fig. 37: Some of the measures in the land use sector need further constraints, since for example afforestation right now is strongly overrepresented in the results.

# 6 Validation and Quality Assurance

Validating the outputs of a decarbonization model is essential to ensure the credibility, accuracy, and real-world applicability of the strategies it generates. Without rigorous validation, flawed assumptions or internal inconsistencies may go unnoticed, potentially resulting in ineffective policy recommendations or misallocated investments.

Although the validation framework is still under development, several key strategies are planned to assess the robustness of the MIDAS model:

**Measure-Level Validation with GCoM**:
The mitigation measures included in the model's database will be validated against the Global Covenant of Mayors for Climate & Energy (GCoM), which provides a comprehensive repository of local climate action plans. By cross-referencing MIDAS measures with those documented in GCoM, we can assess their practicality and

alignment with real-world decarbonization efforts at the local level.

**Contextual Validation Using Regional Socioeconomic Profiles**:
To verify whether the proposed mitigation strategies are contextually appropriate, the model will incorporate socioeconomic and regional characteristics—such as population size, level of urbanization, and dominant economic sectors. These profiles help ensure that the recommended measures are tailored to each region's capabilities and constraints.

**Investment-Efficiency Scaling Analysis**:
This validation step involves examining the relationship between input investments and output efficiency, such as emission reductions. The goal is to confirm that the model exhibits realistic scaling behavior, where larger investments result in proportionally greater impacts, reflecting empirical trends.

**Cross-Regional Comparison**:
The outputs of different regional analyses will be compared to assess whether the model appropriately accounts for region-specific constraints. This step helps validate that the optimization results are not generic, but genuinely responsive to local conditions.

**Cross-Model Benchmarking (if feasible)**:
Where possible, MIDAS outputs will be compared with results from other established decarbonization models operating under similar assumptions. This cross-model comparison provides an additional layer of validation, reinforcing confidence in the accuracy and relevance of the model's outcomes.

# 7 Conclusions

This deliverable and the examples showed that the MIDAS model is delivering feasible results for all regions, but there is still some validation that remains to be done. The results show a good spread of measures across different sectors, aggregated countries reach net-zero and individual regions mostly show expected measures. Some sectors, such as industry or energy still need further refinement. Especially the energy sector is challenging to model on a regional level, since for example power plants tend to also supply neighboring regions.

# 8 References

Patil, S.; Verstraete, J.; Pflugradt, N. (2024), Disaggregation Methodology and Working Disaggregation Tool (LOCALISED Deliverable 3.1)

Verstraete, J.; Patil, S.; Pflugradt, N., Radziszewska W. (2023), Database with all relevant data for the year 2020 (LOCALISED Deliverable 3.3)

Martinez Görbig, G.; Flacke, J., Keller, M., Reckien, D. (2022), Database of current, planned and potential adaptation and mitigation measures (LOCALISED Deliverable 4.1)

Seshadri, A.; Keller, M.; Hezel, B.; Pflugradt, N. (2023), Definition of Application Programming Interface (LOCALISED Deliverable 4.2)

Reckien, D.; Pflugradt, N.; Ghaddar, T.; Görbig, G.; Flacke, J. (2025), Report of risk and vulnerability levels in each NUTS3 region resulting from mitigation trajectories as well as entailing feasible adaptation measures (LOCALISED Deliverable 4.5)

# Appendix 1: Example Measure Definition


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.2",
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Rios, Camilo; Melica, Giulia; Treville, Aldo; Bertoldi, Paolo (2023): GCoM - MyCovenant,
4th Release - March 2023. European Commission, Joint Research Centre (JRC) [Dataset] PID:
http://data.europa.eu/89h/b425918f-53a1-495c-8619-cd370c302eb0"
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