



**Alliance for Modelling Industries towards the  
Green Deal's objectives And circuLArity**

## **D1.1 - Decision framework & integrated model architecture design**

### **Lead Beneficiary: TNO**

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## Note to the reader

This document delivers the blueprint of the AMIGDALA modelling framework. Hence it is full of ambition and may therefore contain ideas that might not be realised, realised partially or in a different way than described in this document.

For the project's final scope of delivery the agreed project proposal remains leading.

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## AMIGDALA Project Summary

Achieving climate neutrality by 2050, as envisioned in the European Green Deal, poses a multi-faceted challenge. Europe must foster a sustainable industrial sector that is not only climate-neutral but also globally competitive and resilient. This transformation requires strategic foresight to navigate the complex interplay of demand, global trade, and industrial production.

Decision-makers face critical choices, from crafting policies and regulations to investing in advanced technologies for public infrastructure and industrial assets. Supporting these decisions with actionable insights is essential to steering the evolution of the basic industry within the European Union.

The EU-funded AMIGDALA project aims to provide public and private decision-makers with insights from scenario analysis. The analysis is augmented by computer models to project transformation pathways towards climate neutral destinations. The scenarios are grounded in economic indicators and options to drive change that both policymakers and industry leaders can recognize and act upon.

To reduce the number of exogenous parameters, AMIGDALA is developing a modelling tool that integrates models from different domains. This integrated tool will link critical factors such as demand and trade, industrial production, energy and feedstock consumption, and climate effects. The data will span historical timelines from 1990 and make projections up to 2070, offering a comprehensive view of industrial transformation.

Additionally, the project will analyse local decision-making by industry clusters and utility operators. These insights will illuminate the practical implications of various pathways toward climate neutrality.

## Public summary of this document

Basic industries such as cement, steel, chemicals, and glass manufacturing require vast amounts of energy and generate unavoidable process-emissions. To reduce CO<sub>2</sub> emissions and become climate neutral, these industries must transition to non-fossil sources for energy and feedstock. This involves increasing the use of renewable energy, reusing waste materials, and integrating biomass into their processes.

The goal of this project is to analyse transformation pathways of the basic industries in Europe. To explore transition scenarios, we develop a computer model that shows how a combination of low-carbon energy systems and basic industries in Europe can achieve climate neutrality. The model incorporates methods for renewable energy generation, low-carbon industrial production, agricultural and forestry practices, and circular use of products and materials.

This document outlines the project team's perspective on the challenges, the planned approach, and the tools that will be developed to provide insights into achieving climate-neutral industrial production in Europe.

## Executive summary of this document

This document provides the blueprint of the AMIGDALA framework.

This framework will consist of a computer model and scenarios analysis to make projections of basic industry in Europe that is not only climate neutral, but also globally competitive and resilient.

Special features of the AMIGDALA framework are an integrated computer model and analysis of decision-making by public and private stakeholders. The computer model integrates established models of the energy system, industrial and soil-based production, demand and trade. The decision-analysis provides insights in the circumstances, as they are perceived by different stakeholder groups, that lead to their decisions to issue regulation, invest in clean production technologies or divest from uneconomic assets.

This document first provides the function of the AMIGDALA framework as a whole to deliver pathways to climate neutrality for the European basic industry. Climate neutrality is the result of switching industrial production to renewable energy sources and feedstock based on circular & renewable sources. The energy and feedstock can either be sourced from within Europe or be imported. At the same time European industry needs to be globally competitive and resilient, in the interest of European strategic autonomy and to make the new assets investable from a business perspective.

This document finally contains the description of the AMIGDALA framework, which consists of nine dependent modules. This deliverable contains functional descriptions of each module and technical specifications to define the interactions with the other modules. This enables to start the activities for constructing each module by one of the four expertise groups of the project.

This blueprint concludes Work package 1 and it is the basis for the proof of concept that will be delivered in Work package 2.

## Acronyms and abbreviations

|             |                                          |
|-------------|------------------------------------------|
| <b>CBAM</b> | Carbon Border Adjustment Mechanism       |
| <b>CCUS</b> | Carbon Capture, Utilization, and Storage |
| <b>GDP</b>  | Gross Domestic Product                   |
| <b>MAVT</b> | Multi Attribute Value Theory             |
| <b>MCDA</b> | Multi Criteria Decision Analysis         |
| <b>NPV</b>  | Net Present Value                        |
| <b>SSP</b>  | Shared Socio-economic Pathway            |
| <b>WP</b>   | Work Package                             |
| <b>MACC</b> | Marginal Abatement Cost Curve            |
| <b>ROW</b>  | Rest of World                            |

## Glossary

|                               |                                                                                                                                                                                                                                  |
|-------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>AMIGDALA CONCEPT</b>       | The combination of decision-making analysis with integrated multi-domain modelling for making projections.                                                                                                                       |
| <b>AMIGDALA FRAMEWORK</b>     | Structure in which the modules of the AMIGDALA framework work together.                                                                                                                                                          |
| <b>MODULES</b>                | Distinct functional units that operate within the AMIGDALA framework.                                                                                                                                                            |
| <b>SCENARIO BUILDING</b>      | Expertise focussed on scenario analysis, to develop consistent (foreground and background) scenarios and control levers on a global, EU and local level.                                                                         |
| <b>INTEGRATED MODELLING</b>   | Expertise to develop a consistent and converging integrated model suite to analyse energy, material and climate system transitions and their impacts at global, EU and local level.                                              |
| <b>DATA MANAGEMENT</b>        | Expertise on data management and data validation.                                                                                                                                                                                |
| <b>DECISION ANALYSIS</b>      | Expertise on decision support, decision analysis and dashboard display.                                                                                                                                                          |
| <b>INTEGRATED MODEL SUITE</b> | Module consisting of a combination of models on economy and trade, feedstock and energy, circularity and environment to analyse energy, material and climate system transitions and their impacts at global, EU and local level. |
| <b>DATA EXPLORER</b>          | Module consisting of combination of data repository, historical data and data output from models.                                                                                                                                |
| <b>SCENARIO MODULE</b>        | Module consisting of combination of drivers, archetypes and control levers.                                                                                                                                                      |

|                                   |                                                                                                                                                                                              |
|-----------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>DECISION SUPPORT DASHBOARD</b> | Module consisting of the graphical user interface and interaction process for the application of the decision analysis logic.                                                                |
| <b>DATA REPOSITORY</b>            | Module consisting all existing data-sets that are already used by the models.                                                                                                                |
| <b>DECISION-MAKER</b>             | Roles in governmental and industry organizations that have a mandate to formalise and implement decisions.                                                                                   |
| <b>PARAMETER</b>                  | piece of information identified in interviews                                                                                                                                                |
| <b>INDICATOR</b>                  | A parameter that decision-makers find relevant to assess the situation from their perspective and that may drive the decisions                                                               |
| <b>CONTEXT</b>                    | Larger environment that puts a perspective on the themes                                                                                                                                     |
| <b>THEME</b>                      | Categories that group parameters into coherent subjects                                                                                                                                      |
| <b>KEY PERFORMANCE INDICATOR</b>  | Sub-set of indicators that are high-graded for their relevance across government and industry                                                                                                |
| <b>CONTROL LEVER</b>              | Control options that decision-makers have to influence reaching the Green Deal objectives. The levers can be actuated through e.g. subsidies, pricing, mandates, investments or divestments. |

## Guidance notes for the document

The AMIGDALA **project** has brought partners together around the challenge to deliver modelling insights for advanced scenario projections in support of policy development and investment decisions required for a transformation to a sustainable European industry.

The AMIGDALA **concept** is the partnership's approach to address the challenge to develop advanced foresight on what may be climate neutral, competitive and resilient configurations of the energy intensive industries in Europe.

The AMIGDALA **framework** is the combination of modules in which the solutions that we develop materialise.

## Current project phase

This document finalises Work Package 1, in which we design the framework and specify which features of the concept we need to develop and how to prove their functionality.

Chapter 1 introduces the project, provides grounding in the context and states the objectives. Chapter 2 explains the concept, introduces the features that let us move beyond the state of the art and what we need to prove about the concept. Chapter 3 reports on the preparatory work of analysing the preferences of the public and private decisionmakers. Chapter 4 outlines the framework with its modules and the expertise areas that drive their development. Chapter 5 defines the activities to deliver the proof of concept in the next phase.

## Next project phases

The next phase of Work Package 2 is an important milestone to pass, because we need to prove that all features of the concept can work together in the AMIGDALA framework.

In Work Package 3 we will then finalise the integrated model, decision framework and scenarios to reach technical completion.

Work Package 4 is the deployment of the new modelling capacity to make projections of pathways to climate neutral destinations and analyse the pathways from the perspectives of different stakeholders.



## 1 Introduction

The AMIGDALA project will deliver modelling insights for the transformation of industrial operations in Europe towards climate neutrality.

The project combines advanced modelling with analysis of decision making practice in government and business. The advanced model integrates established domain models of industrial production with integrated assessment models (TIAM-ECN and TIMES-Europe), a model of global trade (EXIOMOD), soil-based production (GLOBIOM) and circularity (CITS). To align the modelled projections with the practise of decision making, important control levers and performance indicators for businesses and governments will be identified and used to set-up relevant modelling scenarios and to create the opportunity to review the resulting pathways from different perspectives.

While most features that we build upon have already been deployed separately, we add ambitious features that have not been demonstrated before. This document outlines the concept and describes its features.

### 1.1 Background of the transformation

Human activity has profoundly impacted global systems, reaching a critical juncture. Some stakeholders, including academics, propose recognizing a new geological epoch: the Anthropocene, reflecting humanity's significant influence on Earth's natural cycles. The IPCC has confirmed with certainty that human-induced greenhouse gas (GHG) emissions are the primary driver of rising atmospheric GHG concentrations, leading to climate change. The rapid extraction of resources—fossil fuels, agriculture, and critical minerals—to meet human demands is destabilizing Earth's ecosystems at an unprecedented scale and speed. Even without considering additional factors, the conclusion is clear: our current way of living is unsustainable. Achieving sustainability will require a fundamental transformation of our consumption patterns, economic models, and production systems.

Europe has chosen to play an active, leading role, in this transformation. Industrial activities, the backbone to our economic production, are at the forefront of this transformation. Meeting 2050 objectives<sup>1</sup> requires

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<sup>1</sup> [https://climate.ec.europa.eu/eu-action/european-climate-law\\_en](https://climate.ec.europa.eu/eu-action/european-climate-law_en)

transforming production processes soon, as investment lead times are long, and production technologies tend to have long lifespans.

Importantly such transformation in industry should not come at the cost of decreased competitiveness or significant social costs (employment, quality of life). Furthermore, investing in more sustainable production technologies today comes with increased uncertainty on demand, technology costs, availability and cost of raw materials and energy, and the evolution of the regulatory framework. Numerous dynamic and interacting pieces come into play over a time horizon that extends beyond habitual corporate strategy decisions. Gaining insight into the key factors conditioning this successful transformation requires new tools: integrated models capable of providing advanced scenario projections on the impact of economic actors' decisions on economic, social and environmental outcomes.

AMIGDALA seeks to meet such ambitious objectives.

## 1.2 The European Green Deal and P4Planet partnership

The world, and Europe as an integral part of that, is going through a major system transition away from unabated use of fossil resources. In this transition, Europe has set targets for itself to lead this transition to sustainability while remaining economically competitive and strategically autonomous.

The European Green Deal<sup>2</sup> will transform the EU into a modern, resource-efficient and competitive economy, ensuring:

- Net zero emissions of greenhouse gases by 2050
- economic growth decoupled from resource use
- no person and no place left behind

To this aim, EU directorates and industry represented by A.SPIRE have established the Process4Planet (P4Planet) partnership<sup>3</sup>, which is implemented as part of the Horizon Europe programme to drive innovation essential to the transformation.

In September 2024, Mario Draghi's report highlighted Europe's declining competitiveness, urging comprehensive reforms. It serves as a foundation for the EU's forthcoming Clean Industrial Deal, aiming to

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<sup>2</sup> [https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal\\_en](https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en)

<sup>3</sup> [About Processes4Planet | A.SPIRE \(aspire2050.eu\)](#)

revitalize industry, promote sustainability, and achieve climate neutrality. In that sense, Europe's new Clean Industrial Deal aligns fully with the European Green Deal and the Processes4Planet (P4Planet) partnership.

## 1.3 Objectives of DG CLIMA and A.SPIRE

To develop policies that lead to a climate neutral industry, the European Commission, through DG CLIMA, seeks insights from science-based modelling. While the European Commission (and DG CLIMA in particular) grounds its analyses in numerous modelling tools, current models are not yet fully developed to represent the EU industry's pathways to climate neutrality in an integrated and holistic manner.

To support and plan technology development from lab to market and toward industrial scale up, A.SPIRE seeks outlook on specific technology options and to understand enabling conditions grounded in modelling outputs. This approach offers a comprehensive view of risks, costs and tipping points across industries on a cross-industrial basis.

### 1.3.1 Requirements outlined by the Horizon call

The functional requirements for this modelling capability described in the Horizon Europe call (HORIZON-CL4-2023-TWIN-TRANSITION-01-36) are:

- The model should cover historical development starting in 1990 and projections up to 2070.
- The regional scope should encompass the European Union and Associated Countries altogether, as well as each Member State/country individually, and the European Economic Area.
- Global sourcing and trade have to be captured with relevant granularity and based on exogenous assumptions or links with global trade models or both.
- The industry model should be integrated into a fully consistent energy system framework linked with broader macro-economic developments (particularly in relation to demand for industrial products) and aligned with meta-trends such as digitalisation.
- The model covers five dimensions of climate neutrality:
  - energy demand and use and energy efficiency,
  - emissions including process emissions,
  - use of raw materials, chemicals and water,
  - production of consumer goods / equipment / construction products,

- possibility of replacing fossil carbon in materials by more sustainable streams.

Several “what-if” scenarios need to be developed that capture all dimensions of climate neutrality in a consistent way. The scenarios should be:

- Contrasted but internally consistent in their policy and economic contexts;
- Presenting different pathways for climate neutrality transition in terms of energy needs;
- Addressing the process emissions, the needs and supply of materials, and technological options.

The new modelling capacity is to be deployed to explore options through development of scenarios.

## 1.4 Modelling for systems analysis – state of the art

To make scenario projections, technical, economic, political, social and behavioural aspects are all relevant. Currently, these are largely considered within the silo of their respective scientific disciplines only.

The historical development of energy modelling has followed several major phases. In the 1990s, energy systems modelling became sufficiently widespread, and standardization was required to ensure the coherence of the multitude of individual initiatives and approaches. This led to a consolidation phase where energy system modelling became reliable and representative, with a trend in modelling focused on long-term, multisector, multiperiod, bottom-up, linear programming and perfect foresight, and Energy System Optimization Models (ESOM) progressively becoming the most used methodology for energy system analysis, see references (Lopion, 2018), (Plazas-Niño, 2022), (Pfenninger, 2014) in paragraph 7.1. Similarly, economic modelling followed its own path to standardization. Modelling of industrial materials flow and especially modelling of circularity is still in its infancy today, certainly compared to energy systems modelling.

Also, there is a significant gap between the way that model results are generated and presented, and the way that they are interpreted and used for making decisions. While models may often provide useful outputs enabling decision support, these are rarely aligned with the sufficient and necessary information needs of either policy makers or industry leaders. This discrepancy means that state-of-the-art models’ outputs are often “lost in translation” and, while scientifically admirable, their real-world impact remains hard to demonstrate. The output of

complex models must be presented in alignment with the needs of those faced with the decision to which they provide answers to.

While all individual models may have built on their own consistent data-set, combining models requires that the data used is harmonized between the models. Validated data requires specialist knowledge and is therefore hard to come by, especially a consistent set across modelling domains and for the same geographical regions. The absence of a validated and integral data-set also hampers model integration. Often, existing information on the current industrial system and on assumptions that underlie policy plans remain inaccessible. Currently, no single, unified, publicly accessible, structured “go-to” source of information, at the European level, on energy and process industry sector data exists.

## 1.5 The AMIGDALA partners and project

The AMIGDALA project has emerged from the ‘Trilog’ collaboration of DECHEMA, TNO and VITO. The research organizations have since long been involved in systems modelling and scenario development and built up decades of experience and expertise in these areas. The Trilog collaboration has sought expertise partners to attain the objectives outlined in the Horizon call as such go beyond the state-of-the-art of current scenario-based modelling, and leverage the opportunities that the partnership has identified below

The models built and maintained by these institutes are recognized by scientists and used for work to help governments understand options and outline possible futures. However, the models are restricted to well-defined knowledge domains. This entails making assumptions about ‘exogenous’ parameters that represent the broader context that the models require to be able to run. The opportunity for development here is to link models of adjacent domains and accordingly reduce the number of exogenous parameters. It is expected that when several of these parameters are endogenized, in an integrated model this should improve the representation of reality.

The current de-coupling of the modelling domains also means that they have their own datasets and scenarios. This makes it impossible to make a like-for-like comparison of model outputs and assemble the information in one consistent view. Basic data that is input for models needs to be reviewed and updated regularly to provide a representative description of the current situation and to capture technological developments. The opportunity here is to work from a harmonized and validated set of basic data, ensuring that parameters intended to

represent the same information have consistent values throughout the models.

The presentation of systems analysis through models is usually not tailored to serve the perspectives of different stakeholders. Such situation makes it difficult for decision makers in both businesses and governments to extract valuable information in support of their decision making process. The opportunity here is to ensure that the output and input of the model align consistently with the needs for information and control of all decisionmakers and in terms that make most sense to them.

The processes for decision making within governments and within (global) business entities are not fully transparent. Both have different priorities for their objectives and have a fundamentally different perception of risk and reward. Having more transparency on their objectives, means, and mandates for the long term should increase mutual understanding. The opportunity here is to work from a transparent decision framework that enables economic partners to experience each other's view.

Although the system and the interactions between its components, including energy requirements, emissions, trade, technological developments, investments and policy, are complex, it seems plausible that there are deep trends hidden within. Thorough analysis of the climate neutral pathways may uncover trends that reveal the inevitable consequences of decarbonisation objectives and correlations between policy and regulation and business decisions. The opportunity here is to discover those hidden relations – if they exist – bringing forward the main characteristics of pathways and identifying which ones are mutually exclusive or reinforcing. This may help to define distinct policy directions to choose from.

We believe that resolving the bottlenecks that stand in the way of exploiting these opportunities can effectively leverage the state of the art and contribute momentum to achieve the Green Deal objectives.

## 1.6 The AMIGDALA project objective

The objective of the AMIGDALA project is to make projections of optimised **pathways** of **systems change** that lead the European industry to a climate-neutral **destination**. The AMIGDALA framework should also be capable of identifying the **framework conditions** for the market uptake of transformative solutions in a global context. A distinguishing feature of the concept is the alignment of the scenario

projections with the perspectives of public and private actors to maximise the supporting potential in taking decisions.

Systems change denotes the transformation away from unabated fossil resources towards clean & renewable energy and the manufacture of products from renewable and circular feedstock. Because this is a global transformation, it is likely that it affects the competitive positioning of industrial production worldwide and therefore also global trade flows.

Most probably there will be various climate-neutral destinations, each of which may be accessible via several pathways. The destination and pathways are expected to have distinctly different characteristics (e.g. with respect to energy, cost, risk, autonomy, competitiveness) and the various stakeholders will have a preference, each from their own perspective.

Framework conditions denote the conditions for the private sector to invest in the conversion of their assets to climate neutral production. This includes global market forces as well as subsidies, pricing, and mandates.

Decisions pertain to the options available to actors within their means and mandate. Public actors can essentially choose to subsidise, apply pricing or mandates. Options for private actors are to invest in assets, or mothball, sell them or abandon them. Their choices will mainly be driven by the markets for the products and strategic choice.

## 1.6.1 Translating objectives to the model

The pathways of industrial transformation that will result from the integrated modelling suite will all have in common their pursuit of climate neutrality. The pathways will materialize from the optimisation exercise of the integrated model suite within the context of the multiple scenarios that will be applied. The scenario input parameters serve to describe external factors which impact the model optimization and as such the projected pathway. These parameters typically include population growth, resource potentials, development of techno-economic parameters, but also (EU) policies with respect to energy, climate and circularity. While climate neutrality is the primary focus, to address all three key features of the future European industry, we also aim to define indicators for competitiveness and resilience. This will enable us to monitor the development of competitiveness and resilience along the projected pathways and potentially identify enabling framework conditions.

## From scenarios ....

To ensure realistic scenario projections which are relevant to the stakeholders, the optimization problem is subject to real-world boundary conditions, which are captured in scenarios. Scenarios describe both qualitatively (in words) and quantitatively (in numbers) important elements which provide the context to the optimisation problem. In AMIGDALA, this context is rather broad, spanning the domains of energy, economy, environment, materials and policies on multiple geographical scales. In the context of the domains mentioned above, typical scenario parameters include limitations on the production or use of commodities and the deployment of technologies and assumptions on the future development of techno-economic parameters of technologies. In addition, they are used to simulate policy measures and instruments, such as feed-in tariffs, subsidies and cap and trade systems. In the AMIGDALA concept the developed scenarios should support decision making in policy and industry, anticipating on a range of possible future developments. An important part of the AMIGDALA concept involves identifying businesses and government's most important control levers and capture these in modelling constraints / scenario parameters where possible. This is part of our efforts to set up a decision analysis system, which further includes identification of stakeholder's key performance indicators related to the transformation to a sustainable industry to improve the alignment of modelling results with the stakeholder needs.

## ... to optimizing pathways.

The modelled scenarios should result in the development of coherent and contrasting pathways that provide insight into how key concerns could be addressed under a range of possible futures. The pathways of industrial transformation materialise from the integrated model scenario runs as the development of capacities of generation, production and end-use technologies, the utilization thereof as well as from the flow and trade of commodities. These follow from a time-series of decisions on investments, process activities and decommissioning taken by the model, based on a model-specific optimization procedure, which typically seeks to minimize the NPV of total system cost. The model optimisation condition is captured by the *objective function*, which is a mathematical expression that defines the goal of the optimization process. As such the modelled pathways correspond to possible futures within the context of the scenario parameters optimised from an economic rationale.

## 1.6.2 Conclusion on modelling approach

To guarantee projection of pathways of industrial transformation relevant to the decision making process in industry and governments:

- Scenarios are developed to ensure that the pathways comply with all dimensions of climate neutrality.
- We will seek to incorporate business' and government's most important control levers in scenarios to identify pathways, which leverage investment opportunities.
- We will study the possibility to define and quantify competitiveness and resilience in our models. If this can be realized, these may be used as an indicator for the status of a destination. If possible, they may be used for co-optimisation of the destination.

## 2 The AMIGDALA concept

The AMIGDALA concept combines four key elements. For each element we have a separate expertise group to apply the state of the art:

1. Decision analysis, to reflect and align the input and output with the interaction of public and private decisionmakers
2. Scenario building, centred on economic indicators and the decision options employed by decision-makers.
3. Integrated modelling, with models from different domains to reduce the number of endogenous parameters
4. Data management, to harmonize input data for the different models

### 2.1 Implementation of the concept

Preparatory research, reported in Chapter 3 of this document, has studied public and private decision-makers shaping industrial transformation. In this preparatory work we have discovered economic indicators preferred by these decision-makers and decision options that they utilise to fulfil their objectives. This approach increases the likelihood that our model results, though our tailored presentation, will provide more valuable insights to decisionmakers, aiming to strengthen their action perspective.

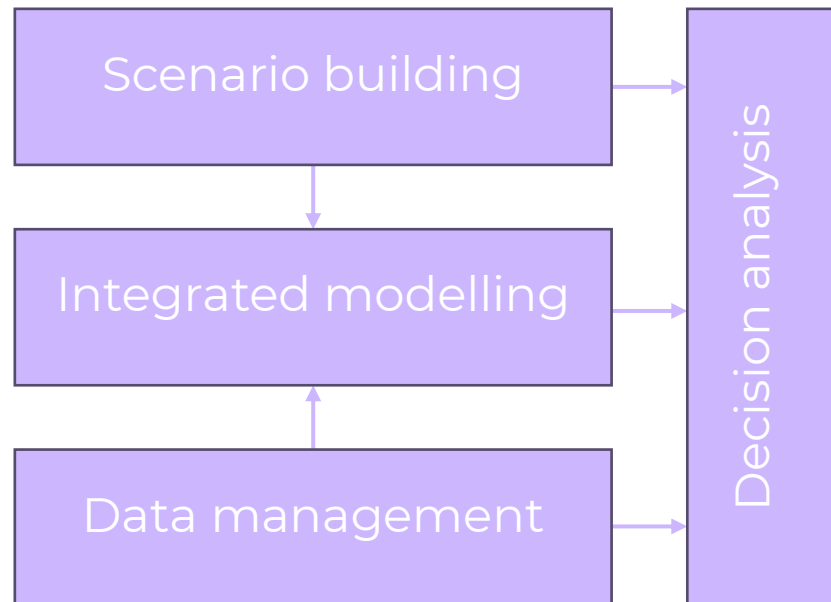
On the key element of Decision analysis, the related expertise team investigates the relation between economic indicators and the decision options employed by governments or industrial businesses.

On the key element of Scenario building, the expertise team will construct scenarios and deliver narratives in terms of these identified economic indicators and how these affect the utilization of decision-options.

On the key element of integrated modelling, this means that an explicit link is to be made between the economic indicators and the decision options with the parameters of the models. The integrated model should thus be capable of representing as much of the economic indicators as possible in terms of endogenous parameters, while the propensity to use decision options should be captured in the exogenous parameters.

On the key element of data management, this means that ideally historic data becomes available on the economic indicators and decision options. Data management is needed to validate basic data and harmonize the use of data by all models.

Figure 1 depicts the relation between the expertise in brief, which will be further described in the next paragraphs.



*Figure 1 Schematic overview of the AMIGDALA concept*

## 2.1.1 Decision analysis

Decision-making is a complex process that involves both emotional factors and the judgment of individual and collective actors. It requires assessing of the relative importance of different options at a given time to maximize their interests across different time horizons. These interests cover economic, social, environmental and even individual interests which can be expressed through performance indicators that are a measure of their accomplishment. Control levers on the other hand refer to the means and mandates at the disposal of a given decision-maker. For example, a control lever may be the level of subsidies on CAPEX or OPEX for the deployment of technologies that contribute to the desired objectives. In turn, the realized capacities of this technology can be an economic indicator.

Decision making will be supported by the presentation of scenario projection results and the selection of different profiles, representing the preferences of specific stakeholder groups such as decision makers from industry and government. Profiles differ because of different weighing applied to KPI's and dimensions of climate neutrality. Consequently, the same scenario results can be viewed from different perspectives adding to transparency and mutual understanding among stakeholders.

## 2.1.2 Scenario building

Scenarios characterise possible futures by key trends and uncertainties. Within these scenarios, public and private actors may take different positions to serve the interest of their stakeholders. For scenarios, using the identified economic indicators as a basis means ensuring that the range of values for a given control option, which may be explored across different scenarios, are recognizable by decision-makers. It further entails that the set of decisions available to decision-makers, such as a policy maker's choice to provide funding or legislate, or an industrial decision maker's option to divest, invest or invest beyond the frontiers of the EU, are taken into careful consideration when defining different scenarios to be explored. In a more detailed fashion, it also means that the scope of European decision-makers' influence (that is to say the domain within which they can affect decisions) is reflected by the overarching boundary conditions.

## 2.1.3 Integrated modelling

'Integrated modelling' in the AMIGDALA project indicates the soft-linking of computer models from different research domains. With this integration AMIGDALA means to advance the state of the art, by reducing the number of exogenous variables. To do this, AMIGDALA aims to build a "backbone" which will tie in existing models with different spatial and temporal dimensions to develop this European, pan-industry view of pathways to meet Green Deal objectives.

Key to the success of this goal is the ability to layer models by their temporal and spatial domains, and design input and output tables that allow the models to exchange data during an integrated model run. Critical too will be the coherence of results, through the capability to converge not only separately but also in conjunction with other models. Each model has its own optimizing function, that is to say a goal it seeks to reach under constraints. In addition, each model will need to implement its own set of boundary conditions, which depends on the scope, scale and resolution of the particular model, but at the same time is in line with the scenario under scrutiny. The interplay between the models will propagate the boundary conditions through the different scopes, scales and resolutions of the modelling suite and will create an integrated view on the actual economic, technological, social and environmental boundaries within which industrial and policy makers will be able to take decisions.

Integration of domain models is perhaps the most challenging feature of the AMIGDALA concept. The models, which vary in type

(optimization, I/O, simulation), need to be organized in a hierarchy for execution that accurately represents the entire system and effectively demonstrates the logical effects of decisions made by public and private actors.

The model integration succeeds when:

- Scenarios of sufficiently broad scope are used consistently within each domain model to align model results;
- Connections have been established between the different domain models which are consistent in terms of units, spatial and temporal scope;
- The integrated model must converge and do this within reasonable computation time;

## 2.1.4 Data management

Modellers build their own basic data-sets that may contain thousands of parameters from a variety of knowledge domains. Combining models thus means combining data-sets that may contain different values that can be traced back to different sources. To let the models operate as-one and align the interim outcomes and exchange variables, requires harmonizing the data that models share. Besides the harmonization, all data should be validated and updated by domain experts. Key to the success is to designate a separate responsibility for data management, because modelling is an expertise of its own. The concept thus foresees a central data management function for harmonization between models and validation with recognized experts in the specialist fields.

## 2.2 User-centred approach

### 2.2.1 Project organisation

Within AMIGDALA, we use a user-centred design approach. This means that we incorporate the feedback of the project stakeholders - via the Community of Practice – throughout the project. By continuously evaluating and processing the feedback of our stakeholders, the framework will be extended and improved in an iterative manner.

Throughout the project period of 4 years, the following four phases or work packages (WPs) are defined:

WP1. Describes the function of modules in the AMIGDALA framework and provides their technical specifications for function and interaction. This Work Package starts with engagements with decision-makers to bring forward the levels at which decisions are made, the decision

criteria, the mandate of these levels, and the ambitions of their stakeholders.

WP2. Proof of concept (PoC) to demonstrate the feasibility of operating and integrating the modules. The local models show a PoC for a cluster within a region, the interaction between the local models and the agent-based models is demonstrated as a concept. The PoC will be demonstrated and validated to our stakeholders in workshop

WP3. Technical completion to make the AMIGDALA framework operational. In this WP, we will realize the technical completion of the integrated model suite, the basic data repository and the D-support dashboard. This is achieved by replicating the PoC across the remaining sectors. The foreground scenarios and the conversion to model input are fully developed. The D-support dashboard shows the control options and performance indicators.

WP4. Use of the AMIGDALA framework to make projections and perform analyses. The integrated model suite is deployed to the scenarios and delivers the pathways to climate neutrality in WP4. On a system-level the objective of this work package is to deploy the integrated modelling capability to find transition pathways and identify framework conditions and market uptake of transformative solutions and products. On a local level the objective of this work is to analyse decision-making in transformative investments of clusters and infrastructure.

## 2.2.2 Community of Practice

The AMIGDALA concept may live on in a community of practice beyond the project end-date. If indeed we succeed in making the presentation of results and insights appealing to decisionmakers, they may recognize the value in maintaining and improving the AMIGDALA concept both individually and collectively.

Hence, we start within the AMIGDALA project a Community of Practice. In the early stages of the project this should be regarded rather as a community of interest. Although there may be little response in the early stages, this will likely improve once the first results that are disseminated resound with those who are in a position to make critical decisions.

As a start, the decision makers' preferences have been investigated. The conclusions of this analysis have been worked out in Chapter 3. This provides a basis for the Community of Practice as well as for a user-centred development of the AMIGDALA framework.

## 3 Analysis of decision makers' preferences

The transition towards climate neutrality will involve many choices - critically by decision-makers in government and industry. To maximize the impact of AMIGDALA project results, potential end-users have been interviewed to understand the transformation from their perspectives and responsibilities.

### 3.1 Approach

We have interviewed key decision makers split across two different populations: policy decision-makers (both at European and sub-European administrative levels) and industrial decision-makers (executives from companies in sectors covered by the AMIGDALA project operational perimeter). To be able to appreciate what information decision-makers need to make decisions with regards to Green Deal objectives, our approach consisted of 4 steps:

1. Identifying persons across populations, industry, and countries.
2. Reaching out to the identified persons to be interviewed.
3. Running open-ended interviews.
4. Analysing interview results.

We analyse the interviews to identify indicators that reveal how decision-makers perceive the world. From these, we select and prioritize the most significant indicators to establish them as Key Performance Indicators (KPIs). These KPIs form the foundation for developing scenarios and analysing decisions throughout the project.

#### 3.1.1 Target setting

The initial aim in the selection of interviewees was to ensure a balance between policy and industrial decision makers split across different sectors or administrative levels and positions. For industry, focus was placed upon higher capitalization industrial companies, which tend to hold a greater share of European GHG emissions and greater environmental footprint and, in consequence, whose decisions have a more significant impact on European Green Deal objective's success.

For policy makers, a comparable short-list was drafted, seeking a balance between administrative levels: European, national and regional. Outreach efforts first focused upon European, moving down towards regional.

## 3.1.2 Outreach

Between February and July 2024, 150+ e-mails were sent across the Deloitte network. The response proved variable across geographies and sectors. To enhance the impact of the outreach, two webinars were organized to improve AMIGDALA project visibility and raise interest among key decisions makers. Given limited results in early June, an additional e-mail campaign, focusing on existing networks of industrial decision makers (also known as C-Suite), covering 120 contacts, was sent out.

In the case where several contacts within a given company expressed interest in interviews, preference was given on a basis of relevance of responsibility with regards to Green Deal issues and seniority.

## 3.1.3 Data collection approach

Given the exploratory nature of the exercise and the seniority and diversity of individuals being interviewed, the approach consisted in undertaking 1-hour open-ended interviews. Interviews were held under “Chatham house rules”, namely: anonymity and the possibility for interviewees to review their answers, and, if necessary, amend them afterwards.

The interview guide sought to set a baseline regarding the understanding of European Green Deal issues, and then progressively investigating from the general to the specific the interviewee’s decision-making approach. The first section aimed at describing the challenges which the company was facing with regards to environmental decisions. The second section looked into the general approach with regards to decision-making processes. The third section sought to investigate what parameters were key to allow decision making and what were useful, if possible recognizable and usual, indicators used to measure and present these parameters. Interviewees were also asked to prioritize, rank and describe the preferred indicators. Detailed interview minutes were drafted for the purpose of data analysis.

## 3.1.4 Data analysis approach

Based upon the minutes from each meeting, textual analysis was applied by 2 people. Each person was given their own series of minutes to synthesize and review. Once synthesized, the series of interviews were exchanged to ensure consistency and reduce interpretative bias. Such textual analysis sought first to list all the indicators which interviewees had mentioned as playing a part in their decision making

process. This was applied to all interview minutes. Interviewees may mention the same indicator whilst using different terms. Commonalities were identified to bring common concepts together, generally preferring the more englobing option.

Indicators were then organised into themes and contexts (environmental, policy, economic, social) in which the themes were used. For example, one interviewee may mention the importance of electricity prices going to 2050. Another may refer to the price of energy. In which case, a parameter on energy price evolution was defined. This was associated to a theme on the evolution of energy availability and price and placed under the ‘economic’ context. This categorization seeks to provide a common and synthetic view of interview results given the heterogeneity of the population and facilitate statistical analysis to prioritize and rank preferred parameters and associated economic indicators. However, classification into themes and contexts is subject to some interpretation. For example, in the analysis below, carbon trajectory and/or price is classified within “policy” while it could be argued that this topic could be placed within another context (ex: “economic”). For a full view on results and therefore how results are associated to themes and contexts, please see (see Table 5, Table 6, Table 7 and Table 8). Indicators were analysed based upon their occurrence across the complete interviewee population. Comparative analysis of their prevalence across both types of interviewee populations was also undertaken to determine where commonalities and differences are.

## 3.2 Interview results

From the interviews with decision-makers 32 unique indicators were derived. As mentioned in the methodology, these were categorised by their ‘contexts’ and ‘themes’.

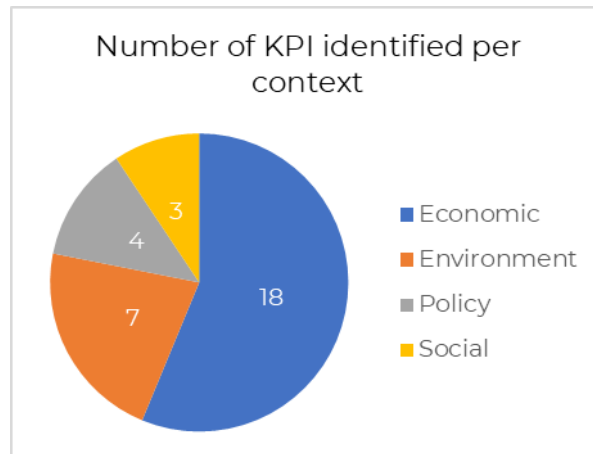
| Number | Indicator                                                 | Context  | Theme         |
|--------|-----------------------------------------------------------|----------|---------------|
| 1      | Energy price                                              | Economic | Energy        |
| 2      | Evolution of technology cost                              | Economic | Technology    |
| 3      | Availability of energy vectors                            | Economic | Energy        |
| 4      | Carbon price                                              | Economic | Climate       |
| 5      | Raw material price                                        | Economic | Raw materials |
| 6      | Industrial demand in Europe relative to rest of the world | Economic | Demand        |
| 7      | Raw material availability (absolute constraint)           | Economic | Raw materials |

|           |                                                               |             |                    |
|-----------|---------------------------------------------------------------|-------------|--------------------|
| <b>8</b>  | Raw material availability (allocation to sectors or products) | Economic    | Raw materials      |
| <b>9</b>  | Share of EU productions vs RoW relative to EU vs RoW demand   | Economic    | Trade              |
| <b>10</b> | Cost of capital                                               | Economic    | Finance            |
| <b>11</b> | Labour costs                                                  | Economic    | Labour             |
| <b>12</b> | European industrial production vs RoW                         | Economic    | Strategic autonomy |
| <b>13</b> | Cost of infrastructure (esp. Energy but also CCS)             | Economic    | Infrastructure     |
| <b>14</b> | Job creation & destruction                                    | Economic    | Job                |
| <b>15</b> | Technological value added                                     | Economic    | Technology         |
| <b>16</b> | Cost of inaction                                              | Economic    | Climate            |
| <b>17</b> | Efficiency of subsidies to emission reduction                 | Economic    | Policy efficiency  |
| <b>18</b> | Tax revenue                                                   | Economic    | Tax                |
| <b>19</b> | GHG emissions                                                 | Environment | Carbon             |
| <b>20</b> | Physical risk exposure                                        | Environment | Climate            |
| <b>21</b> | Production carbon intensity                                   | Environment | Carbon             |
| <b>22</b> | Water availability & usage                                    | Environment | Water              |
| <b>23</b> | Biodiversity impact                                           | Environment | Biodiversity       |
| <b>24</b> | Waste generation                                              | Environment | Waste              |
| <b>25</b> | Degree of product circularity                                 | Environment | Circularity        |
| <b>26</b> | Carbon trajectory/constraint                                  | Policy      | Carbon             |
| <b>27</b> | Subsidy/financing/public & private sector cost                | Policy      | Finance            |
| <b>28</b> | Willingness to pay                                            | Social      | Demand             |
| <b>29</b> | Circularity constraint                                        | Policy      | Circularity        |
| <b>30</b> | Impact on revenues/repartition                                | Social      | Social justice     |
| <b>31</b> | Regulatory uncertainty & interaction                          | Policy      | Regulation         |
| <b>32</b> | Well-being indicator                                          | Social      | Social justice     |

*Table 1 Indicators derived from the interviews, the context of their appearance and classification in themes*

## 3.2.1 Main identified contexts and themes

The 32 indicators were grouped into four **contexts**: policy, environment, economic, social. The majority (18) of these indicators are economic, then environmental (7), policy (4) and social (3).



*Figure 2 Repartition of identified economic indicators by topic*

The importance of policy and social contexts appear to play a less significant role in decision making processes. Setting aside biases associated with the interviewee population (see 3.2.6 section on limitations of the results), this highlights the importance all stakeholders place upon economic indicators in their decision making process beyond other topics.

The 32 indicators pertain to 20 distinct **themes**, as indicated in the table below.

| Theme                     | Number of indicators in the theme |
|---------------------------|-----------------------------------|
|                           |                                   |
| <b>Climate</b>            | 3                                 |
| <b>Raw materials</b>      | 3                                 |
| <b>Carbon</b>             | 3                                 |
| <b>Energy</b>             | 2                                 |
| <b>Technology</b>         | 2                                 |
| <b>Demand</b>             | 2                                 |
| <b>Finance</b>            | 2                                 |
| <b>Circularity</b>        | 2                                 |
| <b>Social justice</b>     | 2                                 |
| <b>Trade</b>              | 1                                 |
| <b>Labour</b>             | 1                                 |
| <b>Strategic autonomy</b> | 1                                 |
| <b>Infrastructure</b>     | 1                                 |
| <b>Job</b>                | 1                                 |
| <b>Policy efficiency</b>  | 1                                 |
| <b>Tax</b>                | 1                                 |
| <b>Water</b>              | 1                                 |
| <b>Biodiversity</b>       | 1                                 |
| <b>Waste</b>              | 1                                 |
| <b>Regulation</b>         | 1                                 |

*Table 2 Number of indicators per theme*

Climate, raw materials and carbon are the themes with the greatest number of indicators considered as key by all interviewees to take their decisions.

Some themes appear in multiple contexts, as shown in Figure 2. While on average, policy associated indicators are mentioned more often by all respondents (>50% for the 4 policy-associated themes), the top 4 indicators are associated to the economic context and strongly tied into themes critical to decarbonization: cost and availability of energy, cost and availability of raw materials, impact on demand and trade.

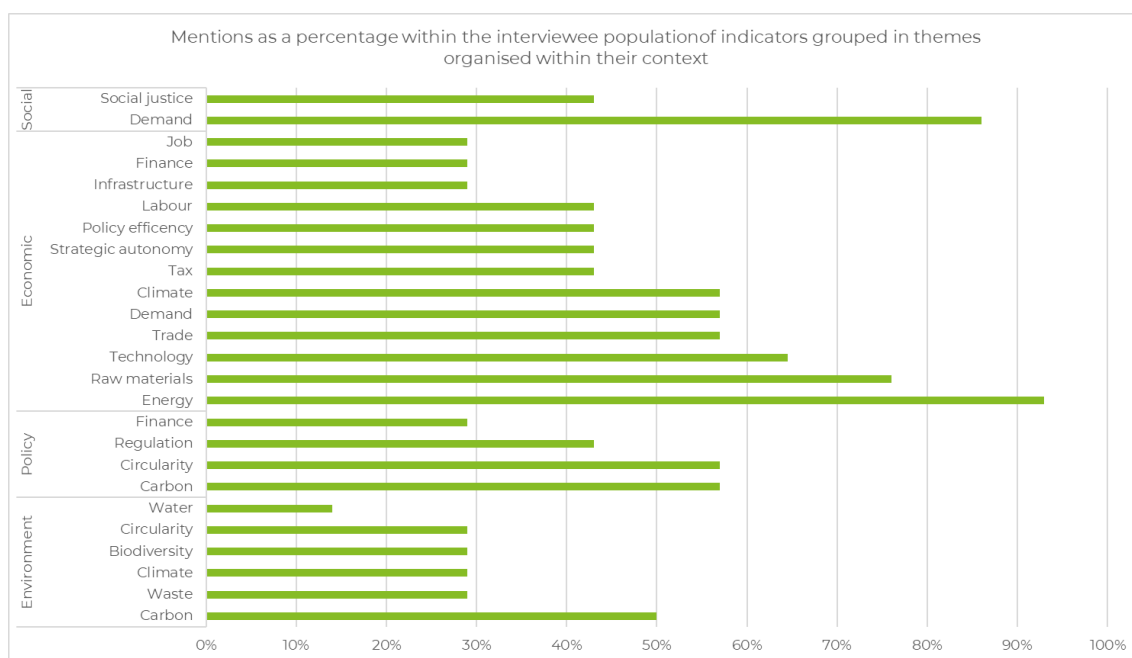


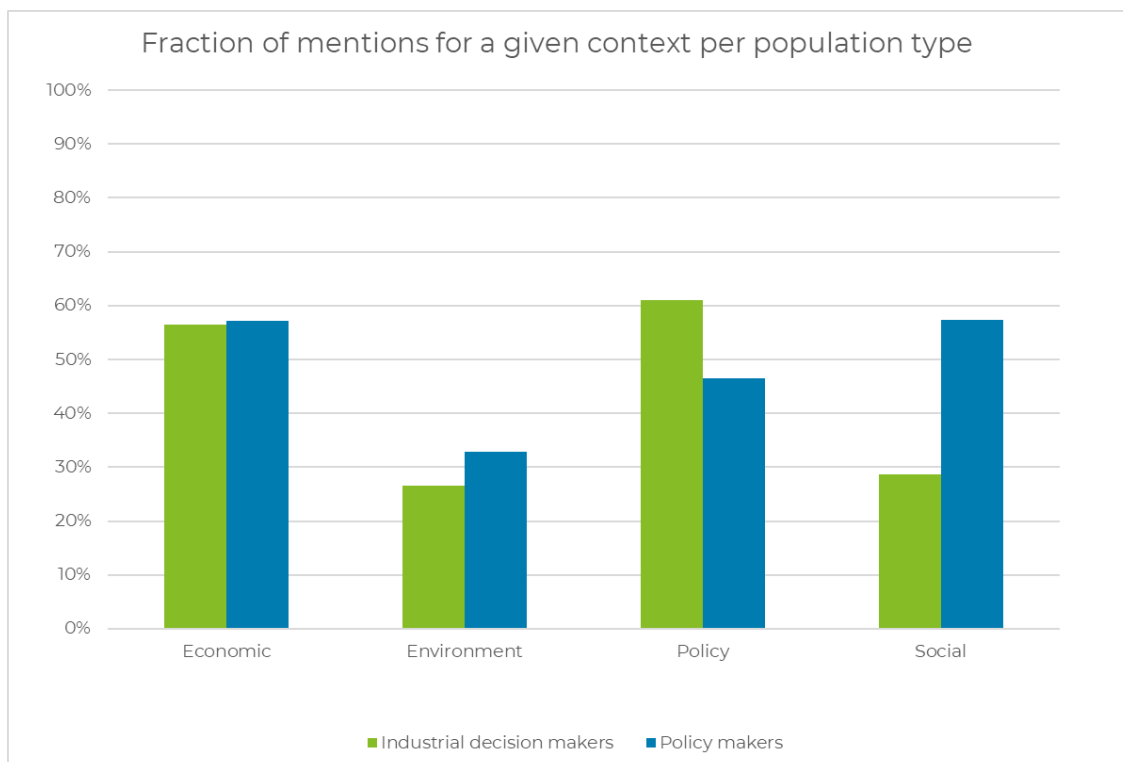
Figure 3 Mentions as a percentage of total interview population of indicators grouped in themes and organised within their contexts.

The major elements of information which sway decision making associated to Green Deal objectives across policy-makers and industrial decision makers are associated to critical dimensions of the Green Deal:

1. Availability & cost of energy vectors
2. Evolution of demand globally and Europe's competitiveness relative to the rest of the world (depending on the sector)
3. Availability and cost of raw materials
4. Evolution and cost of new technologies
5. Evolution and impact of carbon price (mentioned in 2 contexts)

### 3.2.2 Differences across populations

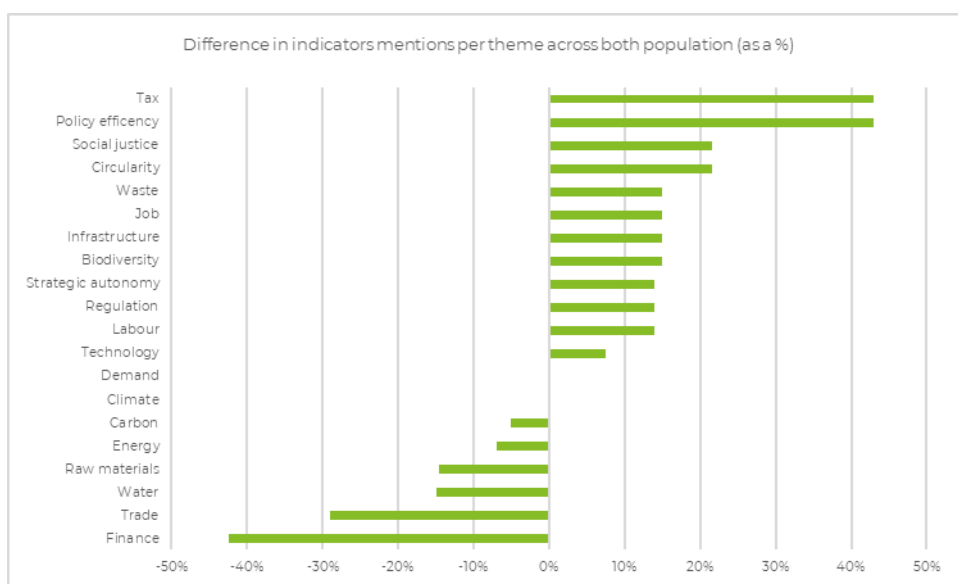
Mentions of the context are different between the industrial and government populations, shown in Figure 4. Industrial decision makers mention the policy context (i.e. the need to measure regulatory uncertainty, the availability of public subsidies, the coherence and congruence of the policy framework to meet both decarbonization and circularity objectives), more frequently than policy-makers. Policy-makers give significantly more mention to the social context than industrial decision-makers.



*Figure 4 Share of mentions for a given context per type decision-maker*

Differences on a thematic level are shown in Figure 5. The difference indicates the relative difference of a key indicator being mentioned by the industrial organizations compared to the policy makers. So -40% means that tax is mentioned 40% less times by industry compared to policy makers.

The main differences are on the one hand on finance and on the other tax and policy efficiency. The finance theme is more often mentioned by industry decision makers. Issues covered under this theme cover the availability and cost of capital as well as the availability and amount of public subsidies for decarbonization technologies and products. Tax and policy efficiency are more important concerns for policy makers. These imply ensuring that the multiple Green Deal objectives are coherent and meet stated objectives for the least costs while maximizing public utility.



*Figure 5 Difference in the frequency of mentions of themes critical for decision making across both populations (policy makers and industrial decision makers)*

More broadly, when seeking to identify how populations use indicators in their decision-making processes, results show that finance, raw material and trade dimensions play a more important role for industrial decision makers than policy makers. In the case of policy-makers tax revenue, policy efficiency, aspects associated to circularity and social justice are more important indicators in their decision-making process. However, many indicators are common in the decision-making process of both populations (ex: demand, climate, European strategic autonomy, etc.)

Despite difference between the profiles of public and private decision-makers, economic indicators are critical in both groups.

### 3.2.3 Selection of the 'Key Performance Indicators (KPI)'

The indicators that were identified are not considered equally important. The table 3 below ranks parameters based upon the number of interviewees having mentioned the parameters as critical to their decision making (represented as a percentage of the total population of interviewees). Only parameters which were mentioned by 70% of the population make the threshold for high-grading and are presented in Table 3.

| Context  | #  | Theme         | KPI name                                                                        | KPI description                                                                                                         | Total |
|----------|----|---------------|---------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------|-------|
| Economic | 1  | Energy        | Energy price                                                                    | What is the price of energy (for different vectors over time depending upon scenario?)                                  | 100%  |
|          | 2  | Technology    | Evolution of technology cost                                                    | What is the relative price of different technologies, how do these evolve and how do these evolve relative to capacity? | 100%  |
|          | 3  | Energy        | Availability of energy vectors                                                  | How are different energy vectors made available for each sector?                                                        | 93%   |
|          | 4  | Climate       | Carbon price                                                                    | What is the trajectory for the carbon price (assumed ETS) and how does it evolve?                                       | 86%   |
|          | 5  | Raw materials | Raw material price                                                              | What is the price of raw materials which are critical inputs for production?                                            | 86%   |
|          | 6  | Demand        | Industrial demand in Europe relative to rest of the world                       | What is demand in the EU and in the rest of the world?                                                                  | 79%   |
|          | 7  | Raw materials | Raw material availability                                                       | What is the efficient repartition of raw material resources given policy constraints?                                   | 79%   |
|          | 8  | Raw materials | Raw material availability                                                       | How much raw materials are produced within the EU and how much beyond?                                                  | 86%   |
|          | 9  | Trade         | Share of EU productions vs Rest of the World (RoW) relative to EU vs RoW demand | How will EU demand be met whether by European or non-European production?                                               | 72%   |
| Policy   | 10 | Carbon        | Carbon trajectory/constraint                                                    | What future constraints (e.g. sectoral emission reduction goals) will be placed on the industry                         | 72%   |

*Table 3 Table of indicators most commonly referred to by interviewees (for parameters mentioned by more than 70% of the population)*

Results show that parameters associated with economic dimensions obtained the highest rating. In particular, demand, the macro-economic and industrial positioning of the EU versus the Rest of the World (RoW), raw material availability and price, decarbonization ambition and how industry will be subject to it are the most important

prevalent indicators, that will thus serve as **Key Performance Indicators**.

### 3.2.4 Less prevalent but equally important indicators

Many other dimensions play a part and are often referred to across interview populations. While dimensions are multiple, the role the public sector will play (in determining responsibility to meet targets and the degree of effort and support) appears most prevalent. Dimensions of social justice and risks associated to social willingness to operate are also mentioned regularly. Further environmental impacts (e.g. biodiversity) play a more moderate role.

| #  | Context     | Theme          | Indicator                                      | Indicator description                                                                                                                                                    | Total |
|----|-------------|----------------|------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------|
| 11 | Social      | Demand         | Willingness to pay                             | What is the customer's willingness and ability to pay for greener products?                                                                                              | 65%   |
| 12 | Policy      | Circularity    | Circularity constraint                         | How much circular materials have to be used (as per potential future policy objectives) for a given sector?                                                              | 65%   |
| 13 | Policy      | Regulation     | Regulatory uncertainty & interaction           | How will future policy interact with existing policies? How can regulatory uncertainty delay investments and meeting Green Deal objectives                               | 65%   |
| 14 | Policy      | Finance        | Subsidy/financing/public & private sector cost | How much financial support with the EU and national member states provide for a given industry and how will this impact the ability to invest toward Green technologies? | 58%   |
| 15 | Environment | Carbon         | GHG emissions                                  | How do future GHG emissions evolve given policy objectives, geopolitical dynamics, and macro and micro-economic evolutions?                                              | 57%   |
| 16 | Social      | Social justice | Impact on revenues/repartition                 | How will achieving Green deal objectives impact the repartition of revenue across Europe and therefore condition willingness to pay?                                     | 50%   |
| 17 | Economic    | Finance        | Cost of capital                                | What will be the cost of capital going forward? Will it be                                                                                                               | 43%   |

|    |             |                    |                                                   |                                                                                                                                                                |     |
|----|-------------|--------------------|---------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------|-----|
|    |             |                    |                                                   | different for "Green" vs "brown" technology?                                                                                                                   |     |
| 18 | Economic    | Labor              | Labor costs                                       | What will future labour costs be to 2050? How can we ensure that wages increase to meet increase in costs of Green products while maintaining competitiveness? | 36% |
| 19 | Economic    | Strategic autonomy | European industrial production vs RoW             | What will be the share of European vs RoW production and production capacity (green and not green)?                                                            | 36% |
| 20 | Economic    | Technology         | Technological value added                         | Where in the value will there be the most added value going forward so that Europe can maximize value added?                                                   | 36% |
| 21 | Environment | Climate            | Physical risk exposure                            | How will climate change physical risk impact productivity?                                                                                                     | 36% |
| 22 | Environment | Carbon             | Production carbon intensity                       | How will the carbon intensity of the European process industry evolve?                                                                                         | 36% |
| 23 | Economic    | Infrastructure     | Cost of infrastructure (esp. Energy but also CCS) | How much will need to be invested in infrastructure to meet Green Deal objectives?                                                                             | 22% |
| 24 | Economic    | Job                | Job creation & destruction                        | How will Green Deal objectives create and destroy jobs? How many?                                                                                              | 22% |
| 25 | Economic    | Climate            | Cost of inaction                                  | What is the cost of inaction relative to the cost of action?                                                                                                   | 22% |
| 26 | Economic    | Policy efficiency  | Efficiency of subsidies to emission reduction     | How can we determine the efficiency of subsidy schemes to reduce emissions                                                                                     | 22% |
| 27 | Economic    | Tax                | Tax revenue                                       | How much tax revenue will be generated toward EU and national MS budgets?                                                                                      | 22% |
| 28 | Environment | Water              | Water availability & usage                        | How much water will be available given a) climate change and b) evolution of production capacities in Europe (location + technology)?                          | 22% |
| 29 | Environment | Biodiversity       | Biodiversity impact                               | How will pathways toward Green Deal objectives impact biodiversity?                                                                                            | 22% |

|    |             |                |                               |                                                                                                                                   |     |
|----|-------------|----------------|-------------------------------|-----------------------------------------------------------------------------------------------------------------------------------|-----|
| 30 | Environment | Waste          | Waste generation              | How much waste will be produced? How will waste volumes evolve given different policy options (esp. Regarding circularity)        | 22% |
| 31 | Environment | Circularity    | Degree of product circularity | To what extent will products be circular?                                                                                         | 15% |
| 32 | Social      | Social justice | Well-being indicator          | Beyond purely economic indicators, what is the impact on European citizens' well-being while moving toward Green Deal objectives? | 15% |

*Table 4 Table of parameters which are referred to by less than 70% of the interviewee population*

### 3.2.5 Other qualitative appreciations: uncertainty

The contribution of the AMIGDALA model results to reducing uncertainty in several dimensions transpired across all interviews, irrespective of the population. The dimensions of uncertainty were:

- The interplay of different policies and what their impact may be across their value-chains, including in other sectors (i.e.: how different policies interact and how they would impact other sectors which are part of their own value chains)
- Interplay on the cost of technology and their deployment rate, particularly beyond their own sector (i.e.: how investments in other sectors could lead to a decrease in the cost of technologies critical for decarbonization within their own sector)
- Global environmental impact and limitations (i.e. How current and future choices may have an impact on sustainability more broadly, for example in terms of fresh water or natural resource availability beyond decarbonization)
- Measuring impact of sub-sector risks upon other sectors and the economy more generally

Commonly, all interviewees also expressed the need to have simple data outputs, ideally with which they could themselves play and or adjust to their needs.

### 3.2.6 Limitations of the results

Results are subject to several limitations. First is **whether results are sufficiently representative** given a) **number of interviewees** b) the **heterogeneity of interviewees** from different sectors but also with different levels of responsibilities and c) the varying quality of interviews. While results tend to show a commonality of views and

highlight the well-known key elements of information, the limited number of participants raises the question as to whether proposed parameters and KPIs are sufficient to meet the need of all stakeholders. This can be considered particularly true for policy-makers at national and regional level. While the open-ended questionnaire approach appeared relevant given the open nature of the exercise and seniority of interviewees, the unequal quality of responses also raises questions on whether results are not particularly biased in favour of a given sector or individuals with tangible and detailed responses easier to qualify or both. Further interviews will be undertaken with a view to strengthen results. Outreach efforts, particularly aimed at less senior industrial decision-makers and on policy decision-makers in countries where consortium members have existing contacts, will continue with a view to reach the initial 40 interviews target.

Second, the segmentation of population into two and the choice of analysis along such lines may create a confirmatory bias toward validating a de facto existence of these two distinctive profiles without giving sufficient emphasis on individual differences. Further results allowing for finer segmentation (for example across sectors or roles), could reduce this bias.

Finally, while the proposed quantification approach does allow to identify KPI, non-rational elements of decision-making are not captured (ex: individual preferences) and, although they were mentioned during the interviews, they were difficult to isolate within individual interviews and across the full spectrum of interviews to identify trends. Such elements will have to be given further thought in the presentation of model results.

### 3.3 From Key Performance Indicators to model parameters

The indicators that were derived from the interviews, including the ones that were high-graded, cannot usually be found as such as a parameter in the integrated model. Therefore a translation is necessary to identify a proxy for the indicators in the set of model parameters, or else develop a way to derive an indicator or proxy from several model parameters.

Further refinement during the proof of concept phase will be necessary to find how the selected Key Performance Indicators (KPI) can best be related to model output. Alignment with model outputs and the capacity to apply these proposals depending upon model data remains to be assessed. In some cases, the way to represent the KPI remains “to be defined”. This is the case for KPIs which are difficult to translate and

measure and are likely to require a composite, possibly partly qualitative, datapoint.

The following Table 5, Table 6, Table 7 and Table 8 for each context (economic, environmental, political, social) list all indicators, also those not high-graded. The tables indicate what could be a proxy that relates directly to model parameters.

| Context: Economic |            |                                |                                                                                                                         |                                                                                                                                                                                                         |
|-------------------|------------|--------------------------------|-------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| #                 | Theme      | Indicator                      | Indicator description                                                                                                   | Proposed proxy for Indicator                                                                                                                                                                            |
| 1                 | Energy     | Energy price                   | What is the price of energy (for different vectors over time depending upon scenario?                                   | 1) Price trajectories for each type of energy vector used over the period<br>2) "High/medium/low" appreciation of the trajectory's ambition<br>3) Relative increase to today (% increase from baseline) |
| 2                 | Technology | Evolution of technology cost   | What is the relative price of different technologies, how do these evolve and how do these evolve relative to capacity? | 1) Marginal Abatement Cost Curve (MACC) of technologies per sector<br>2) Overall increase costs split between capital and operational costs (% from baseline)                                           |
| 3                 | Energy     | Availability of energy vectors | How are different energy vectors made available for each sector?                                                        | 1) Sankey of use of different energy vectors per sector over time<br>2) Total energy use (ex: in PJ) split by vector                                                                                    |

|   |               |                                                           |                                                                                       |                                                                                                                                                                          |
|---|---------------|-----------------------------------------------------------|---------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 4 | Climate       | Carbon price                                              | What is the trajectory for the carbon price (assumed ETS) and how does it evolve?     | 1) Carbon price represented as a trajectory<br>2) "High/medium/low" appreciation of the trajectory's ambition                                                            |
| 5 | Raw materials | Raw material price                                        | What is the price of raw materials which are critical inputs for production?          | 1) Price trajectory over time (to be presented in line with the raw material availability)<br>2) Relative increase compared to baseline (ex: %) per type of raw material |
| 6 | Demand        | Industrial demand in Europe relative to rest of the world | What is demand in the EU and in the rest of the world?                                | 1) Bar charts per sector over time (& potentially per country) at EU Level. 2) Indicator of growth of EU vs RoW (% increase from baseline?)                              |
| 7 | Raw materials | Raw material availability (allocation constraint)         | What is the efficient repartition of raw material resources given policy constraints? | 1) Share of total raw materials imported vs non-imported<br>2) Sankey of raw materials with share of imported & non-imported                                             |
| 8 | Raw materials | Raw material availability (absolute constraint)           | How much raw materials are produced within the EU and how much beyond?                | 1) Sankey of raw material flow per sector                                                                                                                                |

|           |                    |                                                             |                                                                                                                                                                |                                                                                                                                   |
|-----------|--------------------|-------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------|
|           |                    |                                                             |                                                                                                                                                                | 2) Total availability & use of raw materials                                                                                      |
| <b>9</b>  | Trade              | Share of EU productions vs RoW relative to EU vs RoW demand | How will EU demand be met whether by European or non-European production?                                                                                      | 1) Bar chart per sector/country over the period of EU/RoW production share<br><br>2) % of demand met within the EU vs RoW         |
| <b>10</b> | Finance            | Cost of capital                                             | What will be the cost of capital going forward? Will it be different for "Green" vs "brown" technology?                                                        | 1) Total increase of the cost of capital (i.e. a value)                                                                           |
| <b>11</b> | Labour             | Labour costs                                                | What will future labour costs be to 2050? How can we ensure that wages increase to meet increase in costs of Green products while maintaining competitiveness? | 1) Qualitative indicator of expected increase in costs<br><br>2) If possible, increase of labour costs in a quantitative manner   |
| <b>12</b> | Strategic autonomy | European industrial production vs RoW                       | What will be the share of European vs RoW production and production capacity (green and not green)?                                                            | 1) Overall share of EU vs RoW production (pie chart + %)<br><br>2) Overall share of EU vs RoW capacity per sector (ex: bar chart) |
| <b>13</b> | Infrastructure     | Cost of infrastructure (esp. Energy but also CCS)           | How much will need to be invested in infrastructure to meet Green Deal objectives?                                                                             | 1) Total cost of infrastructure investment (bn€)                                                                                  |

|           |                   |                                               |                                                                                                              |                                                                                                                                                                                          |
|-----------|-------------------|-----------------------------------------------|--------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|           |                   |                                               |                                                                                                              | 2) Evolution of cost per sector, per type of infrastructure represented as a bar chart                                                                                                   |
| <b>14</b> | Job               | Job creation & destruction                    | How will Green Deal objectives create and destroy jobs? How many?                                            | Total number of jobs created & destroyed per sector & country                                                                                                                            |
| <b>15</b> | Technology        | Technological value added                     | Where in the value will there be the most added value going forward so that Europe can maximize value added? | 1) Total contribution to GDP<br>2) Split of contribution to GDP per sector over time relative to baseline                                                                                |
| <b>16</b> | Climate           | Cost of inaction                              | What is the cost of inaction relative to the cost of action?                                                 | 1) Qualitative indicator (ex: "high/medium/low")                                                                                                                                         |
| <b>17</b> | Policy efficiency | Efficiency of subsidies to emission reduction | How can we determine the efficiency of subsidy schemes to reduce emissions                                   | 1) Emission reduction for a given sector divided by prior subsidies over a time period to be determined<br>2) MACC representation of the efficiency of public subsidies                  |
| <b>18</b> | Tax               | Tax revenue                                   | How much tax revenue will be generated toward EU and national MS budgets?                                    | 1) Share of taxes taking as a share of production (e.g with a fixed VAT) represented as a total<br>2) Trajectory of taxes vs subsidies for the sector as a bar chart per sector per year |

Table 5 Indicators and their proxies for the economic context

| Context: Environment |         |                             |                                                                                                                                       |                                                                                                                                                                        |
|----------------------|---------|-----------------------------|---------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| #                    | Theme   | Indicator                   | Indicator description                                                                                                                 | Proposed proxy for Indicator                                                                                                                                           |
| 19                   | Carbon  | GHG emissions               | How do future GHG emissions evolve given policy objectives, geopolitical dynamics, and macro and micro-economic evolutions?           | 1) Overall increase of emissions<br>2) Trajectory of emissions per sector over the period                                                                              |
|                      |         |                             |                                                                                                                                       | 3) Total emission value per year, sector and country                                                                                                                   |
| 20                   | Climate | Physical risk exposure      | How will climate change physical risk impact productivity?                                                                            | 1) Qualitative indicator depending on the extent of global warming of the scenario (ex: "high/medium/low")                                                             |
| 21                   | Carbon  | Production carbon intensity | How will the carbon intensity of the European process industry evolve?                                                                | 1) Total emissions split by unit of production in the sector over time (%)<br>2) Relative evolution as compared to baseline (%)                                        |
| 22                   | Water   | Water availability & usage  | How much water will be available given a) climate change and b) evolution of production capacities in Europe (location + technology)? | 1) Qualitative indicator of water availability depending on global warming level associated to the scenario<br>2) Overall water consumption of the scenario per sector |

|           |              |                               |                                                                                                                            |                                                                                                                                                                                            |
|-----------|--------------|-------------------------------|----------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>23</b> | Biodiversity | Biodiversity impact           | How will pathways toward Green Deal objectives impact biodiversity?                                                        | 1) Qualitative indicator of expected biodiversity impact according to the foreground scenario (ex: "high/medium/low")<br>Indicator to be developed                                         |
| <b>24</b> | Waste        | Waste generation              | How much waste will be produced? How will waste volumes evolve given different policy options (esp. Regarding circularity) | 1) Overall volume of waste value (volume)<br>2) Sankey of waste volume evolution per sector - to be associated with circular content                                                       |
| <b>25</b> | Circularity  | Degree of product circularity | To what extent will products be circular?                                                                                  | 1) Share of circular content (%) of products per sector over time<br>2) Bar chart representation of product content depending on raw material input with a focus on circular raw materials |

Table 6 Indicators and their proxies for the environment context

| Context: Social |                |                                |                                                                                                                                      |                                                                                                                        |
|-----------------|----------------|--------------------------------|--------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------|
| #               | Theme          | Indicator                      | Indicator description                                                                                                                | Proposed proxy for Indicator                                                                                           |
| 28              | Demand         | Willingness to pay             | What is the customer's willingness and ability to pay for greener products?                                                          | Indicator to be developed                                                                                              |
| 32              | Social justice | Well-being indicator           | Beyond purely economic indicators, what is the impact on European citizens' well-being while moving toward Green Deal objectives?    | Indicator to be developed                                                                                              |
| 30              | Social justice | Impact on revenues/repartition | How will achieving Green deal objectives impact the repartition of revenue across Europe and therefore condition willingness to pay? | If possible, value added relative to the baseline scenario per new element in the value chain (% increase or decrease) |

Table 7 Indicators and their proxies for the social context

| Context: |            |                                                |                                                                                                                                                                          |                                                                                                                                                                               |
|----------|------------|------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| #        | Theme      | Indicator                                      | Indicator description                                                                                                                                                    | Proposed proxy for Indicator                                                                                                                                                  |
| 26       | Carbon     | Carbon trajectory/constraint                   | What future constraints (e.g. sectoral emission reduction goals) will be placed on the industry                                                                          | 1) Trajectory of industry carbon trajectory (if imposed by policy depending on the foreground scenario)<br><br>2) "High/medium/low" appreciation of the trajectory's ambition |
| 27       | Finance    | Subsidy/financing/public & private sector cost | How much financial support with the EU and national member states provide for a given industry and how will this impact the ability to invest toward Green technologies? | 1) Amount invested (in K€) to achieve the scenario.<br><br>2) Share of public funding as part of total investment cost (%)                                                    |
| 31       | Regulation | Regulatory uncertainty & interaction           | How will future policy interact with existing policies? How can regulatory uncertainty delay investments and meeting Green Deal objectives                               | Indicator to be developed                                                                                                                                                     |

|    |             |                        |                                                                                                             |                                                                                                                                                                                                                                           |
|----|-------------|------------------------|-------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 29 | Circularity | Circularity constraint | How much circular materials have to be used (as per potential future policy objectives) for a given sector? | <p>1) Sankey of material flows focused on circular products (circular carbon, circular raw materials etc.) - products to be defined</p> <p>2) Share of circular material per sector (as a % of total material used within the sector)</p> |
|----|-------------|------------------------|-------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|

*Table 8 Indicators and their proxies for the Social context*

## 3.3.1 Proposed KPI for inclusion within AMIGDALA

In the next steps of the project, **whether model outputs can produce the full list of parameters and KPI and how model data may be used to create currently undefined composite KPI will be investigated.**

To meet the criteria presented in the section above, the AMIGDALA project aims to cover 11 parameters as a proxy for indicators which will cover and bring together the parameters identified above. These parameters are presented below associated to a population profile for the sake of simplicity. However, parameters may, in practice, be common across profiles.

| Indicator # | Industry decision makers                         | # Indicator     | Policy makers               |
|-------------|--------------------------------------------------|-----------------|-----------------------------|
|             |                                                  |                 |                             |
| 2           | Availability and cost of technology              | 4               | Carbon price trajectory     |
| 1 & 3       | Energy mix evolution and price                   | 19              | Industry emission reduction |
| 5 & 7 & 8   | Raw material and feedstock availability and cost | 14              | Job creation                |
| 6 & 12      | Demand evolution in Europe and globally          | 18              | Tax revenue                 |
|             |                                                  | 6 & 9           | Trade balance               |
|             |                                                  | 17 & 18         | Cost to public sector       |
|             |                                                  | 23, 29, 32, ... | Wider environmental impact  |

*Table 9 Parameters targeted for serving as a proxy for high-graded indicators*

## 3.3.2 Perspectives on the GreenDeal and Targets

The social function and objectives of both the subset of actors analysed ought to be recalled here as it will serve to guide toward interpretation of decision-makers' objectives, means and mandates. The private and public sector seem to maintain different perspectives on the Green Deal and the targets under their control.

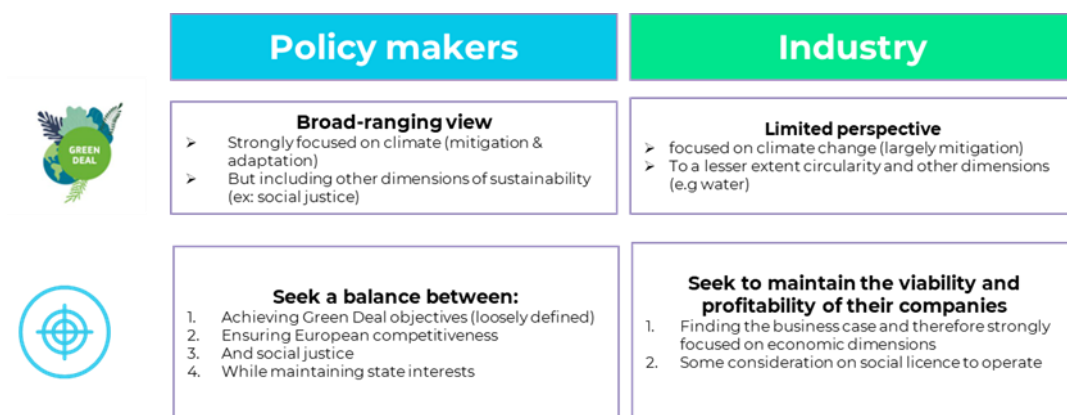


Figure 6 Synthetic illustration of policy-maker and industrial decision maker differences outlook on the Green Deal and approach

### 3.3.3 Objectives and control levers of industry actors

Ultimately private sector stakeholders need to return capital (mostly cash) to their stakeholders (mainly shareholders). This means that they need to sell the products from their operations at a profit. None of their activities can take place without license to operate. Once they are operational, their primary concern will be to maintain a positive balance between their income and their expenses. Hence, they will be watching mainly their cost of operations and the operational cost of their competitors, as they compete with them for market share. Competitive operations are derived from access to technology, infrastructure, feedstock and energy. Competitiveness of products will, besides cost, increasingly include product attributes such as CO<sub>2</sub> footprint and toxicity.

#### Control levers of industry decision-makers

Ultimately, industry actors will need to realise the ambitions of society. The change that is needed requires investments in capital projects of their own operations and also in their feedstock and energy supply. Also they may need to invest in markets for their differentiated products.

Alternatively industry actors may decide to divest from the value chains that they are in, through abandoning production facilities and the resource supplies that they have built around themselves. Also they may decide to abandon entire markets when they assess that they will in the long run not be competitive against other suppliers.

| Investments in   | Markets          |
|------------------|------------------|
|                  | Operating assets |
|                  | Feedstock supply |
|                  | Energy supply    |
|                  |                  |
| Divestments from | Markets          |
|                  | Operating assets |
|                  | Feedstock supply |
|                  | Energy supply    |

Table 10 Control levers of industry decision-makers

### 3.3.4 Objectives and control levers of public policy makers

Policy makers of the public sector have a duty of care toward their citizens, who first of all need reliable supply of shelter, water, food and also safety and security. Beyond fulfilling those immediate and basic needs, the public stakeholders are concerned with citizens' health and well-being. Their primary well-being is derived from access to energy and goods and the opportunity to participate in society.

Governments facilitate businesses to let them provide citizens with goods and services. Businesses contribute to economic activity through the employment that they offer and the added value that they create together with adjacent businesses in a variety of value chains. The economic activity has great benefits for the population's health and wealth. Also governments control adverse effects of businesses and their industrial operations to stop them from dominating the market, polluting the environment, or when products appear to be a danger to people's health.

#### Control levers of public policy decision-makers

Four distinct control levers may be distinguished: regulation & mandates, subsidies, pricing and facilitation. Regulation & mandates act on the allocation of resources to industrial operations. Subsidies and pricing are fiscal incentives to stimulate desired developments or discourage the undesirable side effects. Besides these direct measures governments facilitate businesses e.g. through trade agreements, infrastructure and education.

| Regulation & mandates | Markets for products  |
|-----------------------|-----------------------|
|                       | Markets for feedstock |
|                       | Markets for energy    |
|                       | Use of feedstock      |
|                       | Use of energy         |

|                     |                                  |
|---------------------|----------------------------------|
|                     | Land use                         |
|                     |                                  |
| <b>Subsidies</b>    | Exports, imports                 |
|                     | Deployment of desired technology |
|                     | Feedstock                        |
|                     | Energy                           |
|                     |                                  |
| <b>Pricing</b>      | Import, exports                  |
|                     | Feedstock                        |
|                     | Energy                           |
|                     | Emissions                        |
|                     |                                  |
| <b>Facilitation</b> | International trade agreements   |
|                     | Infrastructure                   |
|                     | Education                        |

*Table 11 Control options of public policy decision-makers*

### 3.4 Conclusions and project implications

Results from decision-maker interview lead to the following conclusions concerning how to address the communication about the model results:

- First, from the perspective of decision-makers it is necessary to include parameters over all 4 contexts: economic, environmental, social and policy.
- Second, for industrial decision-makers, having recognisable indicators for economic performance (such as project NPV) and a comparable vision of European versus global economic performance is vital.
- Third, for policy-makers – and to a lesser extent for industrial decision-makers – some measure of social well-being is necessary as well as policy efficiency and public sector revenue. While the exact means to measure this remain to be validated, one approach could consist in developing a blended indicator bringing together macro-economic and environmental criteria to reflect the progress in quality of life from a material and environmental perspective.

The challenge now becomes to parameterise the indicators that were identified in this preparatory work, especially the ones high-graded.

## 4 Building the AMIGDALA framework

The AMIGDALA framework can be visualised as shown in Figure 6. The modules each have a well-defined function within the framework and are built by one of the four expertise groups, shown in colour.

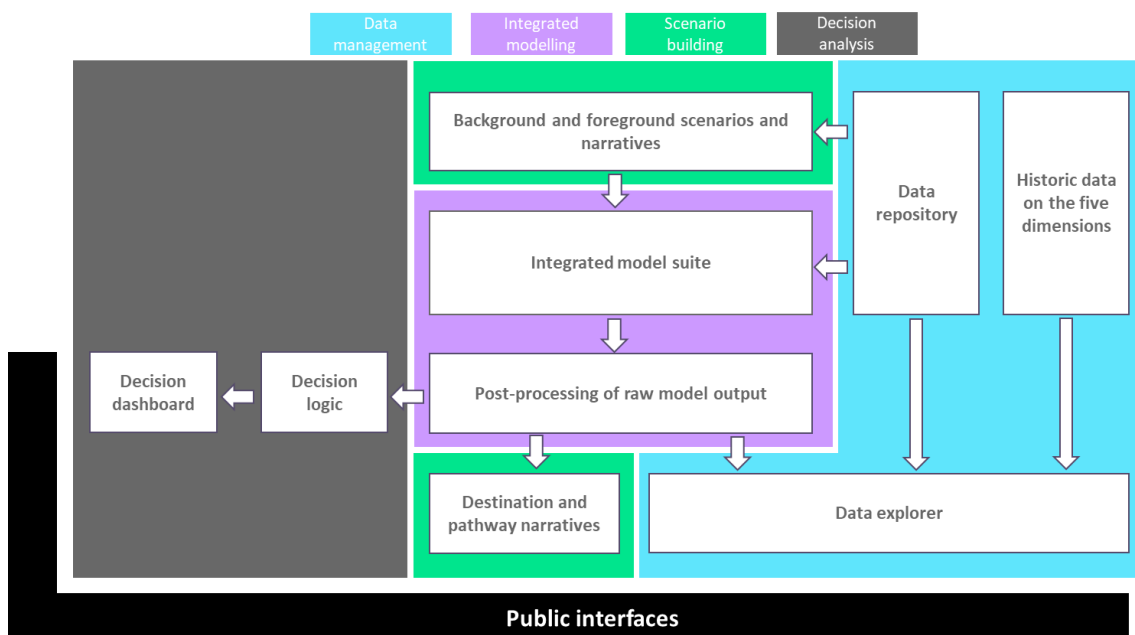


Figure 6 Modules in the AMIGDALA framework, with arrows indicating the flow of information. The Data-explorer, Narratives of destination and pathways and the Decision dashboard are interfaces with the public.

The nine modules of the framework and the expertise groups that produce the modules are:

| Expertise group      | AMIGDALA project module                                        |
|----------------------|----------------------------------------------------------------|
| Scenario building    | Background and foreground scenarios and narratives             |
|                      | Destination and pathway narratives ( <i>public interface</i> ) |
| Integrated modelling | Integrated modelling suite                                     |
|                      | Post-processing of raw model output                            |
| Data management      | Data repository                                                |
|                      | Historic data on the five dimensions                           |
|                      | Data explorer ( <i>public interface</i> )                      |
| Decision analysis    | Decision dashboard ( <i>public interface</i> )                 |
|                      | Decision logic                                                 |

Table 12 Modules of the AMIGDALA framework and the expertise group producing them

The public interface will allow stakeholders and user groups to explore the scenario projections.

In the following chapters, each expertise group provides:

- The state of the art of their expertise
- The goal of the expertise
- The functional description and specification of each module that it will deliver to the AMIGDALA framework

## 4.1 Decision analysis - expertise

Decision-analysis is a feature of the AMIGDALA concept that means to bring modelling closer to the decision-making process. The decision analysis expertise group delivers the modules:

- Decision logic
- Decision dashboard

### 4.1.1 Introduction and state of the art

Traditional decision-making often relies on intuition or past experiences (Kahneman & Tversky, 1979), which can be susceptible to cognitive biases and limited by the availability heuristic (Tversky & Kahneman, 1974). Decision analysis offers a more rigorous approach, grounded in principles of probability and utility theory (von Neumann & Morgenstern, 1947).

Decision analysis is a systematic, quantitative, and visual approach to decision-making with a well-defined framework (Clemen & Winkler, 1999). It involves several key steps:

- Identifying the Decision: This initial stage clearly defines the problem and outlines the available options.
- Structuring the Decision: The decision context is organized, including criteria, potential alternatives, associated uncertainties (probabilities), and the decision-maker's preferences (Howard, 1964).
- Evaluating Alternatives: criteria values of each alternative are analysed mathematically considering its potential outcomes, probabilities, and the decision-maker's values (Raiffa, 1968).
- Selecting the Best Option: The alternative is chosen that maximizes the expected value (or utility) based on the analysis (Fishburn, 1970).

This structured framework ensures all relevant factors are considered and weighed objectively, leading to more informed and defensible choices.

Decision analysis is a versatile tool with applications across various domains, like *business* (e.g. capital budgeting, product development, investment decisions, risk management), *engineering* (e.g. project evaluation, design selection, resource allocation), *public policy* (e.g. healthcare interventions, environmental regulations, resource allocation) and *personal decisions* (e.g. career paths, investments, healthcare choices).

By providing a structured framework for making informed choices under uncertainty, decision analysis empowers individuals and organizations to navigate complexity and achieve their goals.

## 4.1.2 Goals of decision analysis

The decision analysis of AMIGDALA is focused on high level management decisions involving the achievement of complex long-term goals related to climate change. The analysis allows decision makers to select different initial conditions and boundaries as well as preferences in the available policies and rank all possible alternatives according to their scores among the five dimensions of climate neutrality.

The different alternatives, the Decision-Maker can select resemble paths composed by sets of related decisions, e.g. on technology investments, utilization and resource allocation, which drive the future developments of the assessed system from the baseline conditions to reach the defined goals.

Through the decision dashboard, a user-friendly web interface, the decision maker can make use of the complex underlying models. Simplified inputs and sliders can be used to select preferred pathways (scenarios). Based on Multi Criteria Decision Analysis (MCDA), the decision logic will generate a ranking of the selected pathways. Their associated indicators can be evaluated through clear graphical representation to gain deeper understanding of how the ranking was established.

## 4.1.3 Functional requirements of the Decisional logical module

The Decisional logic should allow filtering of the different transformation pathways according to the Decision-Maker selections of control levers and / or performance indicators.

From the selected, preferred projections meaningful indicators will be extracted. Such indicators should be statistically assessed to obtain global descriptors which outline distinction or resemblance of the selected pathways with respect to the selected indicators.

The module should also rank the selected scenario projections according to their scores in the five dimensions of climate neutrality as well as the preferences set by the Decision-Maker.

The ranked alternatives provide the Decision-Maker with insights into the possible developments of energy related sectors given the ensemble of scenario parameters.

#### 4.1.4 Functional requirements of the Decisional Dashboard module

The Decisional Dashboard module consists of the graphical implementation of the Decisional logic module. This module should allow users to register and log in, to input their account information, create assessment projects and share them with other users if needed. Assessment projects are named containers for specific settings of scenario parameters and performance indicators related to the five dimensions of climate neutrality. Each assessment project produces several alternative results represented by projections and associated pathways.

The Decision-Maker should be able to visualise charts and data related to indicators values' statistical distribution across all alternatives generated in the assessment project as well as visualizing the list of alternatives ranked according to the specified preferences.

#### 4.1.5 Functional description of the Decisional logic module

Transformation pathways are selected by the user through the selection of relevant control levers (and indicators) and by setting their values (low, medium, high) Indicators, which correspond to (aggregated) model outputs are used to i) calculate statistical descriptors to supply an overview of their variability between scenario projections, ii) to calculate a corresponding score for each of the five dimensions of climate neutrality.

The five dimensions are finally aggregated into a single score which is used to rank the alternatives considering Decision-Makers' preferences among the dimensions.

Whenever hierarchical aggregation is needed the decision framework will make use of Multi Criteria Decision Analysis (MCDA). MCDA is a

broad discipline within operations research that provides a structured approach for evaluating and comparing alternatives when faced with multiple criteria (Roy, 1990 [1]).

More specifically, the decision framework makes use of Multi Attribute Value Theory (MAVT), which is a specific value-focused approach within MCDA (Keeney & Raiffa, 1976 [2]). It focuses on eliciting the decision-maker's preferences for different levels of each attribute (criterion). MAVT employs techniques like utility functions (mathematical function that assigns a value to each attribute based on its relative importance for the decision maker) to assign numerical values reflecting the decision-maker's priorities for each attribute (Fishburn, 1978 [3]).

MAVT can be represented mathematically using additive utility functions. Additive utility functions integrate the values of each attribute using utility functions, which represent the preferences of decision-makers. By combining the utility functions with the attribute values and weights, MAVT enables the computation of the overall utility or satisfaction derived from each alternative.

If we consider a decision-making problem with  $m$  alternatives  $\{A_1, \dots, A_m\}$  and  $n$  attributes  $\{X_1, \dots, X_n\}$ , then the functional form of the additive model is:

$$v(A_i) = \sum_{j=1}^n w_j v_j(x_{ij})$$

where  $X_{ij}$  is the performance over attribute  $X_j$  for alternative  $A_i$ , and  $v_j$ ,  $w_j$  are the value function and the weight for attribute  $X_j$ , respectively. Note that  $\sum_{j=1}^n w_j = 1$  and  $w_j \geq 0$ .

A more detailed definition of the utilised aggregation functions is reported in the technical specifications.

## 4.1.6 Functional description of the Decisional Dashboard module

The decisional dashboard module should be able to allow registration of users, their log in and input of account information.

It allows to create assessment projects and share them with other users by first being able to search among registered users as then to associate specific view, editing or administrative permission.

For each assessment project the dashboard allows to set the goals, constraints and preferences by utilising simple selectors or sliders.

It allows to view and download results by means of charts and excel tables. Provided results consist in two main areas: indicators' value distribution according to the resulting alternatives and alternatives' ranking according to users' preferences.

Where possible, indicators values' distributions will be presented as violin plots as well as box and whiskers plots providing a detailed visualization of the main statistical descriptors needed.

Ranking of alternatives will be presented as an ordered list of alternatives which can be clicked to obtain detailed information about the underlying model's results and aggregated scores.

The Decisional dashboard will be initially developed as a Microsoft Excel simplified prototype acting as proof of concept with limited capabilities. Afterwards it will be migrated to a web application and incrementally improved by standard software version updates towards the final release.

## 4.2 Scenario building – expertise

The scenario building – expertise bundles the capabilities in the AMIGDALA team to set the scene for different model runs. This team delivers the modules:

- Background and foreground scenarios and narratives
- Destination and pathway narratives

### 4.2.1 Introduction and state of the art

In the context of sustainability and the environment, integrated scenarios may be described as “coherent and plausible stories, told in words and numbers, about the possible co-evolutionary pathways of combined human and environmental systems” (Swart et al., 2004). This description is particularly relevant for the AMIGDALA approach as it highlights the integration of words (stakeholders, qualitative insights) and numbers (models, data) as an important scenario element. Another relevant scenario characteristic is being a basis for action (van Notten, 2005). Scenarios help to make better, more ‘robust’ decisions in policy, industry or other sectors, anticipating on a range of possible (possibly surprising) future developments. The scenario typology of (Börjeson et al., 2006) distinguishes three main scenario types - predictive,

explorative and normative - based on the principal questions<sup>4</sup> the scenario study aims to answer. Explorative scenarios can be sub-divided into 'External scenarios' focussing on possible impacts of external factors beyond actor control, and 'Strategic scenarios' addressing impact of strategic decisions and policy measures. A mix of these scenario elements is relevant to the AMIGDALA scenario approach, which will explore the impacts of external factors (background scenarios), strategic decisions and policy measures (foreground scenarios) to address a normative question: how to decarbonize?

Regarding EU industry decarbonisation, a suite of scenario and policy-oriented studies have been undertaken. Recent EU studies like the EU Impact Assessment for the 2040 emissions target (EC, 2024) and the draft scenario report of TYNDP2024 (ENTSO-E & ENTSG, 2024) sketch the broad picture of industry transformation with increasing levels of direct electrification, hydrogen and other 'clean' molecules consumption, and Carbon Capture Utilization and Storage (CCUS). Future infrastructure rollout has been assessed for hydrogen (Enagás, Energinet, Fluxys Belgium, et al., 2020; Neumann et al., 2023) and carbon (JRC, 2024). Global studies like the Net Zero study of (IEA, 2021) and the Low Energy Demand scenario study of (Grubler et al., 2018) address industrial transformation, also from the perspective of global materials demand. Multi-model analyses of EU pathways (Boitier et al., 2023; Crespo del Granado, 2020) have been undertaken, typically linking macro-economic, energy system, and sector specific models at global and EU levels. (Auer, 2022) apply a single modelling framework for a multi-scale analysis developing consistent EU level and regional specific pathways. Industry oriented analyses (Agora, 2022; BBR, 2021; compasslexecon, 2024) have looked at energy transition pathways from the perspective of industrial competitiveness. Finally, geopolitical perspectives zooming in on international dependencies, strategic autonomy and Carbon Border Adjustment Mechanism (CBAM) have been explored (Marcu et al., 2022; van den Beukel & van Geuns, 2024).

The research under the umbrella of the Shared Socio-economic Pathways (SSPs) can be considered a leading example of integrated scenario analysis in the context of climate mitigation and adaptation. This work departs from five SSP narratives (O'Neill et al., 2014, 2017) that set the stage for integrated model analyses producing sets of baseline

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<sup>4</sup> What will happen?, What can happen? and How can a specific target be reached?

and mitigation scenarios (for an overview see (Riahi et al., 2017), for specific modelling applications see e.g. (Bauer et al., 2017; Kriegler et al., 2017; van Vuuren et al., 2017, 2018). Global SSPs have been extended and detailed to better cover specific regions (like the EU) and topics (such as agriculture, industry) (Kok et al., 2019; Mitter et al., 2020; Nagesh et al., 2023; Pehl et al., 2024). The SSPs have high policy relevance, having been applied under the 6th IPCC climate assessment report (AR6) (Shukla & Skea, 2022). A range of AR6 scenario results are available on the IIASA scenario service manager<sup>5-6</sup>, together with a wealth of scenario data from other recent leading studies. An update to the SSP macro-economic scenario drivers (population, GDP, urbanization) was recently published<sup>7</sup>.

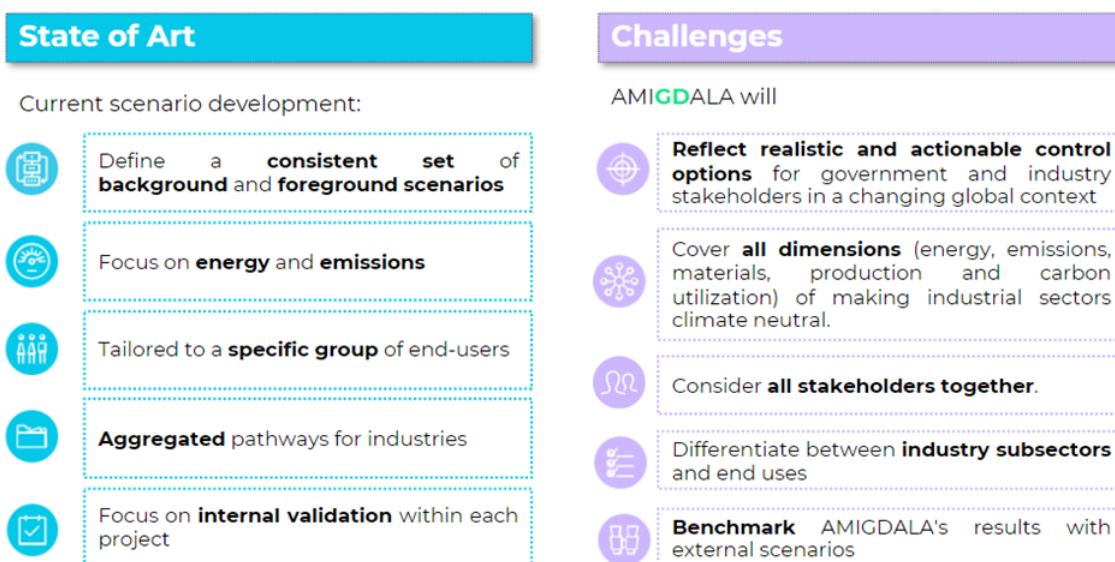


Figure 7 State of the Art scenario development and Challenges addressed within AMIGDALA

Despite the wealth of state-of-the-art scenario analyses, challenges remain in enhancing the scope and applicability of these scenarios (Figure 7). Whereas current state-of-the-art emphasizes the creation of consistent background and foreground scenarios, more work is needed to reflect realistic and actionable control options for government and industry stakeholders. There is a need to move beyond energy and emissions as main scenario dimensions, including material flows, industrial production, and carbon utilization. While scenario studies

<sup>5</sup> <https://manager.ece.iiasa.ac.at/services/overview/public>

<sup>6</sup> <https://iiasa.ac.at/scenario-ensembles-and-database-resources>

<sup>7</sup> <https://data.ece.iiasa.ac.at/ssp/>

often focus on specific end-user groups, the integration of multiple stakeholder perspectives remains a challenge. Scenario pathways need to reflect more industry detail, differentiating between industry subsectors and end uses. Finally, while scenario results are often validated internally, more cross-validation with other studies is needed to improve the quality and consistency of the scenario results. In sum, a yet more integrated approach is needed to provide more robust and actionable insights, driving the industrial sectors closer to achieving climate neutrality.

## 4.2.2 Goals of scenario analysis

The primary goal of the scenario analysis is to generate insights through which policy-makers and industry stakeholders can make better decisions. Scenario work thus aims to develop coherent and contrasting pathways that show how key concerns could be addressed under a range of possible futures. Scenario work thus aims to reflect realistic and actionable control options for government and industry stakeholders, as well as a range of external (e.g. global) developments deemed relevant by the same stakeholders.

The scenario analysis will focus on addressing several key concerns that will influence the future of energy-intensive sectors. Examples are derived from literature and events supported by EU industries (BBR, 2021; Nijs & Lenaerts, 2024; European Commission., 2023; Verbist et al., 2024):

- **What strategic risks European industry clusters are facing from 2030 to 2050: global competition, resource scarcity, and energy market shifts?** There is concern over the vulnerability of European industry clusters due to global competition, resource scarcity, and shifting energy markets. Understanding how to enhance their resilience and maintain Europe's industrial leadership is crucial.
- **Should we import intermediate products from regions with more renewable energy?** A significant concern is whether importing intermediate products from regions with abundant renewable energy could reduce Europe's domestic energy-intensive production while still ensuring supply chain security and sustainability. To what extent could industrial production shift within Europe to areas with relatively high renewables, maintaining strategic autonomy at the EU level?
- **How complex and costly is developing a hydrogen pipeline network?** The complexity of establishing a hydrogen pipeline

network across Europe is a major concern. Evaluating the technical, regulatory, and economic challenges is essential.

- **How much renewable carbon is needed, and where will it come from?** There is uncertainty regarding the amount of renewable carbon required for producing materials like plastics and identifying reliable, renewable sources for this carbon.
- **What incentives are necessary for effective carbon removal?** A critical concern is determining what incentives will be required to make carbon removal technologies economically viable and widely adopted.

## 4.2.3 Functional requirements of the Background and foreground scenarios and narratives module

To fulfil the goals of the scenario study, the scenario analysis is subject to different functional requirements. We distinguish general scenario requirements, operational requirements, scenario coverage requirements and requirements for policy and stakeholder relevance.

### General scenario requirements

The scenarios must fulfil several key requirements to ensure they are robust and useful for decision-making. First, they should represent **consistent or coherent pathways**, adequately describing cause-and-effect relationships, as well as the impacts of external developments and policy or stakeholder actions. Second, the pathways must be **plausible**, capturing the appropriate ranges of uncertainty while ensuring that these uncertainties are interpreted in a legitimate and credible manner. Lastly, they should be **diverse or contrasting**, offering a wide range of possible futures to provide a comprehensive view of what may lie ahead.

### Process requirements

The process of developing the scenarios must be collaborative, emphasizing a **collaborative approach** between modellers, stakeholders, and scenario experts. This ensures that a wide range of perspectives is integrated into the process. Furthermore, scenario results should be **benchmarked** against other relevant scenario studies that focus on industrial transformation, enhancing credibility and ensuring alignment with state-of-the-art methodologies.

### Requirements for scenario coverage

Scenarios must thoroughly explore key aspects of industrial transformation. They should assess the impacts of a **comprehensive**

**set of key drivers** deemed highly relevant, drawing from the latest knowledge and stakeholder insights. The **background scenarios** must include at least the exogenous assumptions for contextual drivers, providing a solid foundation for feeding into models, but they may also go beyond these assumptions where necessary. A **reference scenario** is essential, offering a baseline for comparing alternative scenarios. Additionally, scenarios must address **relevant dimensions** beyond energy and emissions, such as material flows, industrial production, and carbon utilization. Industry detail is critical, with pathways differentiating between **industry subsectors and end uses**. Scenarios also need to cover both **spatial and temporal dimensions** appropriately. For spatial coverage, they should range from global to EU, country, and even industrial cluster levels. Temporally, they should extend to a **long-term horizon** of 2050-2070, incorporating milestone years at 5- to 10-year intervals to track progress.

## Requirements for policy and stakeholder relevance

Scenarios must directly support the broader, long-term goals of the AMIGDALA framework. They should contribute to achieving **climate neutrality by 2050**, including any interim 2040 targets. Additionally, they must aim to **avoid critical dependency on foreign materials and energy imports**, while also exploring potential future dependencies on third countries as a reference point. Additionally, some imports, such as intermediate (semi-finished) products, may increase and should be considered in the analysis. The foreground scenarios should explore **realistic and actionable control levers** for both government and industry stakeholders, demonstrating how these levers can influence outcomes. Ultimately, the scenarios must address how key policy and stakeholder concerns could be managed **under a variety of possible futures**, providing actionable insights to navigate uncertainty.

### 4.2.4 Functional description of the Background and foreground scenarios and narratives module

The scenarios in the AMIGDALA framework provide consistent sets of constraints to represent distinctly different circumstances under which the development of regulation and industry will take place. In contrast to scenarios for a more limited scope, the AMIGDALA scenarios need to differentiate between all sub-sectors of industry and consider all dimensions of climate neutrality.

The scenarios will be tailored to reflect the main interests of all stakeholders, as assembled in the analysis of chapter 3, and aligned

with the decision framework (see chapter 4.1.3). The scenarios are expressed in a narrative in terms of the preferences to relate to the decision-makers.

Based on the above requirements, we can describe the main *building blocks* of the AMIGDALA scenario analysis:

**Scenario drivers:** Scenario drivers are those factors and developments that influence the variables of outcome of the scenario topic at hand. One can broadly distinguish ‘**direct drivers**’ with a direct influence, and indirect drivers whose influence runs via other drivers. Moreover, one can distinguish ‘**external**’ or ‘**contextual**’ drivers as drivers being outside the sphere of influence of targeted actor group(s) and ‘control levers’ (or ‘policy drivers’ or ‘leverage points’<sup>[1]</sup>) as drivers that are within their sphere of influence.

**Background scenarios:** Background scenarios comprise a consistent set of assumptions for the external / contextual drivers that are outside the sphere of influence of targeted actor group(s). Examples are global developments such as industry transformation in China or USA, or generic EU level socio-economic developments like population growth.

**Foreground scenarios:** Foreground scenarios comprise a consistent set of assumptions for the scenario drivers designated as ‘**control levers**’. Examples are EU level policies like emissions regulation, investment support, or import requirements.

**Scenario archetypes:** A scenario ‘archetype’ qualitatively describes a set of future images about the topic at hand. Archetypes are needed as a basis to consistently define a range of concrete assumptions on scenario drivers, both for external drivers and control levers. Scenario archetypes often take the form of a grid or 2 × 2 matrix, where the dimensions reflect the most relevant drivers based on ‘impact’ and ‘uncertainty’. Similar dimensions often emerge across scenario studies, for example based on the importance of free markets, the level of sustainability awareness and behavioural shift, or the main rationale of social organisation (centralized versus decentralized) (Boschetti et al., 2016). Alternatively, an ‘inverse approach’ can be used, as in the development of the SSP narratives (O’Neill et al., 2014, 2017), where scenario quadrants are defined by the combinations of drivers that lead to the highest / lowest challenges for climate mitigation / adaptation.

**Baseline scenario:** A baseline scenario<sup>[2]</sup> includes background and foreground elements and is needed as a basis for comparison for any

alternative scenario. Often this includes decided policies, including climate and energy targets.

**EU Industrial transformation pathways** are the evolutions of key indicators that show how process industries can become climate neutral under a range of future conditions. They are based on the combined evolution of background and foreground scenarios as well as the model outputs. As such, these will be at the core of the scenario analysis of risks and opportunities of industrial transformation.

## Building blocks in the context of AMIGDALA

|                                    |                                                                                                                                  |
|------------------------------------|----------------------------------------------------------------------------------------------------------------------------------|
| Scenario drivers                   | Factors and developments that influence the industry transformation towards carbon neutrality in Europe.                         |
| External driver                    | Scenario drivers falling outside the sphere of EU and national level policy-making and industry.                                 |
| Control lever                      | Scenario drivers falling within the sphere of influence of EU and national level policy-making and industry.                     |
| EU Industry transformation pathway | The evolutions of key indicators that show how process industries can become climate neutral under a range of future conditions. |

*Table 13 Definition of building blocks in the AMIGDALA project*

<sup>[1]</sup> <https://donellameadows.org/archives/leverage-points-places-to-intervene-in-a-system/>

<sup>[2]</sup> In the climate modelling community, baseline scenarios include mostly background elements, assuming

the absence of policy or specific stakeholder actions.

### 4.2.5 Functional requirements of the Destination and pathway narratives module

The Destination and Pathway Narratives module must be **outcome-oriented**, focusing on crafting narratives that are directly linked to desired future states, such as achieving climate neutrality or enhancing energy security. This demands a strong connection between the **outputs of the integrated model suite** and the pathway narratives, ensuring that they are grounded in quantitative evidence while remaining accessible and relevant.

To cater to the needs of various stakeholders, the block must allow for **customization of narratives**, addressing the specific concerns, priorities, and interests of different groups, such as policymakers,

businesses, and civil society. Additionally, it should facilitate **trade-off management**, offering tools and frameworks to balance competing priorities or trade-offs that may emerge during the modelling process. This ensures that the narratives are comprehensive and considerate of varying perspectives.

An **iterative feedback mechanism** is essential, enabling stakeholders to refine pathways and adapt narratives in response to new data or shifting circumstances. This iterative process ensures that the narratives remain dynamic and responsive to changing realities, fostering stakeholder ownership and continuous improvement.

Moreover, the block must provide robust tools for **visualization and communication**. Interactive, visually engaging outputs are critical for presenting pathway narratives to non-technical audiences, ensuring that complex information is conveyed in an understandable and compelling manner. Clear visual representations can enhance stakeholder engagement and promote a shared understanding of the pathways.

Finally, the narratives must **explicitly link to policies and strategies**, bridging the gap between high-level aspirations and practical implementation. This connection ensures that the pathway narratives are not merely theoretical exercises but serve as concrete, actionable roadmaps for achieving the desired outcomes.

#### 4.2.6 Functional description of the Destination and pathway narratives module

The "Destination and Pathway Narratives" module develops forward-looking, actionable narratives that describe how specific goals can be achieved. Unlike the broader scenarios from the first block, this component translates high-level aspirations (e.g., carbon neutrality by 2050) into specific, actionable steps.

The process starts with raw model outputs, which are post-processed to identify feasible, cost-effective, and socially acceptable pathways. Key dimensions include:

- Technical feasibility: Detailing the technologies, systems, and infrastructures needed to achieve the goals.
- Economic viability: Highlighting costs, benefits, and investment requirements.

- Societal acceptance: Addressing equity, inclusivity, and public acceptability.

Regarding **trade-off management**, we provide some examples to clarify possible conflicts:

- Technical vs. economic. Pathways might propose technologies that are technically feasible but economically expensive. For instance, achieving climate neutrality may involve deploying advanced carbon capture technologies, which could impose significant costs on industries or consumers.
- Short-term vs. Long-term goals. There might be tension between policies or actions that provide immediate benefits and those that align with long-term objectives. For example, subsidizing fossil fuels to stabilize energy prices in the short-term conflicts with the long-term goal of transitioning to renewable energy.
- Political and stakeholder disagreements. Policymakers, businesses, and civil society may have divergent views on the pace of change, preferred technologies, or regulatory approaches.

Narratives are crafted to resonate with diverse audiences, ensuring clarity and actionable insights. These narratives are iterative, refined through consultations with stakeholders and real-world validation, and ultimately serve as guides for decision-making dashboards.

In conclusions, whereas the first Scenario module focuses on exploring a wide range of possible futures by constructing **broad exploratory** narratives (both background and foreground) to identify potential challenges, opportunities, and uncertainties, this module concentrates on creating targeted, prescriptive narratives that map out **specific steps** to achieve desired outcomes.

### 4.3 Integrated modelling – expertise

Computer modelling is used for making projections of pathways towards climate neutral destinations. The computer model for this project consists of soft-linked models from different domains working together. The modelling expertise team delivers the modules:

- Integrated model suite
- Post-processing of model output

## 4.3.1 Introduction and state of the art

Integrated Assessment Modelling has a long tradition and is focussed on energy and economy modelling in relation to acidification (EU e.g. RAINS/GAINS) and climate change (global UNFCCC / IPCC model suites). These models are either dynamic (balance-type) macroeconomic models or techno-economic (optimization-type) energy models. Here, competitiveness is simplified to technology costs and behaviour is rather static and/or simplistic (least-cost). Up to now, material and Circular Economy models are underrepresented, as this topic has become relevant since a decade only. Also, environmental impacts other than climate change, acidification and air quality are scarce in modelling. In general, models are domain specific for economy, energy, land-use, materials, industry sectors and/or environment..

Hence, relating to the challenges we are dealing with in AMIGDALA, each model covers only part(s) of the puzzle. Coverage of other domains such as social and human behaviour is poor. In AMIGDALA a selection of models, that covers a broad range of domains relevant for the transformation of the European industry, within the context of the climate and energy assignments, is brought together. They cover economy, energy, environment and materials including recycling at a geographical scale ranging from global, via EU and its member states to local level.

## 4.3.2 Introduction to the AMIGDALA models

1. Global models
  - 1.1. EXIOMOD: Global economic Input-Output and equilibrium model for analysis up to 45 countries. It includes consumption (industries, households, government, investors), sectoral production and trade. It is a monetary model that links to physical materials flows (e.g. metal, mineral, biomass use) and GHG emissions up to 2050
  - 1.2. TIAM-ECN-ECN: Techno-economic cost-optimisation and partial equilibrium calculation of energy supply and demand including energy intensive industrial sectors and GHG emissions for the whole world (divided into 36 regions) up to 2100
  - 1.3. GLOBIOM: Global partial equilibrium model of land based production and demand for food, feed, forest, fibre and bioenergy of world regions up to 2100
2. EU / MS models

- 2.1. CITS: Physical representation of plastic & metal materials and products production and demand and associated environmental impacts for EU MS up to 2060
- 2.2. PRISM: Techno-economic cost-optimisation of plastic waste recycling and GHG emissions up to 2050
- 2.3. TIMES-EUROPE: Integrated, energy-economy-environment, partial equilibrium, techno-economic cost-optimisation of energy supply and demand including energy intensive industrial sectors and GHG emissions of each individual EU member state up to 2050
- 3. Local models
  - 3.1. CALLIOPE: Techno-economic and spatiotemporal and sectoral specification of energy demand and production in EU MS up to 2050
  - 3.2. CIMS: Techno-economic cost-optimisation of chemical production and GHG emissions at industrial cluster level up to 2050
  - 3.3. ELDEST: Agent-based representation of investment and consumption behaviour in the electricity sector of an EU MS up to 2050

Table 14 gives an overview of the models and their characteristics, showing that all domains (economy, energy & climate, materials & environment) are covered. The challenge will be to integrate them in a consistent and sensible way to reduce exogenous parameters.

| Level      | Model        | Application field                                                                              | Goal of the model: Problem(s) to be solved                                                                                                                                                                                                                        | Output KPI's                                                                                                                                                                | User Expertise Level Needed | Resource Demand / Calc Time                                                                                           |
|------------|--------------|------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------|-----------------------------------------------------------------------------------------------------------------------|
| GLOBAL     | EXIOMOD      | Economy                                                                                        | Economic model able to measure the environmental impact of economic activities                                                                                                                                                                                    | Effects on total output by sector, trade, household demand, prices, emissions. It is an economic model, so most output is in monetary units.                                | Advanced                    | In general no longer than 5 minutes for 2011-2050.                                                                    |
|            | GLOBIOM      | Agriculture, forestry, bioenergy                                                               | Maximization of consumer and producer surplus                                                                                                                                                                                                                     | AFOLU, prices, production, trade. Land cover, land use, AFOLU emissions, food production, water and fertilization demand, biodiversity indicators                           | Advanced                    | ~3 hours for one scenario                                                                                             |
|            | TIAM-ECN-ECN | Energy system                                                                                  | Global cost-optimization model that minimizes discounted global energy system's cost based on a partial equilibrium that supplies end-use service demands.                                                                                                        | All energy system characteristics (CAPEX, OPEX, CO2 emission, technology capacity, primary and secondary energy commodity use/production, trade flows, marginal costs ..... | Advanced                    | ~20 minutes                                                                                                           |
| MS / EU    | CITS         | Material Transition                                                                            | Analysis of energy & material use of products throughout society and the related environmental impact of different interventions (R strategies) when applied in the metal and plastics industries in NL & Europe                                                  | Circularity of system, Material Uses, Impacts                                                                                                                               | Moderate to high            | Moderate                                                                                                              |
|            | PRISM        | Material Transition / Recycling impact model                                                   | Analysis of the impact and cost of recycling technologies applied to mixed streams, providing balanced / optimal choices                                                                                                                                          | Circularity of system, Material Uses, Impacts,                                                                                                                              | Moderate to high            | Low                                                                                                                   |
|            | TIMES-Europe | Energy system and related sectors                                                              | Partial equilibrium, EU level cost-optimization model that minimizes discounted total system costs of the modelled regions over the full time horizon, within the context of EU / national policy scenarios.                                                      | All energy system characteristics (CAPEX, OPEX, CO2 emission, technology capacity, primary and secondary energy commodity use/production, trade flows, marginal costs ..... | Advanced                    | ~20 minutes                                                                                                           |
| LOCAL / MS | CALLIOPE     | High resolution Operational and Planning Energy System Optimization, strategic planning of E&M | To support decision making support for industry stakeholders by providing insights into impact of policies and investments in the member state levels with higher resolutions (such as local and industrial sites) on costs and availability of energy "upstream" | All energy system characteristics (CAPEX, OPEX, CO2 emission, technology capacity, primary and secondary energy commodity use/production, trade flows, marginal costs ..... | Advanced                    | Hours to days (depending on the resolution of the model and number of constraints, can range from 10 hours to 3 days) |
|            | ELDEST       | Electricity systems                                                                            | 1. Understanding the impact of different decision making models on the deployment of electricity generation capacity; 2. Understanding the impact of loss and risk aversion on the deployment of electricity generation capacity                                  | Energy capacity mix; electricity prices; production and consumption of electricity                                                                                          | Advanced                    | Hours to days                                                                                                         |
|            | CIMS         | System modelling of large industry                                                             | Calculate optimal pathway accounting for given options and constraints using NPV (for Chemelot towards zero CO2 emissions)                                                                                                                                        | Pathway showing which investments and raw materials are used to comply with constraints                                                                                     | Advanced                    | Low, calculation time about 5 minutes per scenario                                                                    |

Table 14 Short overview of models and characteristics in the AMIGDALA model suite (see Appendix for an extended overview)

## 4.3.3 Goals for integrated modelling

This expertise group delivers an integrated model suite to make projections of EU industry's transformation pathways for a CO<sub>2</sub> neutral, circular and competitive EU process industry up to 2070. We develop a method to combine established models of separate domains to produce a consistent integrated set of outcomes.

This integrated model suite provides insight into the combined effect of 'background' scenario assumptions and various 'foreground' control options on economy, trade, energy, materials flow, biomass and industrial production on an EU systems-level and within a global context, which result partly from stakeholder preference analysis. On a local-level we use models on a case basis to analyse the consequences on the investment environment in industry clusters for investing in transformative solutions and utility operators to build infrastructure.

With the integrated model suite we run scenarios that are expressed in terms of control levers and key performance indicators that reflect those of public and private decision-makers. The model output then reflects their effect on the uptake of transformative solutions and products, as well as on energy demand, emissions, and material use.

## 4.3.4 Functional requirements

The functional requirements of the integrated model suite can be specified from two different angles, i.e. from a content and a practical perspective.

Content related functional requirements are:

- Include materials and circularity options (from recycling to remanufacturing, reduce, rethink, re-use and refuse);
- Integrate Economy, Energy, Materials & Environment;
- Align societal and business perspective / different types of models;
- Combine global, EU, MS and local scale;
- Detail all process industry sectors

Main practical functional requirement is that the integrated model suite should take in data (facts) and parameters from scenarios, and make projections of optimised pathways towards feasible destinations.

It is expected that running the Integrated Model Suite will take substantial time and expertise, so it will not be directly suitable for real time operation and online access by lay person audience in policy

making and industry. Nevertheless, the results of the Integrated Model Suite have to become interactively accessible for Decision-Makers. This will be done in close cooperation with the other expertise within AMIGDALA, especially decision-analysis.

## 4.3.5 Functional description

### 4.3.5.1 Content wise

To use the Integrated Model Suite to project the pathways to reach a CO<sub>2</sub> neutral, circular and globally competitive EU process industry, the following functions are needed from a content point-of-view:

- Energy options on different energy applications varying from fuel switch, renewable energy (hydro, solar, wind, biomass), electrification, energy recovery, energy saving and carbon capture, storage and use
- Circularity options on a great variety of products and materials ranging from material substitution, close the loop (energy recovery and recycling), slow the loop (life time extension: reuse, repair, refurbish, remanufacture, repurpose) and narrow the loop (refuse, rethink, reduce)
- Modification of existing and implementation of completely new innovative energy and economic production pathways from resources through production and use to end-of-life for all sectors in the economy and all their interactions within the system

### 4.3.5.2 Sectors and product groups

As the focus is on the EU process industry, in principle all ASPIRE sectors can be included:



Figure 8 Sectors united under A.SPIRE

However, based upon CO<sub>2</sub> and material relevance, the following sectors have been selected:

- Cement
- Ceramics
- Chemicals (plastics, fertilizer, chemicals)
- Non-ferrous (aluminium, zinc, copper, lead, etc.)
- Minerals
- Paper & pulp
- Refining
- Steel

We exclude Food processing, Water and Engineering since these sectors are not represented in detail in our model suite.

The Circular Economy material streams are highly relevant to assess the demand for materials from the process industry and require modelling of product application groups in the CITS model. This will be done except for Food, water and nutrients:

- Electronics and ICT & textiles
- Batteries and vehicles
- Construction and buildings
- Plastic products & packaging

For these streams, scenarios with different levels of circularity will be drawn up.

#### 4.3.5.3 Key Performance Indicators

The Integrated Model Suite outputs have to be presented in a consistent and understandable way in the form of KPI's suited for decision-makers in governments and industry. These KPI's need to meet the demand from stakeholders (result from the inventory made and presented in section 0 and analysed in the Decision analysis).

Figure 9 depicts an inventory of output parameters currently available in the Integrated Model Suite. The normalized score for a particular category of indicators refers to the share of models acting on a specific geographical scale, which produces related output. Clearly, for most dimensions of climate neutrality and economics KPI's are available from the models' output, though this is not (yet) the case on each geographical level.

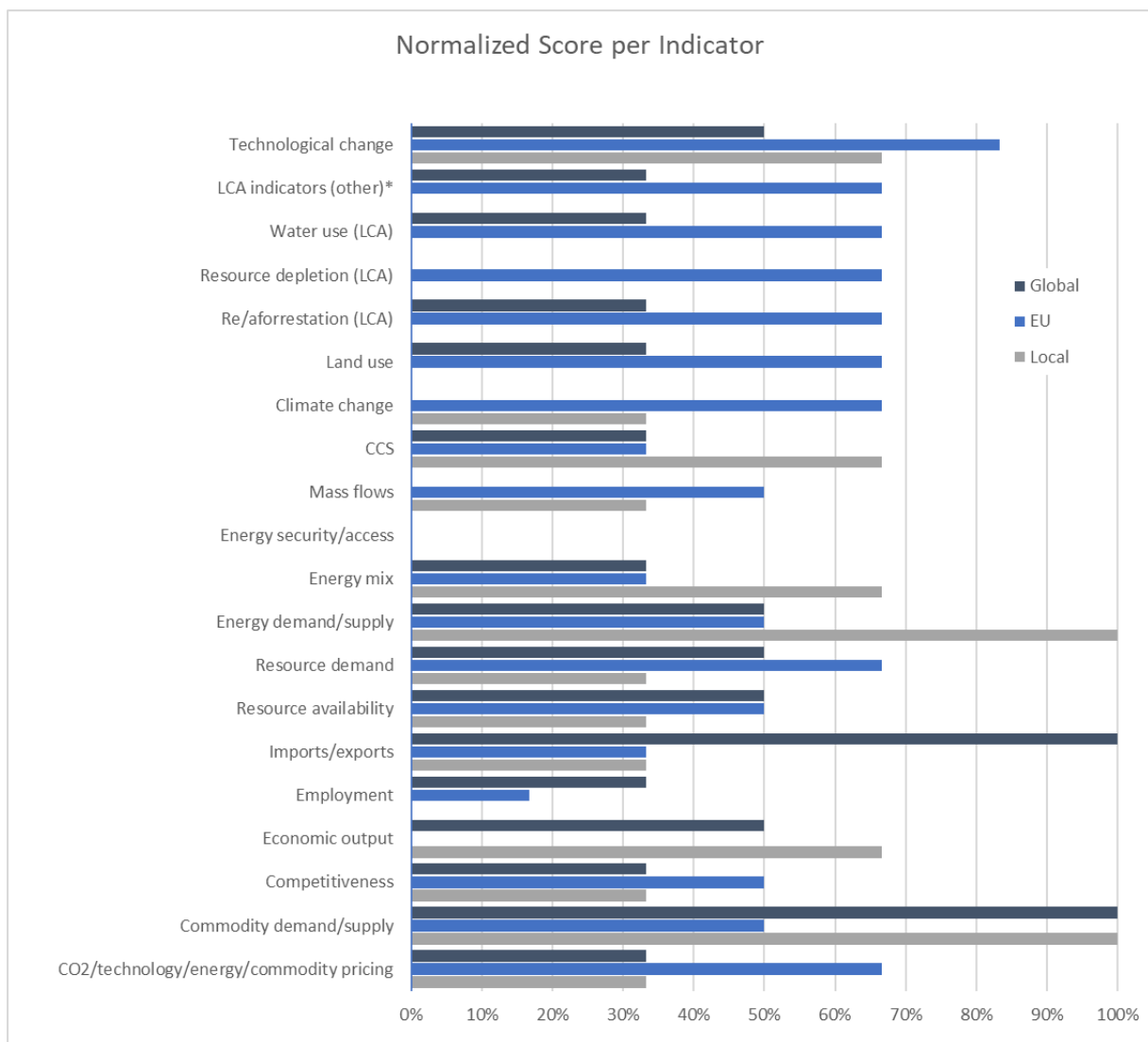


Figure 9 Overview of types of indicators available in the AMIGDALA models per geographical level.

## 4.4 Data management – expertise

Data management has been identified as a key enabler for the AMIGDALA project. This expertise delivers the modules:

- Historic data of the five dimensions
- Data repository
- Data explorer

### 4.4.1 Introduction and state of the art

The data management expertise ensures that the basic data from various sources and for various purposes within the AMIGDALA project is harmonized and validated, accessible for use by the models and possible to display to users of the AMIGDALA results.

The state of the art of data management for modelling is that each model has its own set of input data. Even though models have been set up for different domains, they need to some extent have similar input parameters. Currently, as a result of the use of different sources of data, the data used for model input parameters may vary among the models. In addition, data is not static, but changes as technology advances or insights develop. It is of great importance for the successful integration of the individual AMIGDALA models that data sets become aligned and are updated.

## 4.4.2 Goals of data management

The goal of data management is to feed the project with accurate and harmonized data. The data can pertain to e.g. the models of the integrated model framework and to the historic data of the ‘five dimensions’. A data-explorer is to be developed to explore historic data, as well as data in the repository and output-data from models that might serve as input data for other models.

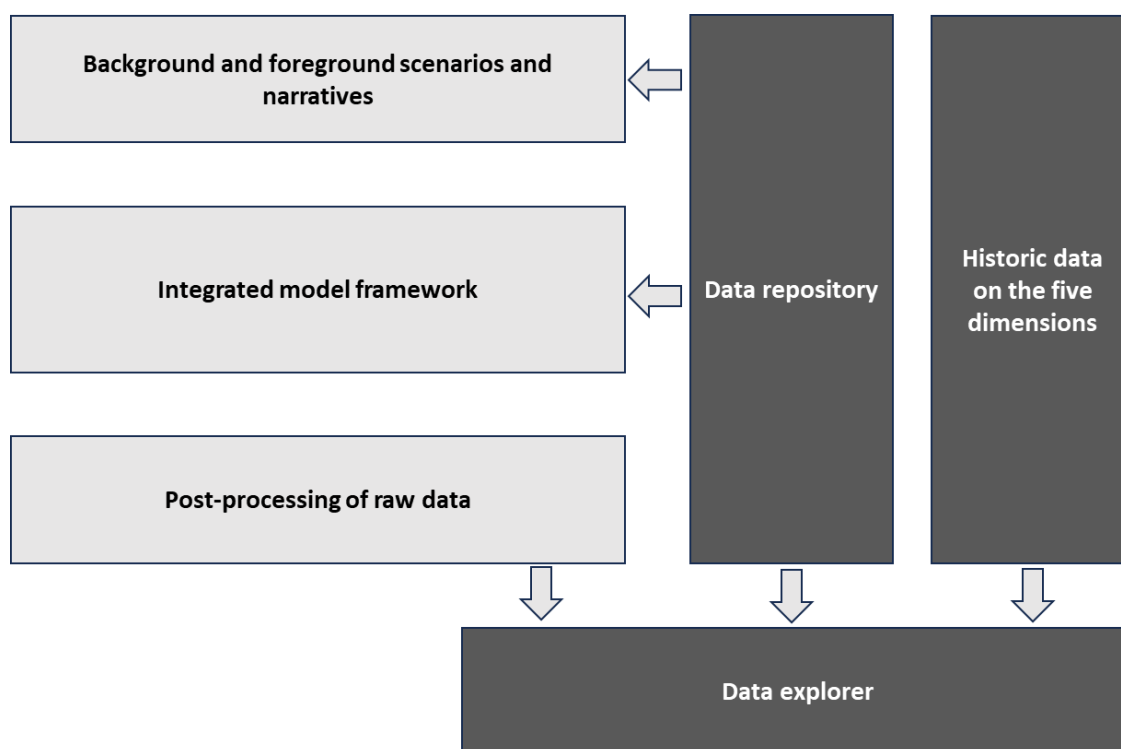


Figure 10 Interaction of the data management modules with the other modules.

The **data explorer**, shown in Figure 10, is the interface to all data that is employed by the AMIGDALA project: existing data sets used by the model suite for projections, as well as selected historical data following the ‘five dimensions’ as specified for the project.

Primary **data sources** are the basic data and existing data sets of each model, as well as historic data from public sources. The data from the models needs to be validated against standard independent external references and benchmarks. Ultimately, the objective of the data management expertise is to ensure that each model uses the data needed for its specific exercise. When two or more models require data input for the same purpose, that these models use the same value.

To support the diverse needs of the entire AMIGDALA framework, the following data will be collected:

- Historical data covering the five dimensions
- Input data for the scenarios
- Input data for the models

The pathways delivered by the models mean to describe how the transition progresses along these five dimensions. The exact interpretation of the five dimensions and the data to collect is to be agreed with project stakeholders, and with the AMIGDALA project team. This means that there is a Decision-Makers to agree with the project stakeholders (DG CLIMA, A.SPIRE) which data best represent their key indicators.

#### 4.4.3 Functional requirements

Active data management is necessary to let the project data repository be the single source of truth that is relevant for all project partners. Before constructing the repository, the following aspects need to be taken into account and their implementation must be ensured:

- Consistency of numerical input of all models
- Validation of the numerical inputs
- Traceability back to reliable sources
- Regular updates of the data repository and dissemination of the updated data
- Determination of the scope of data along the five dimensions and collection of historical data from public sources
- Respecting data license/rights
- Ensure that sensitive data is protected and accessible only to authorized users

#### 4.4.4 Functional description

To ensure that the data repository fulfils all the functionalities required by the users, the input data with the necessary specifications are

discussed in close cooperation with the model owners and modelers. The aim is to make the input data uniformly available across all models so that each model can access the same database.

The data repository needs to be interoperable, ensured by a seamless interface and standardized formats. It also needs to be scalable and flexible. Diverse data types will need to be supported, and regular updates of the data will need to be possible. A main Decision-Makers of the data repository will be the data governance by ensuring and managing the data quality and confidentiality.

It is sometimes impossible or only with restricted conditions to share the input data of the model due to the license conditions. In order to still include data in the data repository, derived or aggregated data and indicators - such as estimated values, indicators for competitiveness and commodity dependency, for example, as well as aggregated country-specific trade data – would be used.

Necessity and characteristics of the data repository:

- Ensures consistency, accuracy, harmonization and accessibility of data across all models,
- Enhances model performance & reliability through standardized and high-quality data.

#### 4.4.5 Next steps

The specific model needs and specific data requirements will be assessed in bilateral interviews with model owners and modellers (planned Sep-Nov 2024). Tailored questions address the temporal and spatial resolution of the models, data standardization and interoperability, data confidentiality and security and the development of the respective model. The summarized results of those interviews are going to form the basis for the schema and structure of the data repository. Based on the outcomes of the interviews, the functional requirements of the data management will be revised and adapted if needed.

**Possibility** to synergize with the TRANSIENCE project

The TRANSIENCE and AMIGDALA projects may have a good opportunity to synergize on the collection and validation of (selected) basic data, such as performance of technologies. Ideally, the used data-sets should have a high degree of similarity, so that dissimilarities of outcomes are reduced when they should be comparable.

## 5 Technical specification of the AMIGDALA framework

This section defines the modules of the AMIGDALA framework in more technical detail. As a starting point the intended execution sequence of the framework is outlined. All module have their place in this sequence. The next sections will describe in more detail what are the elements of the modules and how these elements will be connected.

### Execution of the framework

The AMIGDALA framework of modules is executed in several steps. The individual steps in full mode of operation, after technical completion in WP3 are listed below:

(1) Data preparation

(2) Decision framework analysis

- On the basis of stakeholder interviews define control levers and performance indicators which will be included in the scenario parameterization.
- Derive decision propensities to inform the scenarios on the relation between performance indicators and control levers.
- Derive parameters for steering the model through boundary conditions and objective functions

(3) Scenario definition

- Background scenarios of parameters outside sphere of influence
- Selection of scenario archetypes
- Foreground scenarios of parameters within control
- Preparation of the scenario narratives, e.g. in terms of performance indicators, control levers and use of actuators
- Parameterization of a scenario narrative

(4) Preparation and execution of an integrated model run

- Implementation of scenario parameters (exogenous parameters, policies and boundary conditions)
- Initialisation of the models
- Execution of the model run

(5) Post-processing of the model output and export to decision support system

Characterisation of the climate neutral destination

- European demand for products

- Make-up of industry sectors in Europe
- Competitiveness and resilience (if these can be defined)

Characterisation of the pathway in time series:

- The ‘five dimensions’
- Market uptake of transformative solutions
- Performance indicators according to stakeholders
- Risk and opportunities (if these can be defined)
- Control levers and their actuation, e.g. by subsidies, pricing, mandates, investments, divestments
- Trade balances on selected commodities

(6) Publishing of the results through the data explorer

(7) Engagement of the AMIGDALA community of interest

(8) Search for destination and pathway narratives

## Modules of the framework

To build the modules, they need to be specified in more detail. The details provide clarity on the requirements for each module to function and the interaction with other modules.

### 5.1 Decision analysis

#### 5.1.1 Definitions

In the context of the AMIGDALA project, the decisional framework is based on the following considerations.

**Decision-Makers (DM)** are defined as entity representatives which oversee decisions considering predefined goals. Such Decision-Makers can be organised in Decision-Maker **Categories** according to the type of institution they represent (e.g. Regulators, private companies, public managers, trade associations, etc.).

The framework is aimed at aiding Decision-Makers in deciding how to manage the institutions they represent given a set of available alternatives towards a predefined goal given specific constraints.

Each category of Decision-Makers can only operate on some specific areas of their institutions through a set of predefined **Control levers** which are represented in labelled classes (e.g. Action: Nuclear power development, Classes: increase, keep, decrease).

A **Goal** is represented by labelled classes of specific **Targets** (e.g. Target: CO<sub>2</sub> emissions decrease, Classes: below 1.5%, below 3%, above 3%). The Decision-Maker sets its goal before assessing the available pathways toward it, by specifying all Target's classes to be reached.

DM freedom of operation is likely limited by their institution and their resources, therefore, once the goal is set, the limiting Constraints must also be set. **Constraints** are represented by labelled classes of specific **Control levers (CL)** (e.g. Control lever: operational costs, Classes: increase, keep, decrease).

Not all Decision-Makers in the same category have the same preferences when dealing with different attributes. To this end the decisional framework allows Decision-Makers to set their preferences related to the five **Dimensions of climate neutrality** which are represented by labelled classes (e.g. Dimension: social wellbeing, Classes: important, average, not important). The set of class selections for all the Dimensions represents a **Preference Profile (PP)** which is specific to a single Decision-Maker. A default PP is available for each Decision-Makers' category.

## 5.1.2 Design and logic

The decisional logic is tightly related to **scenarios** and **models** as presented in Figure 11, it is basically a tool which allows to:

- Obtain statistical descriptors of the performance indicators for the projected scenarios.
- Rank the possible projected pathways according to the Decision-Maker preference profile.

As the amount of information to be modelled is rather big and inhomogeneous, the different models are linked together so as they can be represented as a single **Integrated model (IM)**. Such a comprehensive model is managing so much information that makes it impossible to be run in real time in a user-friendly application. In fact, the IM is run off-line for plenty configurations of inputs so to represent most of the possible inputs Decision-Makers are allowed to select in the decisional framework and the results are stored in the system so that the decisional dashboard acts as a navigator interface for the pre-calculated results.

IM inputs are directly related to Foreground Scenarios which, in turn, are defined by the Decision-Maker through the CLs. The integrated foreground and background scenarios define all inputs of the IM which

are related to specific outputs. IM's outputs are composed by two categories of information: **Pathways** and associated **Indicators**. Indicators define the overall system's future conditions at a specified point in time while Pathways define the set of actions which should be performed by the Decision-Maker to reach those conditions.

Indicators are also associated to Dimensions of climate neutrality so that a value can be associated to each feature and weighed by Decision-Makers preferences towards an aggregated score which is representative of the Pathway and related Indicators. The list of results are finally presented to the Decision-Maker in a score based descending order as the result of the decisional aiding process.

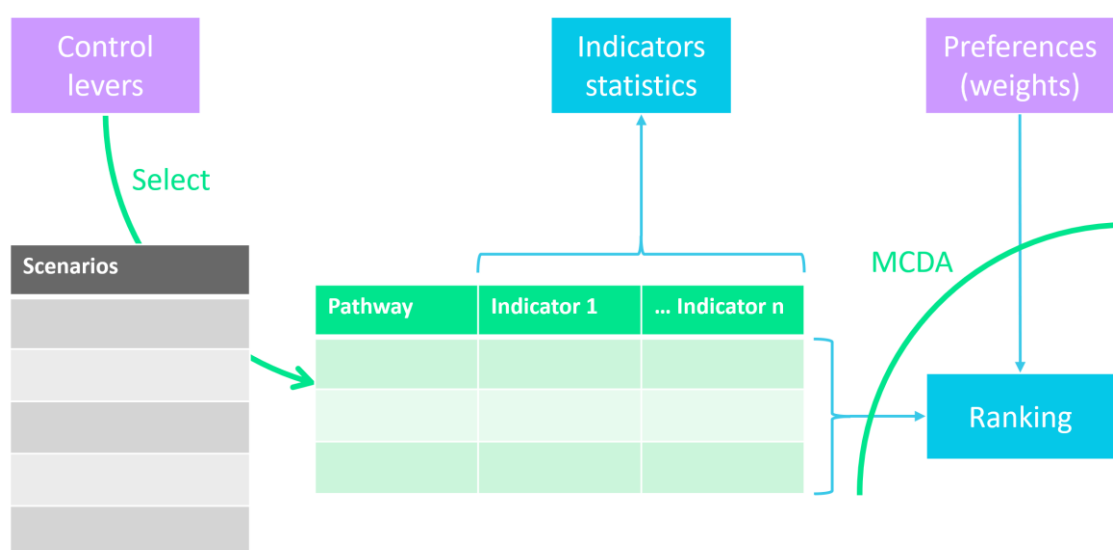


Figure 11 Structure of the AMIGDALA Decision Logic

### 5.1.3 Interaction with other modules

As the Decisional Dashboard is the final decisional interface used by Decision-Makers to interact with all the background scenarios and models results, as well as relevant data. As such it has interactions with all the other modules.

Interaction with the modelling team is needed to understand what models can provide and map inputs and outputs to Decision-Makers' needs.

Interaction with the scenarios team is also important to establish which are the input configurations the users are allowed to select.

Of course, the data management module is needed to collect data from models' runs and store results of the assessment.

## 5.1.4 Development needs

The Decisional dashboard is mainly based on input categories and preconfigured models' runs. In order to develop the software it's mandatory to define:

- The set of control levers.
- The set of relevant indicators.
- The set of relevant background scenarios to be used (at least one).
- The set of foreground scenarios to be associated to users inputs.
- The set of IM runs with associated scenarios, control levers and indicators values

Given the information above it's possible to configure the Decisional dashboard to elaborate user preferences and establish statistical output descriptors as well as ranking of alternatives.

## 5.1.5 Practical implementation

The AMIGDALA Decision dashboard will be implemented as a serverless reactive web application as presented in Figure 12 below.

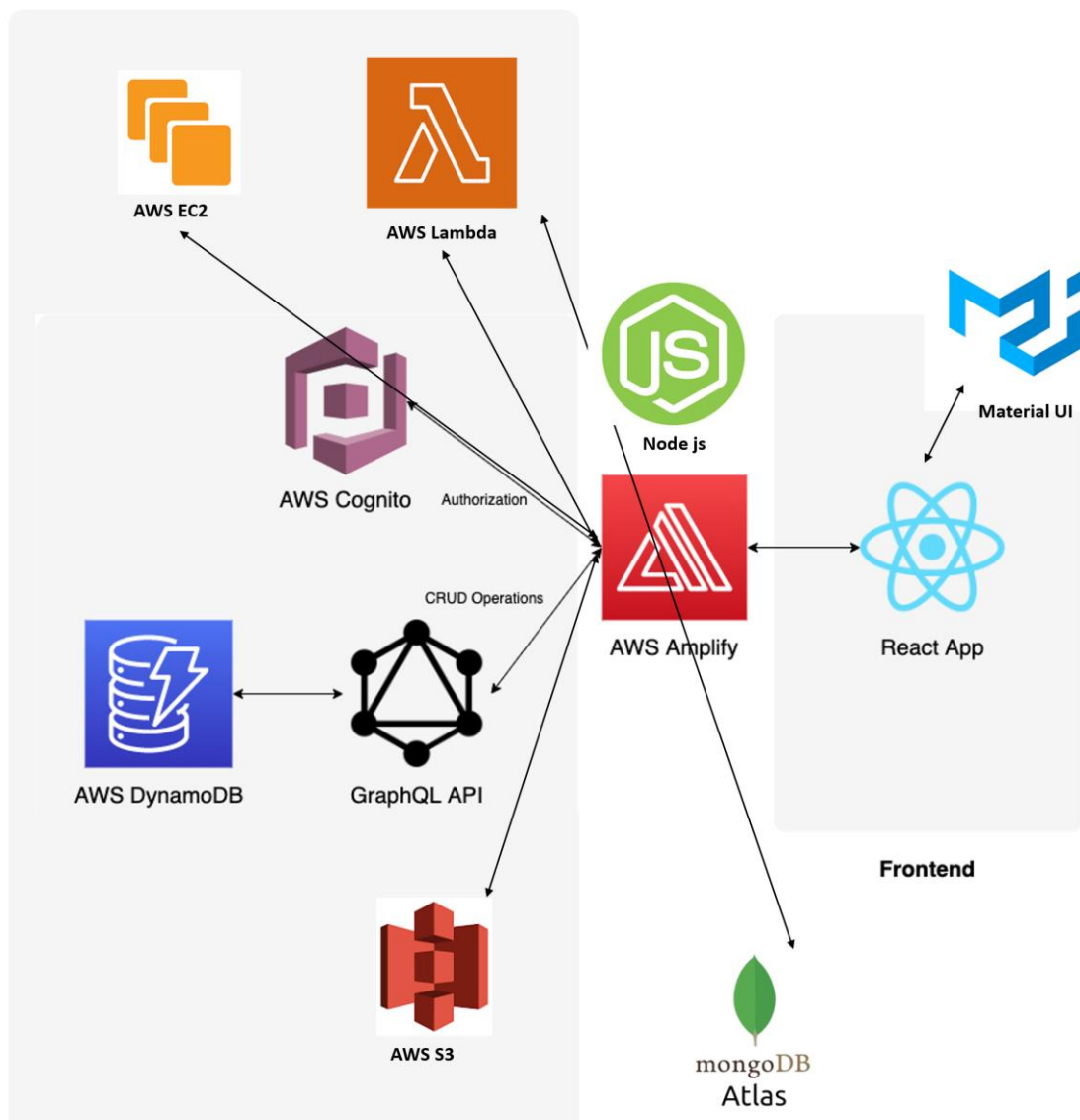


Figure 12: The AMIGDALA Decisional framework software architecture

A serverless web application is a type of application that runs on cloud-based servers without requiring the developer to manage the underlying infrastructure. Instead of provisioning, configuring, and maintaining servers, developers focus solely on writing the application code. This approach significantly reduces operational overhead, allowing for faster development cycles and increased scalability. Serverless applications are typically event-driven, meaning they are triggered to execute based on specific events, and automatically scale to handle varying workloads, making them highly efficient and cost-effective. The AMIGDALA Decision-dashboard web application will be leveraging the Amazon AWS serverless web services suite plus other external services. More specifically, it makes use of: AWS Amplify, AWS

EC2, AWS S3, AWS Lambda, AWS Cognito, AWS DynamoDB, MongoDB Atlas, GraphQL, NodeJS, React and Material UI.

AWS Amplify is a comprehensive platform that simplifies the development and deployment of full-stack web and mobile applications. It offers a suite of tools and services for frontend and backend development, accelerating the development process and providing features like hosting, backend integration, and continuous deployment.

AWS EC2 (Elastic Compute Cloud) provides scalable virtual servers, or instances, that can be used to run various applications. It offers flexibility in configuring and managing computing resources, with different instance types available to suit different workloads.

AWS S3 (Simple Storage Service) is a highly scalable object storage service for storing and retrieving data. It is used for a variety of purposes including website hosting, data backups, and archiving.

AWS Lambda is a serverless compute service that allows you to run code without provisioning or managing servers. It automatically manages the underlying compute resources, making it ideal for applications that need to scale rapidly and efficiently.

AWS Cognito is a user authentication and authorization service that manages user identities and data securely. It provides features for user signup, sign-in, and access control.

AWS DynamoDB is a NoSQL database service designed for fast and predictable performance. It offers automatic scaling to handle varying workloads and is suitable for applications with high read and write requirements.

MongoDB Atlas is a fully managed database service that provides a cloud-based platform for deploying, managing, and scaling MongoDB databases. It simplifies database administration by handling infrastructure, backups, security, and monitoring, allowing developers to focus on application development.

GraphQL is a query language for APIs that provides a flexible and efficient way for clients to request data. Unlike traditional REST APIs, GraphQL allows clients to specify exactly the data they need, reducing over-fetching and under-fetching. It promotes efficient data transfer and improves application performance.

Node.js is a JavaScript runtime environment that enables developers to build server-side applications using JavaScript. It is known for its event-driven, non-blocking architecture, making it efficient for handling concurrent connections. Node.js is widely used for building web applications, APIs, and real-time applications.

React is a popular JavaScript library for building user interfaces. It employs a component-based architecture, promoting code reusability and maintainability. React's virtual DOM efficiently updates the UI, providing a smooth user experience. It is used to create interactive and dynamic web applications.

Material UI is a React component library based on Google's Material Design. It provides a set of pre-built components that adhere to design guidelines, ensuring consistency and visual appeal in user interfaces. Material UI accelerates development by offering customizable components, themes, and utilities, helping to create visually pleasing and responsive applications.

## 5.1.6 Next steps

The first D-dashboard prototype developed in Microsoft Excel will be created in the proof of concept phase. It will be based on a restricted amount of data and inputs so to cover all aspects of the tool even though not containing the complete set of options it will present in its final version.

A foreseeable setup consists in a single background scenario, a limited set of control levers and indicators, about ten fictitious IM's runs, preferences about the five dimensions of climate neutrality. Actual model runs will be included once they become available, e.g. during WP2. Once completed the tool can be enhanced by including more options and data.

## 5.2 Scenario building

### 5.2.1 Design and logic

A first step in the design of scenario building blocks (4.2.4) is the definition of a 'long-list' of scenario drivers. Different sources of input apply. First, these are the SSP narratives (O'Neill et al., 2017)<sup>8</sup> providing a definitions of scenario drivers and categories of *generic relevance* in the

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<sup>8</sup> See Tables 1-3 in O'Neill et al. (2017)

context climate change mitigation and adaptation. The list of scenario drivers is then extended with scenario drivers of *specific relevance* to EU industrial transformation based on stakeholder input (3.3), required model inputs (Appendix), and further brainstorming. For details see Section 5.2.2.

A second step is to further narrow down and classify the scenario drivers based on three criteria. A first criterion is the level of policy / stakeholder influence, i.e. whether the driver is considered as an external driver or control lever. A second criterion is whether the scenario driver influences industrial transformation in a direct or more indirect way. A third criterion is the level of importance, where (for external drivers) the so-called impact-uncertainty matrix (Schwartz, 1996) can be used as a heuristic. The result of this step will be a concise ‘short-list’ of scenario drivers of highest relevance. For details see Section 5.2.3.

A third step is to develop an appropriate scenario archetype as a basis to consistently define scenario assumptions for each high-relevance scenario driver. Different methods are possible, ranging from intuitive to analytical approaches (van Notten, 2005). One option is to seek consistency with the SSP scenario framework, zooming in on industry transformation in the EU, as explained Section 5.2.4. The various steps in developing the scenario building blocks require interaction with other expertise areas as outlined in Section 5.2.5.

## 5.2.2 Drivers of the transformation of EU industries towards climate neutrality

Taking as input the SSP scenarios, a longlist of drivers was built that has the potential to characterize the different scenarios. Drivers that could represent a foreground scenario are **control levers**, since industry policy makers and main stakeholders have the power to directly act on and influence them.

A long list of drivers was built, split into main categories which follow the ratio of SSP methodology. Since it is impossible to follow the same process, the shared socioeconomic pathways have been adapted to capture the peculiarities of EU industry framework, ensuring consistency and highlighting the ways in which the two approaches deviate from each other. In particular, for each driver it has been specified if this comes from the original SSP framework or if it is extended being of specific relevance to EU / Industry transformation and not yet covered in the original SSPs. Original drivers refer to a global development, although the drivers can be interpreted differently for

low, medium and high income countries, while extended drivers can refer both to global or EU specific developments.

As stated, a long list of drivers has been collected for seven main categories:

**Demography.** Population serves as a fundamental driver, encompassing both population growth and the age structure of society. These projections are informed by the Shared Socioeconomic Pathway (SSP) scenarios and include trends such as urbanization. Additionally, Eurostat has developed detailed projections of population dynamics, extending these insights up to the year 2070.

**Human development.** It is part of the SSP scenarios, but its impact on industrial transformation and competitiveness shall be low, except for drivers related to labour (labour productivity, employment rate) which could play a role.

**Economy and lifestyle.** This is a key category, since it includes all drivers related to costs (energy, capital, labour, infrastructure, etc...), finance, and economic structure (growth, tertiarization, changes within industry, demand for energy intensive products).

**Policies and institutions – global level.** Drawing from the drivers that are part of SSP (international cooperation, policy orientation, environmental policy and institutions effectiveness), specific policy and geopolitics drivers at global level have been added that affect industry transformation. They are regarded as background scenarios because EU industry and policy have limited influence over them.

**Policies and institutions – EU level.** Specific for EU context, this category comprises circular, energy, industry and technology development policies and regulatory framework. They are not part of SSP framework but have been adapted for AMIGDALA scopes.

**Technology.** Drivers affecting technologies' development, substitution, energy and environmental criteria are listed here. Framework of the category comes from SSP, then industrial specific decarbonisation technologies are evaluated (nuclear, CCS, hydrogen, storage, PV)

**Environment & natural resources.** Originally part of SSP, environmental drivers are included (affecting water, biodiversity, GHG, physical risk) as well as circularity, here intended as degree of circularity and waste generation, critical raw materials, biomass and EU energy availability.

For more details, a long list of drivers is provided in Annex.

## 5.2.3 Practical implementation Background and Foreground scenarios

The following two tables list background and foreground drivers that are important for the transformation of EU energy-intensive industries towards climate neutrality. In a first stage, drivers (or drivers' categories, wherever they are homogeneous) are grouped according to three criteria:

- Control lever: being an exogenous driver (background scenario) or a control lever (foreground scenario);
- Driver of the transformation of energy-intensive industry in Europe: being a direct or indirect driver;
- Being part or not of AMIGDALA modelling outputs.

Indirect drivers are mostly covered by original SSPs scenarios (e.g. population, economy...) while direct drivers are mainly extended for EU-Industry SSP:

- Demand for industrial products (quantity / quality / circularity constraints)
- Resource availability: energy / feedstock, infrastructure
- Labor availability
- Global competition
- Speed of innovation (learning curves for industrial transformation technologies)
- EU market integration
- Industrial policies

Both tables use colour coding to indicate how often a driver is mentioned by industry and policymaker stakeholders as in Chapter 3.2.3: **green** for most often mentioned, **yellow** for moderately mentioned, and **red** for least mentioned.

**Table 15** covers background drivers, which are considered 'exogenous' for the EU. These include factors such as technological innovation, global policies, and willingness to pay. Some drivers also influence the industry indirectly through broader global trends like cost of capital or water availability. Some drivers of the industry transformation are exogenous to the integrated model (treated as inputs) while others are endogenous in standard scenarios (emerge as outputs). Endogenous variables can however also be constrained in certain models to steer a specific driver in a targeted direction.

| BACKGROUND DRIVERS | OUTPUT<br>of Amigdala modelling                                                                                                                                                              | INPUT<br>or information needed                                                                                                                                                                                                                                                                                                                                                                       |
|--------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Direct driver      | <ul style="list-style-type: none"> <li>Global carbon intensity</li> <li>Global energy intensity</li> </ul>                                                                                   | <ul style="list-style-type: none"> <li>Evolution of technology costs, innovation</li> <li>Availability of energy</li> <li>Demand for EU energy intensive products, relative to rest of the world</li> <li>(Critical) raw material availability</li> <li>Willingness to pay (direct and indirect through climate policies repartition of revenue)</li> <li>Global policies and institution</li> </ul> |
| Indirect driver    | <ul style="list-style-type: none"> <li>Water usage</li> <li>Biodiversity impact</li> <li>Waste generation</li> <li>Recyclate availability</li> <li>Energy technology substitution</li> </ul> | <ul style="list-style-type: none"> <li>Cost of capital</li> <li>Climate change impact on productivity (physical risk)</li> <li>Well-being</li> <li>Water availability</li> <li>Cost of inaction</li> <li>Population</li> </ul>                                                                                                                                                                       |

*Table 15 Background drivers considered important for the transformation of the EU energy-intensive industries.*

**Table 16** focuses on foreground drivers, which have a more direct influence on the transformation of EU energy-intensive industries. These include energy prices, carbon pricing, EU-specific policies, regulatory uncertainty, and circularity of products. These drivers are closely tied to the European context and have more immediate implications for industry operations.

The classification and distinction between background and foreground drivers, as well as the assignment of drivers to input or output of the model suite, still need to be discussed further.

| FOREGROUND DRIVERS          | OUTPUT<br>of Amigdala modelling                                                                                                                                                                                                                                                                                                                   | INPUT<br>or information needed                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
|-----------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Direct driver               | <ul style="list-style-type: none"> <li>• Energy price (intermediate like electricity)</li> <li>• Carbon price</li> <li>• Labour cost, productivity and supply</li> <li>• GHG emissions and carbon intensity of industries</li> <li>• Technology value added within EU</li> <li>• Tertiarization and structural changes within industry</li> </ul> | <ul style="list-style-type: none"> <li>• Energy price, including biomass</li> <li>• (Critical) raw material price</li> <li>• EU industry policies and global leadership</li> <li>• EU technology development policies</li> <li>• EU carbon trajectory/constraints</li> <li>• Circular materials quota (material efficiency strategies)</li> <li>• Regulatory uncertainty</li> <li>• Investment support</li> <li>• Cost of infrastructure and subsidies</li> <li>• Circularity of Products</li> <li>• Trade barriers / quotas</li> <li>• EU energy policies (RES, energy efficiency)</li> <li>• Environmental consciousness</li> </ul> |
| Indirect driver             | <ul style="list-style-type: none"> <li>• Water usage</li> <li>• Biodiversity impact</li> <li>• Waste generation</li> <li>• Economic growth</li> <li>• Service demand</li> </ul>                                                                                                                                                                   | <ul style="list-style-type: none"> <li>• GDP Drivers</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| Other possible model inputs |                                                                                                                                                                                                                                                                                                                                                   | <p>Socio-economic</p> <ul style="list-style-type: none"> <li>• Education level</li> <li>• Income distribution</li> <li>• Total factor productivity</li> </ul> <p>Policy drivers</p> <ul style="list-style-type: none"> <li>• Fuel tax, subsidies, standards,</li> <li>• Emission standards (like cars and trucks)</li> <li>• Pricing of carbon stocks</li> </ul>                                                                                                                                                                                                                                                                      |

*Table 16 Foreground drivers considered important for the transformation of the EU energy-intensive industries*

Factors such as health investments, access to health facilities, gender equality, social cohesion, and societal participation are considered less important for the transformation of EU energy-intensive industries. These drivers, mostly related to human development, have limited

influence on this transformation. The table outlining these factors is still under discussion with the project consortium.

## 5.2.4 Towards scenario archetypes

Scenario archetypes should serve the purpose of spanning a range of possible futures that are most appropriate to address main policy and stakeholder concerns. As described under Chapter 3 and 4.3.2, these concerns can be divided into two groups: emissions reduction, circularity and sustainability, and economic viability and competitiveness.

These main concerns can potentially be mapped onto the SSP scenario framework. The SSP scenario framework (O'Neill et al., 2014, 2017) is defined by the combinations of drivers that lead to the highest or lowest challenges for climate mitigation (axis 1) and adaptation (axis 2). The first axis covers drivers that tend to lead to high 'reference emissions'. This appears to be an equally relevant dimension for EU industry transformation as it would imply the most stringent action to reach net-zero emission targets, in line with the main concerns of emissions reduction and circularity. The second axis is about climate vulnerability, covering "socioeconomic determinants of exposure to climate change hazards" and the "limits of autonomous adaptation and the obstacles and constraints to adaptation policies, such as ineffective institutions and governance". Whereas climate vulnerability as such is of lesser relevance to industry transformation, an analogy to industry vulnerability could be made. This could imply re-interpreting the dimension to include the socioeconomic determinants of competitiveness of EU industries compared to the outside world (materials demand, global production, geopolitics, ...) and factors that affect the ease at which industrial transformation can be carried out (including technological change, EU governance, investment dynamics).

There are further practical reasons why consistency with the SSP could be advantageous. First, a suite of global scenario data on SSP research is available. Also, working from an existing 'recognised' scenario framework may allow easier communication with policy-makers and stakeholders. Finally, examples of SSP 'extensions' to different domains and geographical regions have already emerged (Kok et al., 2019; Mitter et al., 2020; Nagesh et al., 2023; Pehl et al., 2024), but a comprehensive extension towards EU level Industry transformation has not yet been performed. In sum, an adapted SSP scenario framework could potentially best serve the needs of the Amigdala project, which will be further explored in the proof-of-concept phase.

## 5.2.5 Interactions with other modules

For developing the *modules*, the interaction between different domains of expertise is paramount. This includes interactions with expertise domains of stakeholders and decision-making, modelling and data, and other scenario studies as follows (see Figure 13). The diagram illustrates the interaction between stakeholders, other scenario studies, AMIGDALA scenarios, and integrated models. Stakeholders provide insights on needs and learn from the scenario outputs, shaping the development of AMIGDALA scenarios. AMIGDALA scenarios act as a bridge, highlighting model development needs and identifying necessary inputs for integrated models. These models, in turn, depend on scenarios to define drivers for projections, while also informing the scenarios about the background and control levers required for accurate modelling. In Work Package 4 of the project, other academic and industry-based scenario studies contribute as a benchmark to refine AMIGDALA scenarios, ensuring alignment with broader efforts.

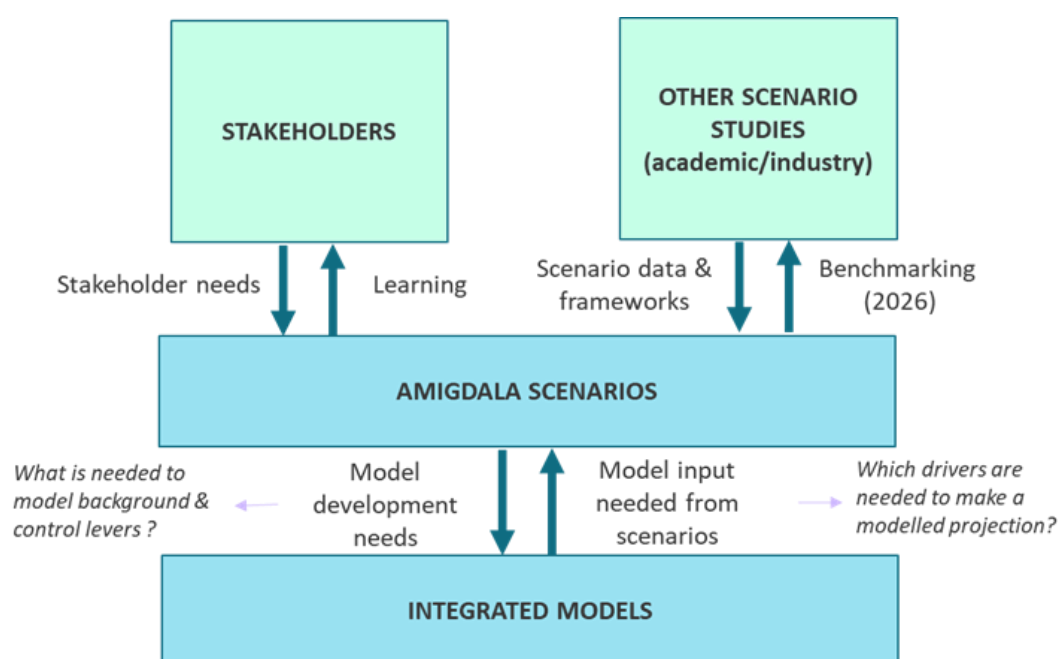


Figure 13: Overview of interactions between scenario analysis and other expertise domains.

### 5.2.5.1 Decision making:

Scenario analysis is first and foremost guided by **stakeholder needs**, including their perspectives on key concerns, relevant external scenario drivers and (realistic, actionable) control levers. In turn, we hope to generate policy relevant insight to support stakeholder learning.

Stakeholders' feedback about drivers has been considered in the scenario archetypes. The 32 drivers pointed out by industry actors and policy makers are integrated into the long list of drivers, some of them as they are, others are merged with already existing ones. Column C of the Excel in Annex states if a driver is an Amigdala stakeholders' input or not.

The weight assigned by stakeholders to the different drivers, expressed in percentage value, will be considered in the next stage when they will be rated based on their importance. Those pointed out in the interviews will be given priority, so that the final list of drivers will be in line with stakeholder views.

## 5.2.5.2 Models:

The interaction with **integrated modelling** is also two-way. Scenarios must present well-supported pathways that illustrate the potential impacts of actions and external developments within a complex energy-material-economy-environment system. On the one hand, integrated modelling requires background and foreground scenario assumptions as model input needed from scenarios. On the other hand, scenario analysis may reveal relevant external drivers or control levers that are currently not sufficiently well represented in the integrated models. This 'gap' can be translated into model development needs to create better scenarios.

In Table 15 and Table 16 of 5.2.3, all identified drivers (model inputs), that are needed for the Amigdala models, were introduced. It is important to clarify which levers are already being modelled, which can be further developed, and which are not feasible for modelling at this time. At the system scale, levers such as energy prices, carbon pricing, and global policies are typically modelled due to their broad influence on market dynamics and industrial behaviour. There is also potential to further develop models for global technological innovations and energy efficiency improvements.

At the local scale, levers such as regulatory frameworks, regional infrastructure investments, and local resource availability can be modelled, but there may be challenges due to data limitations or the complexity of regional differences. Levers like societal participation and local environmental impacts may not be fully modelled yet, as they require more specific data and methodologies that are still under development.

### 5.2.5.3 Data

A third interaction is with the expertise **data**. A strong alignment must be created between model inputs, background scenarios, and control levers on one side, and model outcomes and highly relevant impacts on the other.

The Scenario Expertise team will provide available scenario metrics from existing frameworks. If certain data is missing or not directly related to scenario definitions, the partner with the closest expertise will be responsible for collecting it. This includes historical, sector-specific, and technology data. To ensure efficient data collection, it is crucial to establish a common understanding among all partners about who is responsible for gathering specific data, based on their expertise.

### 5.2.5.4 Other scenario studies

A last interaction applies to **other scenario studies** described in the literature, possibly with retrievable results at data platforms. In the initial stages of scenario development, scenario studies act as a source of plausible assumptions. Moreover, consistency with existing scenario frameworks such as the SSP may be sought. In later stages, other scenario studies will be used in a bench-marking process of new Amigdala scenarios.

## 5.3 Integrated modelling

### 5.3.1 Definitions

For being integrated, the models will have the following scopes in common:

- Geographical scales: focus on EU and its Member States (MS), in global context and with local detailing on specific case (Chemelot as example for further extension)
- Time horizon: 1990 - *historic* - 2020 - *prognostic* - 2070

Together, the models in the Integrated Model Suite have to cover the domains: economy, energy, materials (including circularity), climate (environment).

### 5.3.2 Design and logic

The content of the sections on Integrated Modelling, viz. the design, logic and operations, has been developed in three interactive, live workshops and monthly online meetings with the partners owning a model.

A schematic overview of the AMIGDALA framework is given in Figure 14. It consists of the IMS (in the centre), which is dependent on Scenario building (on the left) and Data management (at the bottom) in order to produce output for the Decision analysis (on the right).

The IMS consists of 9 models which are each very different in domain and even type of approach, the models cannot be coupled just like that. This has to be done with a logic, so that integration can be done step by step in order to come to sensible results while being able to check consequences and impacts of this stepwise integration. We identified 2 differentiating aspects, viz. the geographical resolution and the type of model. The geographical scope allowed us to distinguish global, EU (MS) and local models. It is logical to start with global models, since these will provide the context for EU models, which will be subsequently the context for local models.

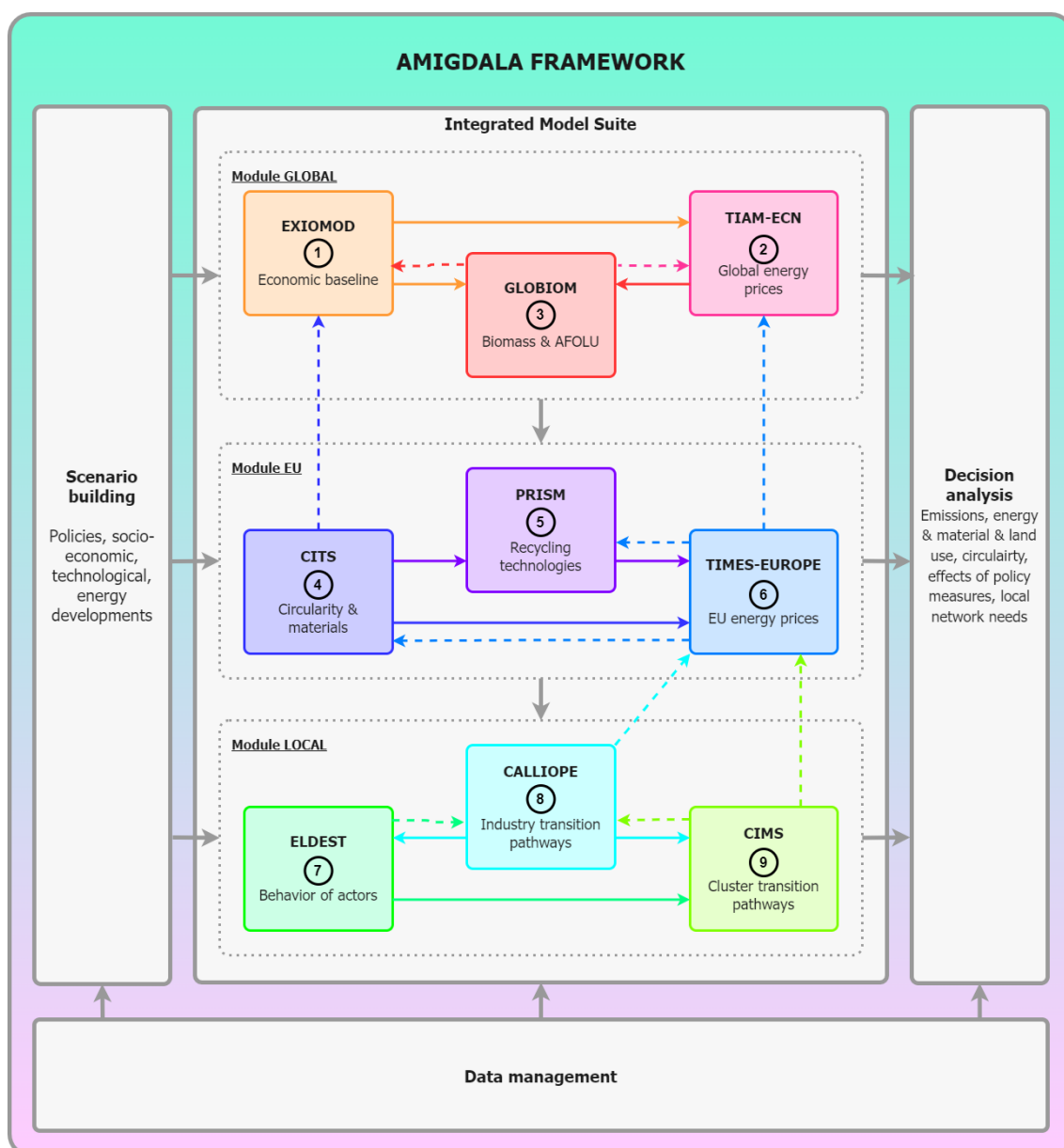


Figure 14 Overview of the AMIGDALA framework and the models and most prominent possible interactions in the Integrated Model Suite.

The type of model varies from simulation models (e.g. CITS), general equilibrium models (e.g. EXIOMOD), Agent Based Model (ELDEST) and cost-optimisation models (e.g. TIAM-ECN-ECN, TIMES-Europe and CIMS). The optimisation models give optimal results for what-if-scenarios. The simulation models give consistent results for scenarios that reflect many assumed aspects of reality. Hence, a logical approach is to start with simulation models, which will provide the “realistic” boundary conditions for optimization models. This is reflected in the schematic representation of the Integrated Model Suite, in Figure 14 where simulation models are depicted on the left and optimization

models on the right (others in between), while global models are on the top, local models at the bottom and EU models in between.

The arrows indicate the links between the models, where solid arrows are feed forward loops and dotted arrows are feedback loops, involving iterations between the models. The next section will describe how to approach this model interaction.

## 5.3.2.1 Model suite operations: a tiered approach

We will take a tiered approach to the operation of the model suite, starting simple and increasing complexity step by step:

1. Scenario alignment & stand-alone model running – [end 2024]
2. Linear model running (no iteration) – [end PoC]
3. Horizontal iteration(s) at each geographical level – [end Amigdala]
4. Upward iteration(s) to higher geographical level is an ambition of this project

With each step, we increase the complexity of the IMS operations, while providing value added with respect to our research goals. In step 1 Scenario alignment, we will include materials and circularity options, detail of the process industry and both societal and business perspectives. In step 2 Linear model running (reached at the end of PoC), we will combine the global, EU and local scale. In step 3 Horizontal iterations, we will add integration, i.e. mutually interactive options in the field of economy, energy, materials and environment. Step 4 will complete integration by feedback loops between the geographical levels, but this is out of scope for the current project. This tiered approach on integration is depicted graphically in Figure 15.

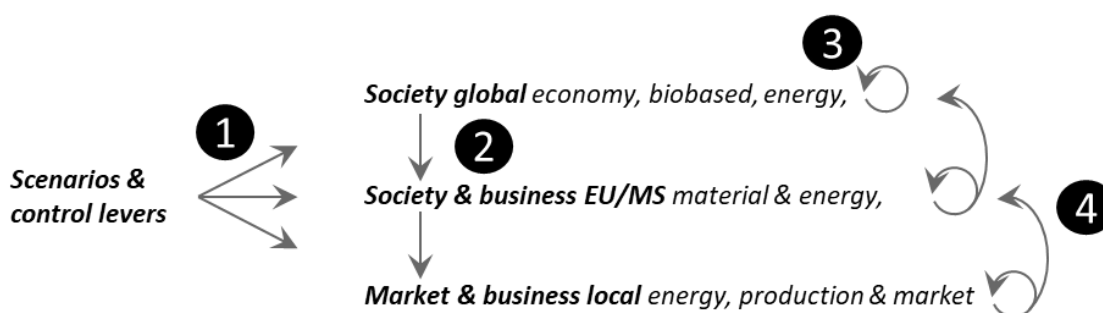


Figure 15. Tiered approach to operate the Integrated Model Suite from simple to increasingly complex.

We do include different optimisation perspectives / criteria (e.g. company CO<sub>2</sub> v. life cycle / system CO<sub>2</sub>, material circularity v no waste

etc.). In first instance, we will represent perspectives by applying different models and boundary conditions (and will not change the existing model objective functions).

### 5.3.2.2 Model implementation challenges

In the Amigdala project, the ultimate aim is to combine multiple existing models into a single simulation / optimization platform. These models all have a different focus and combined will cover a wider and more complete scope, which assumedly will allow for predictions with a broader validity and higher reliability. With respect to the integrated modelling we have identified a number of challenges:

The constituent models are developed on different platforms by different parties. Integration of the functionalities in a single environment may prove challenging.

Additionally, it is already foreseen that feed-back loops will exist in the final model cluster, which, most likely, will have to be solved iteratively. Such iterative processes can be very time-consuming, as they may need multiple iteration loops to converge to a stable solution.

In the case that the individual models are evaluated separately, this may result in multiple hand-overs of the results, which will add substantially to the time and effort needed for final convergence.

Also, convergence is not guaranteed, which would make the situation even more laborious, as multiple efforts may be needed to identify a scenario that allows for a stable solution.

For this to become operational, a model data transfer matrix is needed to exchange inputs and outputs between scenarios and models and between the different models. This will be explained in the next paragraph.

### 5.3.2.3 Model interconnections and exchange matrix

The model interconnections were identified through a speed date session, where each model owner had a meeting (speed date) on model connections with all other model owners separately. This formed the basis for a prioritization of model connections, which are summarized in Figure 16. It appeared practical to organize this roadmap of connections according to geographical level. So, the global models reviewed interconnections between the global models and how these generate output (yellow box) transferred to lower levels, green boxes at

the right. In the right hand column, the anticipated result is formulated, which relates to the Decision analysis.

The same applies for the EU (MS) level and subsequently the local level, although the output (yellow) functions less as an input (green box) since there is only one or no level lower.

| Provides information to           |              | GLOBAL                                                                                                                                            |         |          | EU                                                                                                                                                    |      |              | EU+Local                                                                     | LOCAL                                                                                                             |      | Decision analysis                                                                                  |
|-----------------------------------|--------------|---------------------------------------------------------------------------------------------------------------------------------------------------|---------|----------|-------------------------------------------------------------------------------------------------------------------------------------------------------|------|--------------|------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------|------|----------------------------------------------------------------------------------------------------|
|                                   |              | EXIOMOD                                                                                                                                           | GLOBIOM | TIAM-ECN | PRISM                                                                                                                                                 | CITS | TIMES-EUROPE | CALLIOPE                                                                     | ELDEST                                                                                                            | CIMS |                                                                                                    |
| Scenario drivers & control levers |              | Trade policy, tax policy, GDP drivers, socio economic developments, productivity, service demand, biomass demand, technological development costs |         |          | Technological developments, EU policy, circularity strategies, energy policy                                                                          |      |              | Technological developments, EU policy, circularity strategies, energy policy | Energy elasticities, efficiency developments, EU/Local policy, socio-economic/ technological/ energy developments |      | Research questions<br>Resource availability / feasibility of implementing sustainable technologies |
| GLOBAL                            | EXIOMOD      | GDP, Price indices at sector level, labor price, sector demand, Economic baseline, Biomass types&volumes, AFOLU, Global energy prices             |         |          | GDP, global price indices, sector development, global energy prices, biomass production & feedstock                                                   |      |              | GDP, population, availability and price of biomass, global energy prices     | GDP, population, availability and price of biomass, global energy prices                                          |      | Economic developments, AFOLU, global energy price, effect of upstream circularity policy           |
|                                   | GLOBIOM      |                                                                                                                                                   |         |          |                                                                                                                                                       |      |              |                                                                              |                                                                                                                   |      |                                                                                                    |
|                                   | TIAM-ECN     |                                                                                                                                                   |         |          |                                                                                                                                                       |      |              |                                                                              |                                                                                                                   |      |                                                                                                    |
| EU                                | PRISM        | Phase 2                                                                                                                                           |         |          | Recycling technological data & curves, Material demand at application, circular strategy effects, societal material stocks, EU (energy) price indices |      |              | Recycling technological data, price & availability of energy carriers        | Recycling technological data, recyclate availability, price & availability of energy carriers                     |      | Effect of middle and downstream circularity policy, EU energy price, sustainability indicators     |
|                                   | CITS         |                                                                                                                                                   |         |          |                                                                                                                                                       |      |              |                                                                              |                                                                                                                   |      |                                                                                                    |
|                                   | TIMES-EUROPE |                                                                                                                                                   |         |          |                                                                                                                                                       |      |              |                                                                              |                                                                                                                   |      |                                                                                                    |
| EU+Local                          | CALLIOPE     | Phase 2                                                                                                                                           |         |          | Phase 2                                                                                                                                               |      |              | Industry transition pathways, infrastructure                                 | Price + availability of energy carriers                                                                           |      | Industry transition pathways, resulting infrastructure                                             |
| LOCAL                             | ELDEST       | Phase 2                                                                                                                                           |         |          | Phase 2                                                                                                                                               |      |              | Phase 2                                                                      | Bounded rational Behavior of actors, Cluster technological transition pathways                                    |      | Industry transition pathways, resulting infrastructure, actor behavior                             |
|                                   | CIMS         |                                                                                                                                                   |         |          |                                                                                                                                                       |      |              |                                                                              |                                                                                                                   |      |                                                                                                    |

Figure 16. Tabular description of interaction between models in the Integrated Model Suite (yellow: output; green: input; red: out of scope).

### 5.3.3 Interaction with other modules

The relation of the IMS to the other modules Scenario building, Decision analysis and Data management is very tight. Hence, the interaction with the other modules have been described in the previous section Design and logic of the IMS, particularly in relation to Figure 14 and Figure 16.

## 5.3.4 Development needs

Development needs pertain to specific models and the interactions between them, starting at the separate geographical levels (global, EU, and local). Interactions across these geographical levels were discussed in the previous paragraphs.

For most models, the current time horizon is set to 2050, but it should be extended to 2070. The base year typically falls within the last 5 years and has to be harmonized to 2019, a non-COVID year. Historical time series will be assessed separately, outside of the models.

### GLOBAL MODELS

**EXIOMOD:** In the FIGARO input-output table, the energy sector requires greater detail compared to EXIOBASE, but has a higher validity (updated each year). Furthermore, the plastic value chain is not explicitly included in the model. Option is to combine EXIOBASE detail with FIGARO validity. This should have value added for all process sectors and will be decided after the PoC. The main goal is to model the drivers of plastic demand based on demand from various economic sectors. A simplified approach could be taken, leaving the model as it is, by combining demands in monetary terms (volume index) from EXIOMOD with the current demand for plastics in mass terms from CITS. This will be done for the PoC. Material value intensity will change over time as a result of the circularity scenario and policy developments. This could be modelled by feedback information from CITS to EXIOMOD. Also, the representation of the waste sector in EXIOMOD can be enhanced to make circular waste handling more explicit. Finally, improvements could also be made in modelling the effects of employment (by education level) and capital investment.

**TIAM-ECN-ECN:** Recycling (of plastics) is not explicitly included in the model. The first approach is to leave the model as it is (PoC) and convert EXIOMOD sectoral growth levels to relevant energy and material demand drivers. In this way, TIAM-ECN-ECN will be indirectly linked with CITS, through EXIOMOD. Second approach would be to update the EU region in line with the circular production route updates as will be done in the EU energy system model TIMES-EUROPE.

**GLOBIOM:** There is no need to extend the model itself.

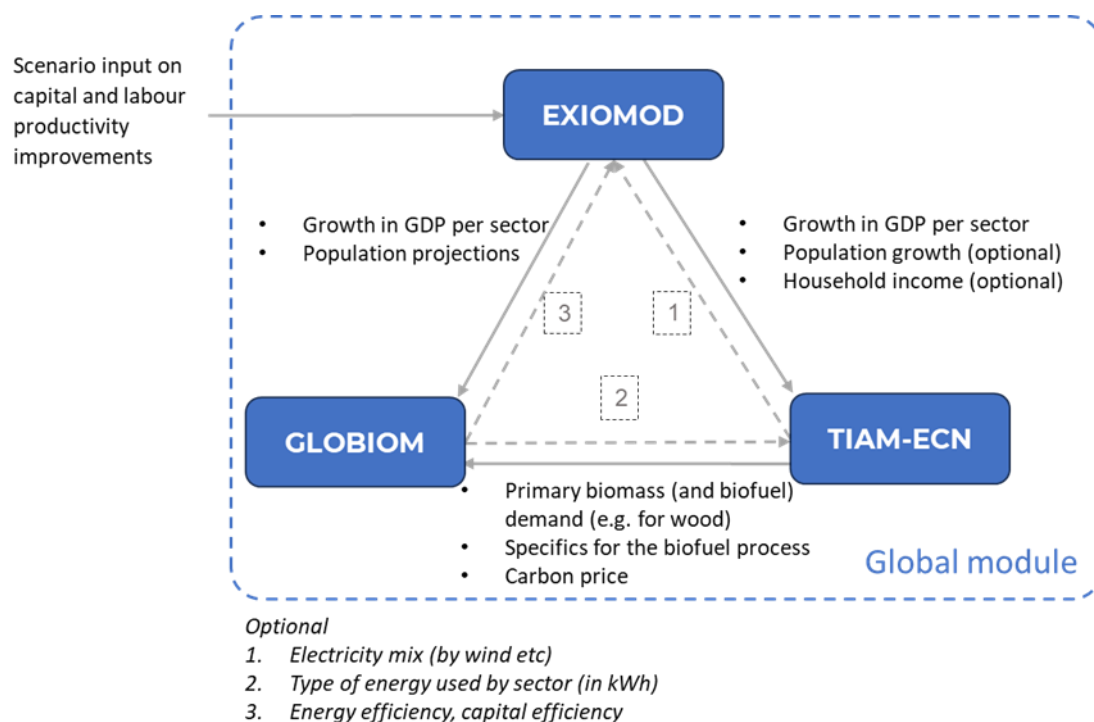


Figure 17. Schematic overview of global model interactions.

**GLOBAL INTERACTION:** The overall global modelling is depicted in Figure 17. Based on scenario input, specifically inputs on population and capital and labour productivity, EXIOMOD will project economic sector growth. This projection will be used as a basis for physical demand for energy services in TIAM-ECN-ECN and biomass based services (food, feedstock, energy) in GLOBIOM.

The TIAM-ECN model will optimize the global energy system and its world regions to reach certain CO<sub>2</sub>-eq emission targets. The resulting demand for energy-related biomass applications and the CO<sub>2</sub> price will serve as inputs for GLOBIOM.

After the PoC, projections of energy and biomass consumption mixes from TIAM-ECN and GLOBIOM respectively can be fed back to EXIOMOD to study its impact on the global economic development.

## EU MODELS

**CITS:** The CITS model has to be extended from the Netherlands to all EU countries. This means that the data on mass flows and stocks including end-of-life treatment in all countries have to be collected and/or assessed, for the current situation as well as for the baseline up to 2070 (in connection to scenario definition). Preferably, different polymers / plastic types have to be distinguished over the life cycle for plastic production, product manufacturing, use and end-of-life waste streams.

Model specification will be polymer and technology specific, as well as country specific. The drivers for plastics (material) demand will be the demand for product applications, which will be driven by EU sector demands from EXIOMOD (country specific growth). In subsequent WPs after the PoC, this approach will be applied for the other basic material streams within the EU (steel, non-ferro, glass, cement, etc.).

**PRISM:** The PRISM model has to be extended from the Netherlands to all EU countries. In principle, technology data (physical, economic and environmental parameters) are similar to those of the Dutch model. Existing situation and waste compositions will be different for the EU countries, but will be the same data as collected for CITS. PRISM will not be applied for materials other than plastics.

**TIMES-EUROPE:** For the PoC, different circular resources (e.g. syngas, pyrolysis oil and mechanically recycled plastic flakes) will be included as feedstock options for existing and new plastic production routes (steam cracking, Fischer-Tropsch, MTO). These resources will be implemented in TIMES-Europe as potentials derived from PRISM outputs. The resource potentials will be differentiated with respect to cost, energy demand and CO<sub>2</sub> emissions. In this way a step-wise cost-curve is generated. To incorporate the mechanical recyclate, the plastics value chain in TIMES-Europe will be extended to include the production of plastic granulate. Its demand will be derived from the CITS model. Furthermore, demands for plastic types, aggregated for TIMES-EUROPE into general plastic granulate, will be based upon CITS data. In WP3 recycling routes will be introduced for the other industrials sectors. Depending on the level of complexity these will be either implemented directly in TIMES-Europe or analysed using a dedicated model similar to PRISM.

**EU INTERACTION:** The overall EU modelling is depicted in Figure 18. In principle, the global model EXIOMOD will deliver sectoral demands to the EU model CITS, which produces demand for materials and waste generation as a result of different circularity scenarios. The material demand is used as exogenous demand in TIMES-EUROPE. The plastic waste generation is used in PRISM to generate the recycling product potentials, which will be implemented in TIMES-EUROPE. In order to start this cycle, energy prices at EU level are also needed for the PRISM model, which can be obtained from TIAM-ECN-ECN or from a base run by TIMES-EUROPE. After the PoC, feedback loops will be considered to model the impact of energy system changes in terms of energy prices,

mix and CO<sub>2</sub> factors in the material system, which may impact the circular feedstock potentials available to TIMES-Europe.

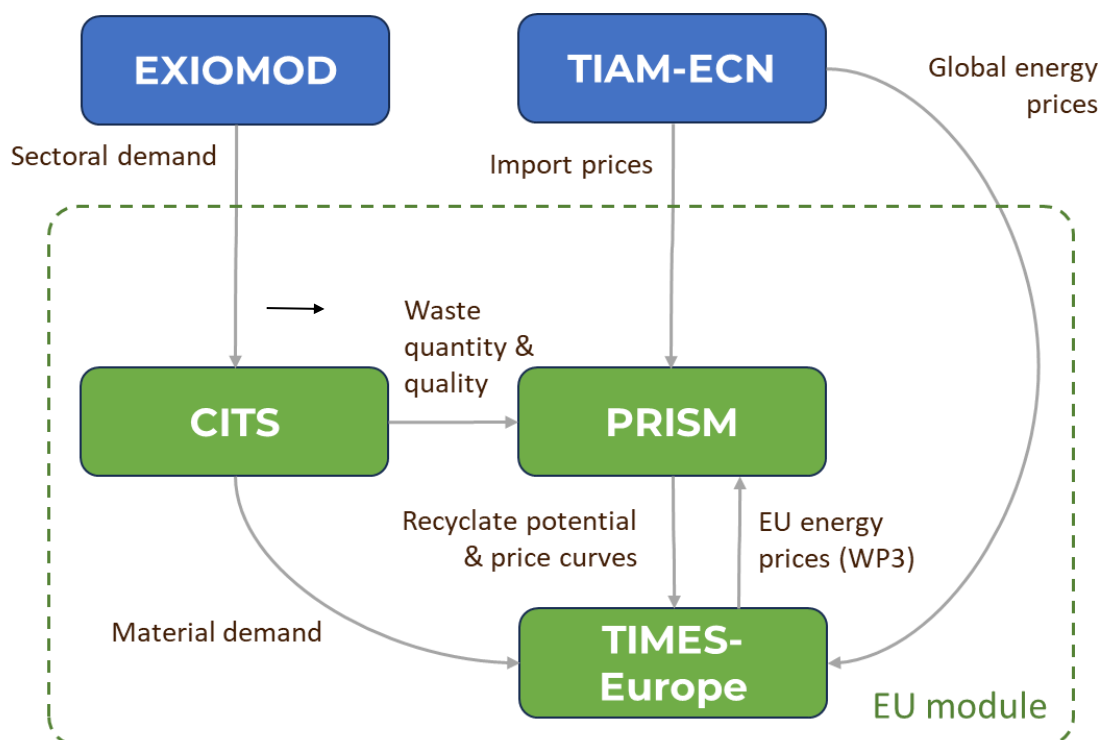


Figure 18. Schematic overview of EU level model interactions.

## LOCAL MODELS

**ELDEST:** The ELDEST model is an agent-based simulation of the social and technical dynamics within an electricity system. On the technical side, ELDEST focuses on the cost-efficient operation of various energy-generation technologies. Currently, these technologies are represented in a simplified manner, categorized as base-load, mid-load, and peak-load. A key area for improvement during the PoC phase is to incorporate specific technology options, such as solar, wind, coal-fired, and gas-fired power plants.

On the social side, the model captures the decision-making processes of boundedly rational investors, generation companies, and consumers related to energy technology investments, as well as electricity production and consumption. Upon successful validation of the PoC, the ELDEST model will be expanded to encompass socio-technical processes within the chemical or steel sectors or both. This enhanced version will provide valuable insights into the co-evolution of the electricity and industrial sectors, elucidating how decisions related to energy technology investments and electricity operations influence, and are influenced by, industrial investments and production.

**CALIOPE:** In the current resolution (98 EU regions, a bespoke clustering of NUTS3 regions), the Netherlands, where the Chemelot industrial cluster is located, is represented as a single node. Consequently, Chemelot cannot be spatially represented in the current version of the CALLIOPE model. A further disaggregation of the geospatial representation needs to be analysed for the Chemelot case (and other potential cases) to determine if the cluster's current energy consumption justifies further disaggregation.

The current version of the CALLIOPE Europe model does not consider CCS options and needs to be further developed.

**CIMS:** For the PoC, but also later for the other value chains, the assumptions behind the alternative technologies implemented in CIMS will be re-evaluated. Also, new technology options should be added and new import options should be considered, in alignment with commodities available from the other models in AMIGDALA (Calliope, TIMES-Europe in particular), like for instance methanol.

Additionally, the intention is to demonstrate that CIMS can be applied to other chemical clusters. This requires specific development work. A test cluster needs to be defined and the relevant data regarding the products, the technologies and the topologies (internal connections) needs to be obtained. The Antwerp cluster is a potential candidate.

**LOCAL INTERACTION:** The foreseen model interactions at the local level are the following (see

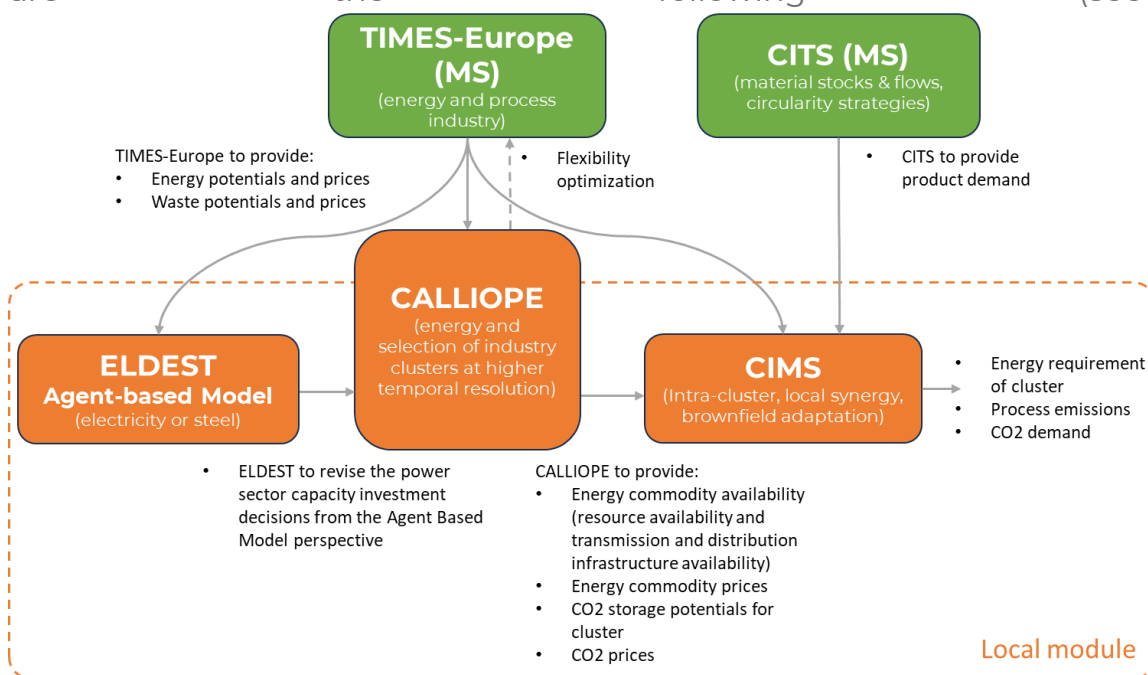


Figure 19). TIMES-EUROPE provides EU MS energy prices to the local models CALLIOPE and ELDEST. ELDEST provides input regarding capacity investment in the power sector (lowest/highest predictions per region) to CALLIOPE. CALLIOPE provides commodity and energy prices to CIMS. However, the CIMS model's input requirements sometimes exceed the range of energy carriers covered by the CALLIOPE model. In such cases, the necessary information must be provided by the TIMES–Europe or CITS model. The economic and environmental impacts will be evaluated in CIMS.

In a next phase, the demand for resources from CIMS will be fed back to CALLIOPE which leads to new prices fed to CIMS.

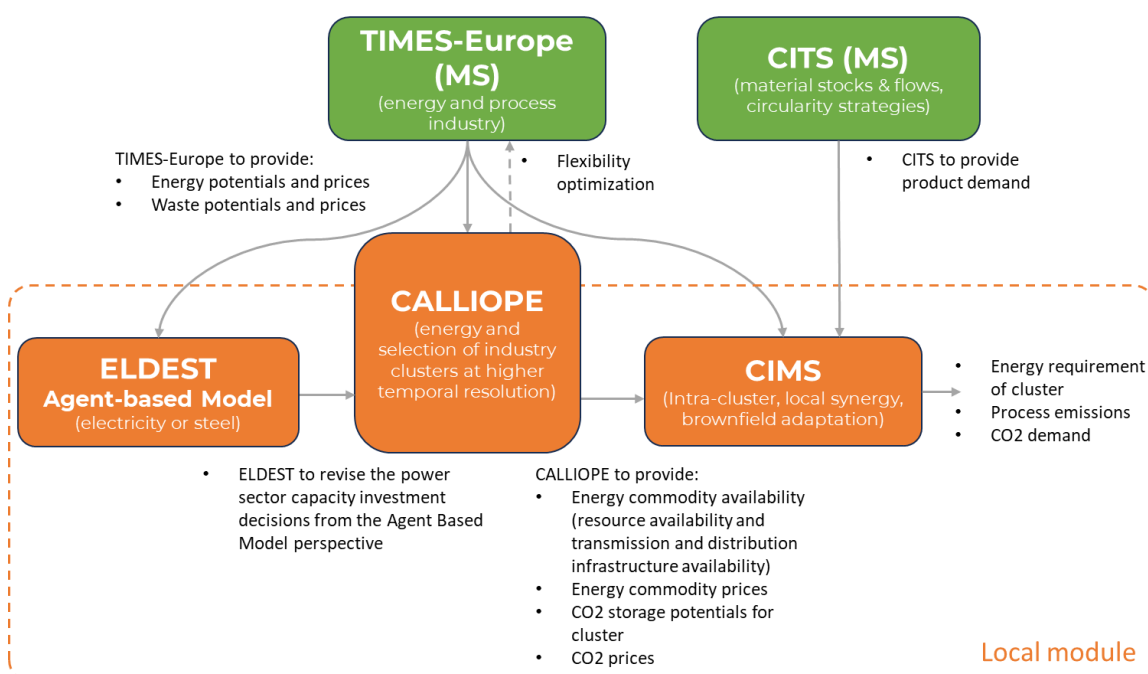


Figure 19. Schematic overview of most prominent local level model interactions.

### 5.3.5 Practical implementation

Practical implementation of the IMS will occur in the following steps:

1. Update models for Plastics Value chain and run under common scenario assumptions (PoC);
2. Set-up transfer matrix to transfer data between models (PoC);
3. Perform linear (sequential) running of soft-linked models (on private servers) by feed forward model data transfer using the transfer matrix on shared sharepoint. Results are on common sharepoint, to be shared with other modules (PoC).

4. After learning in the PoC, this approach has to be extended to other process industry.
5. At each geographical level, feedback between models will be realised in an iterative approach to integrate energy, materials and environment. At first, this will be done in the same way as in the PoC.

## 5.4 Data management

### 5.4.1 Design and interaction with other modules

Two types of data are to be distinguished: the historical data on the five dimensions and the input data that will be used by the model suite to generate projections (pathways).

The overarching goal is that all the models within the model suite will use data that is suited best for each model. For this, a validated set of data is required. After setting the scope with the model suite, data types, units and other information such as the temporal and spatial resolution of the data will be defined. We aim for a unified input database but - realizing that this might be too ambitious and not always the best way to ensure consistent results – we will adopt a pragmatic approach and design an input database that is fit-for-purpose. The design of this fit-for-purpose input database will be revised iteratively based on the ongoing interviews with the modelling teams and the experiences gathered during the PoC.

The acquired data will be made accessible for the whole model suite within a data-explorer, for which technical requirements must be clarified. These include:

- **Data harmonization and integration.** This includes data standardization, metadata management to describe the datasets in terms of source, structure, versioning and usage, as well as making sure that interoperability is ensured, when using different data formats
- **Data storage and access.** It is aimed to have a centralized data repository, possibly a cloud-based solution. The underlying data infrastructure shall be based on a robust and scalable system (e.g. SQL-based database), for which user access with different roles and permissions must be established.

- **Data explorer interface.** For a web-based data explorer, the intuitive user interface design (UI) is essential, which will allow users to search, filter and visualize data.
- Data security and compliance.
- Scalability and performance
- Data archiving and public availability
- Hosting of the data explorer

## 5.4.2 Practical implementation and next steps

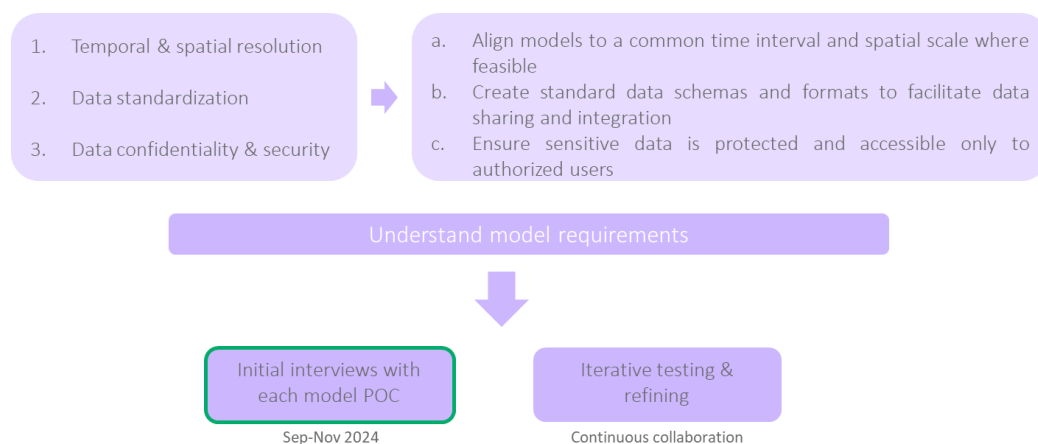


Figure 20 Data management activities on Data for projections used by models

## 6 Conclusion and outlook

Through this deliverable the project team has aligned on the context and purpose of the project, and developed a joint approach to making projections of pathways to climate neutrality for the European process industry.

In the next phase of the project the team will develop the proof of concept, where we will demonstrate the technical feasibility of bringing together scenario development, modelling and decision analysis.

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