# Shaping, and acting upon windows of opportunity for productive capability development in the EU: The outline of a POLYvalent model for the ex-ante evaluation of TRansformative POlicy Scenarios (POLYTRoPOS).


## Abstract

Public policy is now confronted with the extraordinary challenge of transforming our current production and consumption systems within timeframes defined by imperatives such as climate change mitigation. To this end, there are large potential policy gains from aligning, synchronising and/or sequencing demand-side policies for solution deployment with supply-side policies for production capability accumulation and diversification. For example, fiscal policies and regulations in support of solution deployment for the challenge of climate change with policies in support of innovation, investment and skills development. The present paper outlines the conceptual basis for the development of a new System Dynamics model that aspires to quantify these policy gains. The model will be empirically calibrated and intended to capture the joint dynamics of solution deployment (demand) and production capability accumulation and diversification (supply) taking place over time horizons of one or more decades. This will serve as a basis to evaluate the approximate contributions of various policies over time. To facilitate model development, we demarcate an initial analytical space that combines high value for policy, theoretical soundness, sufficient data availability and well-established empirical regularities. The ambition is to offer a simulation environment that allows quick policy experimentation, learning and improvement, and can therefore facilitate the design of powerful packages of policies potentially spanning several policy areas and levels of governance.



Keywords: capability development, public policy, system innovation


## 1 Introduction

The EU and its member states are confronted by major collective challenges rooted in rapid economic, technological, environmental and geopolitical developments. Taken together, they threaten the foundations of future European prosperity, environmental sustainability and broader societal wellbeing (Draghi, 2024). The Draghi report estimated that aggregate investment in EU economy will have to rise by approximately 5 percentage points of GDP to sustain the ongoing processes of digitalisation and decarbonisation and, in parallel, increase the competitiveness of EU and its defence capacity. System innovation is necessary to meet these simultaneous challenges and deliver the upsurge in competitiveness and production capabilities which is envisioned as part of the solution.

In light of this policy objective, it is necessary to reconsider the approaches available to navigate through system innovation processes, to support the relevant policy development processes and evaluate their impact over time. The approaches will have to be tailored to the development of system innovation policies for the current challenges that the EU is facing. The established approaches and tools in use are suitable for relatively stable contexts but are insufficient for capturing crucial features of system innovation processes, such as multiple and interlocking policy inputs across levels of governance, sequencing, tipping points and rebound effects.

In acknowledgement of these characteristics, the European Commission's Joint Research Centre (JRC) has launched a project[1] for the development of a system dynamics model titled: POLYvalent model for the evaluation of TRansformative POlicy Scenarios (POLYTRoPOS). Its distinctive strength is in supporting the exploration and evaluation of EU policies for system innovation. It is intended as a model which will draw on and combine theory on sustainable development, industrial innovation and macroeconomics with a focus on the assessment of public policy for system innovation. The fully fledged model will be a disequilibrium macro model that:

- Focuses on the processes that underpin the development and accumulation of production capabilities in sectors of growing global demand. A particular feature in that respect is the acknowledgement of the fact production capabilities are dynamic, with the implication that the exponents of the respective production functions will be endogenously determined;
- Includes policy inputs from many distinct policy domains covering both the demand- and the supply- side of the economy, thus permitting the evaluation of system-level policy additionality; A more specific area of novelty is a fuller accounting of demand-side policies than is common in other macroeconomic models.

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[1] https://place-based-innovation.ec.europa.eu/projects-0/system-dynamics-system-innovation-polytropos_en

- Accounts for non-priced outcomes relating to the environment (e.g. material footprint, carbon intensities) and societal wellbeing (e.g. quality of life, human health), in addition to economic outcomes.
- Includes a more detailed breakdown of the processes of factor accumulation for physical capital, knowledge (intangible capital) and labour, than is common in other macro models, as necessary to faithfully model bottlenecks in processes such as technology diffusion/deployment and human capital formation, in a dynamic setting, and to evaluate the role of public policies in overcoming them;
- Includes a more detailed breakdown of innovation activity and its impact on productivity, sectoral entry/diversification and material flow extraction and consumption.

These features complement the existing suit of economic models and tools at JRC that are dedicated to public policy support.

The model will be multi-level (EU, national, regional) in keeping with the political economy of EU, and will be tailored to the evaluation needs that arise across public policy domains and their combinations for system innovation (Holtz et al., 2015; Köhler et al., 2018; Papachristos, 2011; Papachristos, 2012, 2014; Papachristos, 2018, 2019; Papachristos and Adamides, 2016; Papachristos et al., 2013; Papachristos and Struben, 2019; Tomai et al., 2024). It is intended for the ex-ante impact assessment of policy options, and the ex-post and continuous evaluation of policy instruments and instrument mixes that have been already deployed. The model development process will include a series of case-specific instances of model application at the EU, national and regional levels. In each of these cases, the envisaged deliverables will provide the support necessary to understand, interrelate and anticipate the uncertain but salient technological and societal processes of change.

This model is necessary for several reasons. In current EU practice, the evaluation of transformative public policies is generally done through qualitative approaches e.g. JRC POINT Policy Reviews (Pontikakis et al., 2020; Janssen et al., 2021; Stefanov et al., 2021; Kim et al., 2022). The use of a simulation model is necessary because policy outcomes take years or decades to manifest, and it is, thus, a way to support policy experimentation and learning for reflexive governance (Feindt and Weiland, 2018; Sterman, 1994, 2001). Moreover, policymakers increasingly require tools to assess the potential policy synergies across various domains and levels of governance, and to expedite and amplify the desired economic, social, and environmental impacts.

In the context of the JRC project, simulation will enable the assessment of costs and benefits of alternative policy mixes (Rogge and Reichardt, 2016). The model will be used to ascertain the required scale and allocation of public investments, and the expected gains in economic output, investment, employment and societal wellbeing. For policy mixes that span across several domains of human activity, there are additional desiderata of sequence and coherence in their roll out and implementation. For example, the Recovery and Resilience Facility (RRF) plans that EU member states had to draft quickly in the aftermath of the pandemic: the ability to quantify likely outcomes could have helped identify the policy scenarios that best align and synchronise traditionally fragmented policy areas.

The current paper is the first in a series of outputs intended to document the scope, objectives, the process and work done so far and provide a tentative overview of the eight modules of the model. The rest of the paper is structured as follows. In section 2, we discuss the model rational and structure as it is currently envisioned. In section 3, we provide an overview of the intended uses of the model, and section 4 concludes the paper.

# 2 Model rationale and structure

## 2.1 Model rationale

The model rationale begins with the acknowledgement of global and EU level challenges of economy, technology, energy, climate and security. The nexus of these pervasive challenges shakes the foundations of prosperity in the EU (Draghi, 2024). In parallel, they harbour opportunities to utilise domestic capabilities in EU and generate new ones triggered by the delivery of the system level innovations envisioned as necessary to deliver the envisioned upsurge in EU competitiveness and production capabilities. For example, significant challenges at the EU level include, but are not limited to low-carbon, digitalisation, and defence technologies and associated capabilities. The flipside to these challenges is that they constitute a transient window of demand for solutions. The task, then, for policy development is to leverage domestic and imported technologies in a timely manner for system innovation such that it will also result capability accumulation in the EU over time. The deployment of system innovations is a long-term process shaped by public policy portfolios which are faced with issues of coherence, sequence and synergies of policies. The model is intended to facilitate the exploration and evaluation of EU policy portfolios and has three key design specifications:

1. Challenge-orientation: a model potentially applicable to many and diverse societal challenges, driven by the deployment dynamics of prospective solutions.
2. Production-focus: a model that permits feasibility assessment of domestic production capability development in sectors/value chains associated with solution deployment and their integrated social, economic and environmental outcomes.
3. Policy portfolio evaluation: a model suitable for the joint evaluation of portfolios of policies across ministries and levels with EU27 aggregate, national (27 member states plus world partners), and eventually, sub-national regional versions of the model, also allowing interactions between territorial levels.

Figure 1 illustrates the underlying rationale of the model. In a nutshell, challenges of global or EU scope give rise to a transient window of demand for solutions. It can be supplied by appropriate supply and demand policies for technology deployment aiming to address a related societal problem. The model will allow the exploration of "what if" scenarios and policy pathways for accelerated technology deployment, and the related development of domestic capabilities necessary to deliver relevant goods and services. At this early stage of development, the model is confined to the deployment and improvement of mature solutions and contains no mechanism for the emergence of new global solutions as this is inherently unpredictable. As new solutions are bound to emerge in simulations that span several decades, this is a limitation that future versions of the model will have to address.


Figure 1 The conceptual basis of the model

## 2.2 Model scope

In keeping with the political economy of EU, the model will span three levels: EU, national and regional, and will be tailored to the evaluation needs that arise across public policy domains, levels and their combinations for system innovation. At present, the application of the model is intended for separate cases at the EU, national and regional levels for policy exploration, while future versions of the model will include interactions among EU, national and regional levels. Model development has begun with a core template at the national level, which will benefit from its application at national level in Sweden and Spain. Development at the regional level will benefit from cases in Catalonia and Navarra in Spain. The development process will provide the necessary ground for validation of the national level and regional level versions of the model.

At each instance of model application, it will be adapted to the challenge of interest, the policy portfolios that are pertinent and the sectors of the economy which are as instrumental in the deployment of technologies. These will constitute the focal unit of analysis. To keep the model simple, it will include the remaining sectors in the economy in an aggregate "rest of the economy" form, and other macro level factors in a "rest of the world" module to account for interactions beyond national and/or EU boundaries. While the economic theory that underlies the model applies to all economies and regions, the development process will provide some as to the generality and applicability of the model. This will set the ground for the next milestone in model development which will include instances of all 27 EU member states, and 242 EU regions.

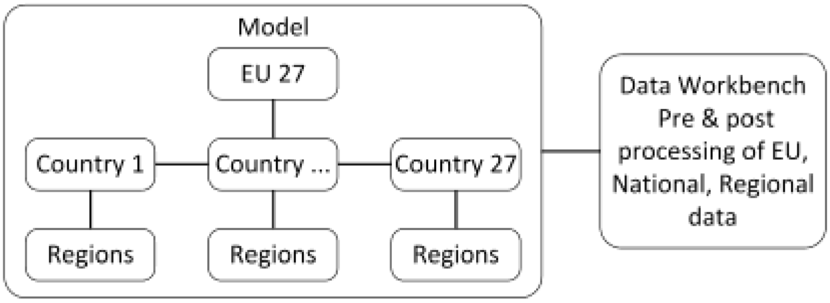


Figure 2 The model scope

The scope of this version 2.0 of the suite of models will require extensive data inputs. This part of model development will benefit from access to unique JRC in-house databases which will be used for input data at the EU, national and regional levels.

## 2.3 Model structure

The model draws on the circular flow of money mental model (Mankiw, 2017) and augments it with separate modules for innovation (of primary interest to production capability accumulation and competitiveness), environment and wellbeing. The fully-features model therefore has 8 core modules: 1. Firms, 2. households, 3. government, 4. financial institutions, 5. "rest of the world", 6. innovation, 7. wellbeing, 8. environment.

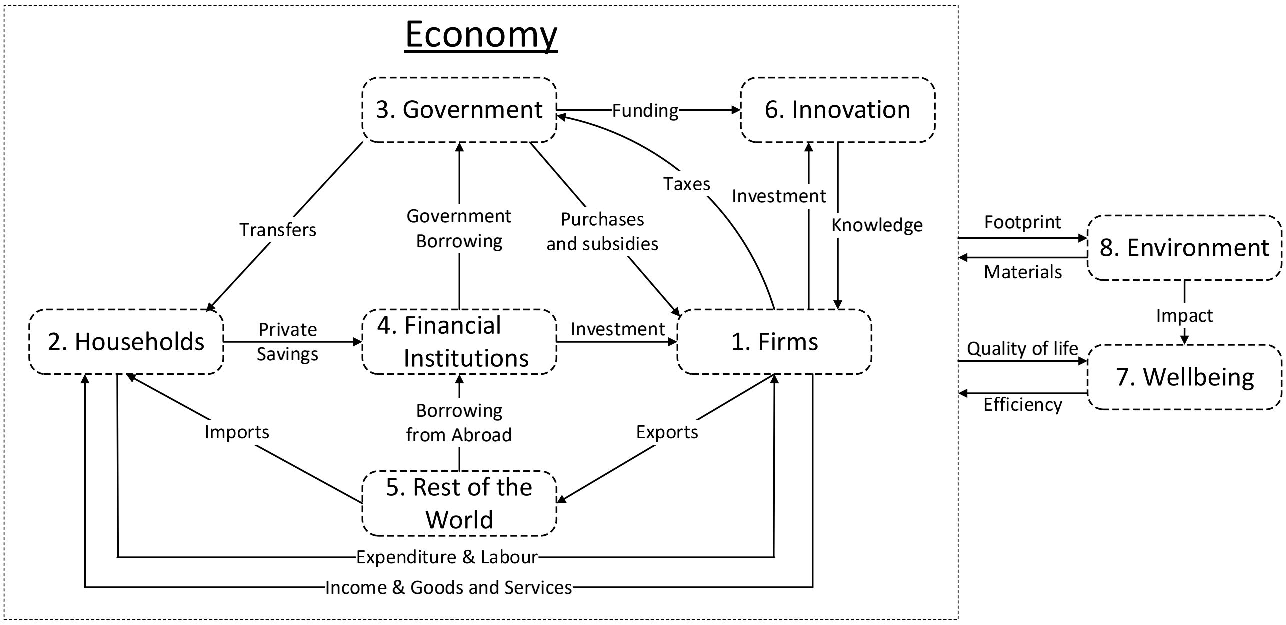


Figure 3 The eight modules of the model

### 2.3.1 Firms

Firms in module 1 are the locus of production, where raw materials, energy, labour and capital are transformed into goods and services for other firms or for final demand i.e. households and government. Their activity drives international trade, with exports of products to foreign markets and imports of raw materials or technology. Thus, the activity of firms is crucial for economic development and innovation. Firms invest in capital, labour and innovation. Profits earned by firms are reinvested into expanding production, distributed as dividends to shareholders, or saved in financial institutions. Firms provide employment and income to employees and suppliers. They are also a source of government revenue through corporate taxes. The success of firms determines employment levels, economic stability, and living standards. This module includes three stages of production: primary, intermediate and final. It includes the production of necessary fuel and energy from renewable energy sources (RES) and fossil sources (Non-RES).

### 2.3.2 Households

Households have multiple roles in the economy. They are the primary consumers of goods and services, and thus they shape the production decisions of firms. In a globalised world, households also consume imported goods and services, affecting trade balances and foreign exchange markets. Ultimately, households are a central force in the circular flow of money, determining the flow of resources, income distribution, and the overall demand for goods and services in the economy. Households provide labour and capital to firms in return for income. They use their income to purchase goods and services, and pay government taxes. In many economies, households also receive government support in the form of pensions, unemployment benefits, and welfare programs, ensuring economic stability. Households also play a critical role in the financial sector, as their savings in banks provide capital for investment.

### 2.3.3 Government

The government ensures economic stability through market regulation and the provision of goods and support for innovation. By implementing fiscal and monetary policies, it influences economic development, inflation, and employment. The government establishes the necessary legal and regulatory frameworks to protect consumer rights, promote fair competition, and ensure environmental sustainability. It collects taxes and allocates funds to essential public services: healthcare, education, infrastructure, and national defence. Through welfare programs, unemployment benefits, and subsidies, it redistributes income to reduce inequality.

### 2.3.4 Financial institutions

The financial sector consists of banks, credit unions, investment firms, and insurance companies that connect savers with borrowers. The financial sector is the backbone of economic activity, which facilitates the efficient allocation of resources and capital. It, thus, plays a crucial role in economic growth as it offers credit to firms for expansion, innovation and production. Stock markets and venture capital investments enable companies to raise funds for large-scale projects, while insurance services protect individuals and businesses from financial risks. Central banks regulate the financial system, managing inflation, interest rates, and money supply to maintain stability. Financial institutions also influence international trade and foreign exchange markets by facilitating transactions between countries.

### 2.3.5 "Rest of the world"

This module represents a country's (or the EU) economic interactions with the global market through trade, investment, capital and knowledge flows. It includes national exports, which bring revenue into the domestic economy, and imports, which allow consumers and businesses to access foreign goods and services. International trade enhances economic development by enabling specialisation.

### 2.3.6 Innovation

The innovation sector drives technological advancement, economic efficiency, sectoral diversification, environmental efficiency and improvements in wellbeing. A key feature of innovation in our model is that it is understood as a multi-level process (global, national), with outcomes that can be quasi-deterministic (governed by empirically measurable risk) and stochastic (governed by unknowable uncertainty). Structural change in our model is triggered by the diffusion of a known mature macro-technology (our canonical example is the deployment of renewable energy solutions), which through collective innovation efforts, is improved upon over time to become cheaper, better performing and more environmentally efficient. Within each country, firms innovate to improve their productivity and also to enter new production sectors. Macro-technologies emerge at the global level, at a time and place that is determined quasi-stochastically, and can therefore potentially disrupt the diffusion of already mature solutions.

#### 2.3.7 Environment

We include the natural environment in our model as an essential source of raw materials and sink of residuals of human economic activity that have an environmental footprint. The scope of the environment module includes extraction of raw materials that are essential for all kinds of production activity including the production of fuels.

## 3 Policy uses of the model

The model is intended for two kinds of applications:

1. Ex-post and ongoing evaluation of policy instruments and instrument mixes;
2. Ex-ante comparative impact assessment of policy options.

In the latter, the model will be used to facilitate experimentation and learning for a wide range of potential policy combinations that involve solution deployment (demand) and domestic production capability development (supply). Evaluate the double impact of solution deployment on: (a) Domestic production capability accumulation and diversification through innovation, and (b) Wellbeing including non-priced outcomes such as improvements in human health and the restoration of natural capital. The greatest value will come from using the model to support the ideation and feasibility assessment of bold, high-impact scenarios, which are currently impossible to conceive currently as there is no common policy framework across policy domains and levels.

### 3.1 Challenge-oriented mapping of policy mixes

A specific feature of the model is its challenge-oriented perspective that counterposes the boundaries and dynamics of the specific problem area to the policy mix of relevance. The model will include policy instruments which span public policy areas that influence technology deployment and the development of production capabilities. The challenge-oriented perspective is agnostic to particular domains of policy, rather the objective is to use the model as the bedrock for the mapping and representation of policy mixes which are likely to be misaligned (Flanagan et al., 2011).

The mapping of challenge-oriented policy mixes is expected to enhance our understanding of the policy areas and policy instruments influence the dynamics of technology deployment and the development of associated production capabilities. The mapping exercise will consider policy interventions regardless of the policy domain they belong to, the governance level or type of intervention, including direct and indirect financial support, governance, regulatory targets and standards, collaborative and shared infrastructures, education and skills. The initial mapping can be extended by further analysis of the identified instruments, their design features and governance, including key actors.

### 3.2 Evaluation of current policy instruments and instrument mixes

The model will include variables pertinent to policy interventions e.g. subsidies, procurement, and taxation or regulatory targets. It thus, can be used to evaluate the impact of policies be it individual instruments or portfolios. Model based evaluation has two components.

First, the model will allow the assessment of existing policy mixes against their stated policy objectives e.g. a higher level of production capabilities and see whether they will meet them. Second, the model can be used to assess the consistency, efficacy, and coherence of existing policy mixes. This can be done by testing "what if" by altering existing policy mixes e.g. removing policy instruments from the model or changing their key parameters such as the level of investment. Third, the model can be used to identify the alternative policy mixes that can produce an aggregate impact to meet the desired policy objectives. In this way, the model will help identify gaps where policy interventions are lacking or are not optimally designed to tap in the leverage points to trigger or scale up systemic outcomes. The gaps can be seen as opportunity areas for new or redesigned system innovation interventions.

### 3.3 Ex-ante comparative impact assessment of policy options

The model will allow the impact assessment of alternative policy options for the acceleration of technology deployment and capability development. The assessment will provide an understanding to policy makers of whether and how different policy approaches may contribute towards the desired policy goals and evaluate their costs and benefits in monetary terms. The options are instrument portfolios composed of different instruments with bespoke instrument designs e.g. different levels of budget, and legal force, each one with its distinct timeline and sequence of interventions. The design and comparative assessment of policy options and their sequence can be supported by simulations tests to identify help identify where substantive differences between possible alternatives lie, in particular regarding the focal areas of intervention, the composition and design of policy portfolios as well as timing and sequence of deployment.

To ensure the options gain traction and generate engagement that leads to implementation, they can be generated in a participatory way with an active engagement of policy makers. For example, policy makers can propose the realistic ranges of key parameters of variables that fully or partially depend on policy intervention. Similar to other economic models, the model will allow the evaluation of impacts between countries, which can be used to compare alternative scenarios of collective EU or individual member state interventions (for a recent example see Rueda-Cantuche et al., 2024). Unlike other economic models however, it will also permit the evaluation of interactions between policy interventions across domains and across levels of governance.

## 4 Conclusions

The EU requires new capabilities of domestic production to address the challenges it faces, and so EU policy making requires new capabilities of analysis to address the challenge of developing policies for system innovation. This paper outlines the first tentative steps taken in the Joint Research Centre for the development of a model intended to support EU policy making. The timing of this project aligns with the challenges the EU faces and so the timing is right for the development of in-house capability of policy support for system innovation. Some of the ingredients are already there. There is a suite of macro-economic models already in place that make use of unique in-house databases, so the development of POLYTRoPOS will complement and strengthen the policy support capabilities in JRC.

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