A novel Multi-Spatial IAM: An application to Italy

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Abstract

This study presents REWIND, a novel Multi-Spatial Integrated Assessment Model (MS-IAM) developed to explore the socio-economic impacts of climate change in Italy within the context of sustainability transitions. Rooted in Ecological Macroeconomics, the model is built on a modular system dynamics framework and extended to capture spatial heterogeneity, within the country, across five macro-areas. Its design enables the analysis of complex socio-economic and ecological dynamics under alternative techno-climatic scenarios, with particular attention to the propagation of regional shocks and their aggregation at the national scale. The main methodological contribution lies in the explicit incorporation of a multi-regional input–output structure, region-specific household consumption, and spatially heterogeneous climate damage impacts. This configuration enables a more detailed representation of how climate-induced productivity shocks affect intermediate goods flows, household demand, and value added across regions and sectors. By comparing results—under the RCP 6.0 climate scenario—over the simulation period 2019–2050, with and without spatial disaggregation, the model shows that neglecting regional heterogeneity can lead to an underestimation of aggregate climate impacts. The findings demonstrate that spatially explicit modelling is essential to capture the dynamics of climate shocks, trace interregional transmission channels, and support the design of policies that address the intertwined socio-economic, technological, and ecological dimensions of sustainability transitions.

Keywords— Scenario Analysis, Integrated Assessment Models, Climate Change, Ecological Macroeconomics, Multi-Regional Input-Output Analysis

JEL: E17, E61, Q54, Q57, R15

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1 Introduction

The urgency of climate change-related emergencies is escalating daily. What was once considered a potential future threat has now become a pervasive and present reality (Gills et al., 2022). Across the globe, the tangible consequences of climate shocks are intensifying in both frequency and intensity, with rising sea levels, droughts, heavy precipitation, and other extreme meteorological events occurring (IPCC, 2023a,b; Mal et al., 2017; Trenberth et al., 2015). This global crisis manifests with regionally diverse consequences that are not spatially uniform (Rosenbloom, 2020). Its impacts are deeply stratified, revealing different dynamics across continents, nations, and even regions within countries (Intergovernmental Panel on Climate Change, 2023). This heterogeneity of shocks underscores the imperative for a more effective policymaking process (Rogge et al., 2024). A "one-size-fits-all" approach is not only inadequate but also risks exacerbating social vulnerability and existing inequalities (D'Alessandro, André Cieplinski, et al., 2020). Consequently, the call for climate action has never been more urgent, demanding a new generation of analytical tools capable of capturing the complex and multilevel nature of the issue (Andersen et al., 2023; Löhr et al., 2024).

Despite the increasing attention dedicated to the impacts of climate change, most economic Integrated Assessment Models (IAMs) have remained focused on either the national or global scale, often neglecting the role of spatial heterogeneity and multilevel linkages (Nykamp et al., 2023). While economic and environmental dimensions receive considerable attention, the connections across regional and national levels are rarely investigated, leaving a critical gap in understanding how local impacts propagate and how national policies are transmitted at the regional scale, both of which are crucial in understanding social vulnerability (Breil et al., 2018). Nonetheless, the literature indicates a growing interest in Ecological Macroeconomics and related interdisciplinary approaches, suggesting a shift toward more integrated perspectives for quantitative policy evaluation analyses (Hafner et al., 2020; Saltelli et al., 2023).

In this context, this study introduces REWIND, a novel Multi-Spatial Integrated Assessment Model (MS-IAM) designed to investigate the local and national impacts of climate change in Italy. Rooted in the framework of Ecological Macroeconomics, REWIND extends and updates the Italian EUROGREEN model (D'Alessandro, André Cieplinski, et al., 2020; Distefano and D'Alessandro, 2023), which employs a system dynamics simulation approach, by incorporating a pivotal innovation: the simultaneous integration of national and subnational dynamics within a coherent modelling structure. The subnational layer comprises five macro-areas of Italy, thus capturing the geographical heterogeneity of the Italian economy. A comprehensive review of the literature confirms that this multi-spatial configuration, which combines national and regional processes in an integrated framework, represents a novel contribution to the field.

This paper addresses the following research questions: How can a multi-spatial IAM capture the interactions between national and sub-national dynamics in assessing the socio-economic and environmental impacts of climate change? To what extent do spatial heterogeneities—in production and consumption—and multi-regional linkages influence the propagation of climate-related shocks? How significant is the bias introduced when spatial heterogeneity is neglected and analyses rely solely on national-scale models? In addressing these research questions, we aim to advance the methodological framework of multi-system and multidisciplinary modelling, while providing novel insights into the spatial dynamics of climate change impacts and the formulation of policies for sustainability transitions.

This article is structured as follows: Section 2 briefly reviews the literature on IAMs and introduces the Ecological Macroeconomics framework. Section 3 presents the new REWIND model by explaining the Multi-Spatial extension, while Section 4 discusses the model simulation results. Finally, 5 discusses the principal findings and limitations, and draws the main conclusions.

2 Ecological Macroeconomics and IAMs

Most of the existing literature on Integrated Assessment Models (IAMs) relies on Computable General Equilibrium (CGE) and Dynamic Stochastic General Equilibrium (DSGE) approaches, with Nordhaus' DICE model representing the first and most influential example (Nordhaus, 1993). The case of DICE is emblematic: despite being awarded the Nobel Prize, it has been widely criticised for endorsing implausible assumptions and generating questionable policy guidance, such as treating global warming of more than 4°C as economically 'optimal' (Sterman, 2002).

While such models have shaped climate policy debates for decades, they rest on highly restrictive assumptions, including perfect competition, full employment, representative agents, and utility maximisation. These simplifications not only misrepresent the complexity of real-world economies but also systematically bias results toward 'optimal' equilibrium solutions, often neglecting transitional processes, structural rigidities, and the instabilities inherent to large-scale socio-ecological transformations. Criticisms have also been articulated by proponents of mainstream economics, such as Blanchard (2017), who argued in his critique of DSGE models that these approaches must *"become less imperialistic and willing to share the scene with other modelling approaches."* Likewise, Stiglitz (2018), another neoclassical economist, emphasised that mainstream macroeconomic frameworks fail to capture essential behavioural and institutional dimensions because of their flawed microfoundations.

Ecological Macroeconomic Models (EMMs) have emerged as a promising alternative over the past decade (Fragio et al., 2024; Victor et al., 2015). These models integrate insights from Stock-Flow Consistent (SFC) modelling and Environmentally Extended Input-Output (EEIO) analysis within a post-Keynesian framework (Fontana et al., 2016; Hardt et al., 2017). They are demand-driven, assuming excess economic capacity, and focus on non-equilibrium dynamics and aggregate demand fluctuations (Lavoie, 2014). They use various indicators and System Dynamics methods to model interdependencies between economic, social, and environmental systems, incorporating feedback loops, delays, and path dependencies (Mediavilla et al., 2025; Sterman, 2001). This methodology enables the capture of interconnections and feedback mechanisms between socio-economic and environmental components (Costanza et al., 1993; Rezai et al., 2013). Often structured as Integrated Assessment Models (IAMs), they analyse long-term policy impacts through scenarios (Nieto et al., 2020; Rezai et al., 2013). By incorporating lagged responses and feedback effects, EMMs offer a more realistic portrayal of transitions, thereby aiding informed policy decisions.

In this study, we refer to a model specifically developed within the field of Environmental Macroeconomic Modelling (EMM), known as EUROGREEN. The model is primarily designed to generate reliable scenarios that can be used to evaluate the effects of different policy options. In doing so, it helps identify potential trade-offs and unintended consequences that may arise from the implementation of isolated policy measures, given the interconnected nature of the real economy. While the foundational paper was originally designed for France (D'Alessandro, André Cieplinski, et al., 2020), subsequent studies have adapted it for application in Italy, by evaluating different low-carbon transition pathways (Cieplinski et al., 2021), social labour policies (D'Alessandro, Distefano, et al., 2023), a new carbon tax (Distefano and D'Alessandro, 2023), the responses to energy price shocks (Morlin et al., 2025), and the interactions between public finance and climate change (Campigotto, D'Alessandro, et al., 2025). Given the model's modular design, versatility, and capacity to capture complex socio-economic and ecological characteristics under different techno-climatic policy scenarios, we have chosen to expand this model by incorporating spatial differences in production, consumption, and climate-related damages.

The path towards a climate-resilient future depends on the ability to design and implement policies that are both effective and equitable. This, in turn, hinges on the sophistication of the analytical tools used to comprehend the problem. Nevertheless, the solutions currently offered by the literature remain limited, constrained by an over-reliance on aggregate national models that obscure critical regional realities and by a lack of attention to the complex social dimensions of climate change. These shortcomings are highlighted not to dismiss past efforts, but to underscore the challenges ahead. For example, regional production interactions and local government interest may increase the degree of challenges for policy coordination (Markard et al., 2020; Rogge et al., 2024). They represent a call to action for the research community: to advance multi-regional, multi-level, and dynamic models capable of capturing the intricate geography of climate change in a world marked by deep disparities.

To fill this gap, REWIND builds upon the modelling architecture of EUROGREEN, maintaining its core structure while introducing significant innovations. For the reader's convenience, the main features of EUROGREEN are summarised in Table A1.1 in the Appendix. The following Section provides a detailed description of the logic and assumptions behind the model.

3 The REWIND model

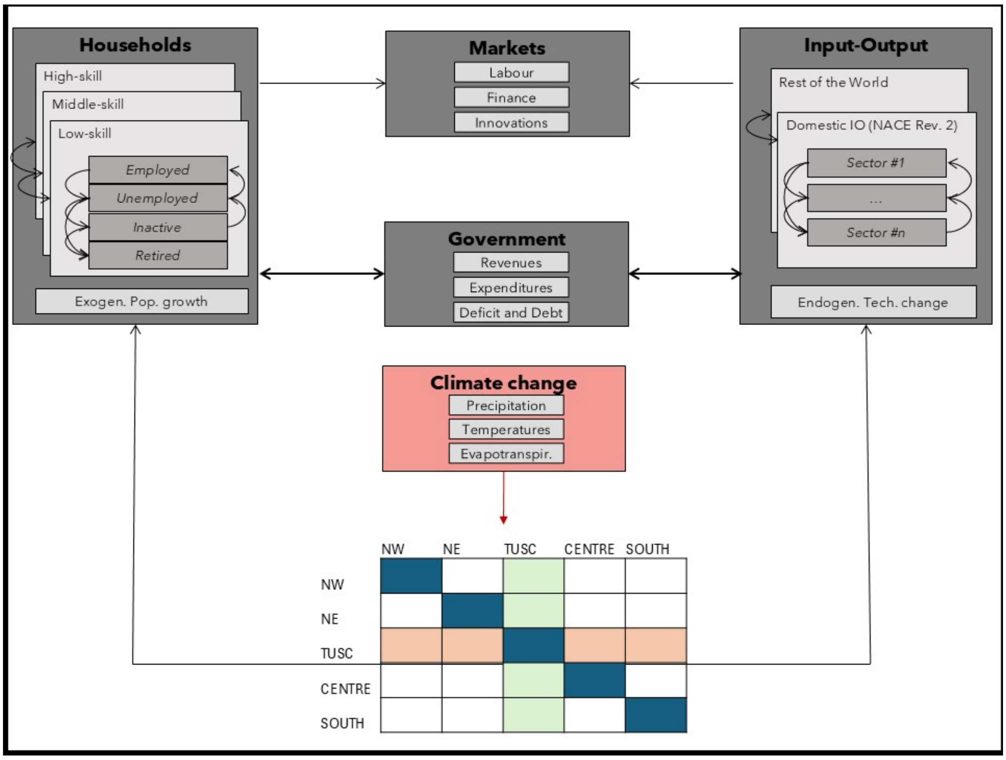


Figure 1: Macroview of the REWIND model structure. This figure illustrates the core components and feedback mechanisms of the REWIND model, which extends the Italian EUROGREEN framework (Distefano and D'Alessandro, 2023) by incorporating spatial dimensions of production (through multi-regional input-output MRIO tables), consumption, and climate damages. The lower matrix depicts the regional disaggregation*: blue diagonal blocks represent intra-regional trade flows, while the off-diagonal rows and columns indicate inter-regional exchanges. For example, the row (column) corresponding to Tuscany shows the volume of goods sold to (purchased from) other regions.
*Northwest (NW), Northeast (NE), Tuscany (TUSC), Centre (excluding Tuscany), and South (including islands).

Figure 1 provides a concise overview of the novel Multi-Spatial IAM, known as *REWIND*, which updates and extends the EUROGREEN model, as described below. In line with the EMM literature, REWIND employs a system dynamics approach to policy analysis and design, which is particularly well-suited to studying complex systems (Richardson, 2013). At its core, the model employs an environmentally extended multi-regional input-output (EE-MRIO) framework, dividing the whole economy into 19 macro-sectors (see Appendix Table A1.2). This structure enables the integration of monetary flows, energy and water use, and labour inputs within a consistent framework aligned with official national accounts, facilitating the analysis of inter-industry linkages. In the current version, REWIND includes five macro-regions—Northwest (NW), Northeast

(NE), Tuscany (TUSC), Centre (excluding Tuscany), and South (including islands)—enabling a more granular spatial representation of production, consumption, and emissions in Italy. The current development of a Multi-Spatial version enhances the model's capacity to capture the heterogeneous effects of national policies across Italy's territory. This advancement also enables the exploration of regionally tailored policy options, providing a more detailed and nuanced framework to analyse economic-environmental interactions that vary significantly across the Italian territory.

REWIND is designed as a modular,[1] multi-system, multi-dimensional, and multi-spatial model, integrating socio-economic and ecological processes within a unified framework. It simultaneously accounts for multiple, often incommensurable, indicators across alternative scenarios and incorporates a spatial disaggregation into five interconnected geographical areas. This structure enables the model to capture both the complexity of socio-ecological interactions and the heterogeneity of regional dynamics. In what follows, we first outline the key assumptions inherited from EUROGREEN, before turning to a detailed discussion of the novel extensions introduced in REWIND in the following subsections.

Technological change is modelled as an endogenous, industry-specific process through which firms adopt innovations aimed at reducing intermediate input requirements—this affects the matrix A of technical coefficients, as described below—and/or increasing labour productivity. Investment dynamics are driven by demand and depend on the level of capacity utilisation, but they are constrained by internal financial resources and the ability to take on private debt. At the same time, investment contributes to improvements in labour productivity and energy efficiency, which subsequently affect wages, profits, and environmental outcomes. Additional central features of the model include the representation of energy flows disaggregated by source—renewables, gas, coal, and oil—enabling the evaluation of environmental sustainability and associated greenhouse gas emissions. On the demand side, households are modelled as heterogeneous agents, classified by economic status (employed, unemployed, inactive, retired, and capitalists). Employed workers are further distinguished by three skill levels, defined according to their highest educational attainment. The model also incorporates a detailed representation of the macroeconomic welfare system, including taxes and transfers, enabling the simulation of the fiscal and distributive implications of public policies on public deficit and debt.

In what follows, we describe the Multi-Spatial extensions introduced by REWIND, which comprise production (3.1), household consumption (3.2), and climate damage (3.3).

[1] The model is organised into 14 interconnected sub-modules: Population, Input-Output and GDP, International Trade, Innovation, Investment and Profits, Finance and Wealth Distribution, Labour, Government, Prices, Consumption, Energy, Climate Damage, Time Use, and Water Use.

3.1 Multiregional Input-Output extension

In a Multiregional Input-Output (MRIO) framework, the total output y_{ir} by industry i and region r is given by:

$$y_{ir} = \sum_j \sum_s z_{ir,js}^{dom} + f_{ir}, \tag{1}$$

where $z_{ir,js}^{dom}$ represents the flow of intermediate domestic goods from industry i in region r to industry j in region s, and f_{ir} is the final demand for domestically produced goods by industry i in region r, constituted of households consumption expenditures by households, gross fixed capital formation (i.e. investments), government expenditures, and exports.

Based on the NACE Classification, industries were aggregated into nineteen categories, as listed in Table A1.2 in the Appendix. Given $i = 19$ and $r = 5$, the resulting intermediate goods matrix $\boldsymbol{Z}$ has dimensions 95×95, while the sum of final demand components results in 95×1 a final demand for domestically produced goods and services vector. Using data from the MRIO table for Italy provided by the Regional Institute for Economic Planning in Tuscany (IRPET) for 2019, the technical coefficients $(a_{ij,rs})$ are calculated as:

$$a_{ij,rs} = \frac{z_{ij,rs}^{dom}}{y_{ir}}, \forall a_{ij,rs} \in \boldsymbol{A}. \tag{2}$$

These coefficients represent the share of intermediate inputs from industry j in region s required per unit of output in industry i in region r, with all values expressed in basic prices. As summarised in Table A1.1 in the Appendix, the technical coefficients evolve endogenously over time in response to technological innovations. This feature is crucial for capturing the endogenous structural transformation of the economy, since the $\mathbf{A}$ matrix embodies the overall production technology of the national economy. Accordingly, any change in $\mathbf{A}$ reflects a shift in the underlying production functions and implies a reallocation of output shares across sectors over time.

Following standard MRIO methodology, total output $\boldsymbol{Y}$ is obtained in the model by multiplying the vector of final demand for goods and services ($\boldsymbol{f}^{dom}$) by the Leontief matrix ($\boldsymbol{L}$), derived from the technical coefficients matrix ($\boldsymbol{A}$).

$$\boldsymbol{Y} = \boldsymbol{L} \cdot \boldsymbol{f}, \tag{3}$$

$$\boldsymbol{L} = (\boldsymbol{I} - \boldsymbol{A})^{-1}, \tag{4}$$

where $\boldsymbol{I}$ stands for the identity matrix and the Leontief inverse $\boldsymbol{L}$ denotes the total requirements matrix given final demand. This structure provides a demand-side approach to determine total output across industries and regions. On the supply side, production is constrained by the full capacity output (y_{ir}^{FC}), namely the maximum output that each industry can produce depending on its total stock of fixed capital. Therefore, the actual output in the model is determined as:

$$\boldsymbol{Y} = \min\{\boldsymbol{Lf}, \boldsymbol{y}^{FC}\}. \tag{5}$$

Imports are determined using constant coefficients calculated from the multiregional input-output table for the initial period and held fixed over time. For intermediate goods imports ($z^{imp}_{ir,j}$) of industry i in region r from industry j in the rest of the world, the coefficients are expressed as ratios relative to the corresponding domestic input demand:

$$\gamma^{z}_{ir,j} = \frac{z^{imp}_{ir,j,t=0}}{z_{ir,j,t=0}}. \tag{6}$$

In contrast, for final demand imports, import shares are computed for each component $\delta \in C, G, I$, respectively household consumption, government expenditures, and investment, so that overall demand of each component ($\hat{f}^{\delta}_{ir}$) is given by domestic plus imported demand:

$$\gamma^{\delta}_{ir} = \frac{f^{\delta,imp}_{ir,t=0}}{\hat{f}^{\delta}_{ir,t=0}}. \tag{7}$$

$$\hat{f}^{\delta}_{ir} = f^{\delta}_{ir} + f^{\delta,imp}_{ir}. \tag{8}$$

This distinction arises from the structure of the input-output tables: while intermediate trade is calculated based on the domestic technical coefficients matrix—requiring the addition of imports to compute total inputs—data on final demand is available only in aggregate form for domestic agents, and must be split between domestic goods and imports using the calculated shares.

3.2 Household consumption

Household consumption data is originally available on ISTAT for six macro regions—Northwest, Northeast, Tuscany, Central (excluding Tuscany), South, and Islands—and is disaggregated by 2-digit COICOP categories[2] and five household income quintiles. In the model, South and Islands are aggregated into a single macro-region, resulting in the five-region structure. Note that consumption (COICOP) and production (NACE) official categorization follows different classification criteria, hence a COICOP-NACE bridge matrix is required to make them compatible and to run the Leontief inverse. The bridge matrix is based on data elaborated from Eurostat

[2]COICOP Consumption categories include: 1) food and non-alcoholic beverages (fo), 2) alcoholic beverages, tobacco and narcotics (at), 3) clothing and footwear (cf), 4) housing, water, electricity, gas and other fuels (hb), 5) furnishings, household equipment and routine household maintenance (fe), 6) health (he), 7) transport (tr), 8) communications (co), 9) recreation and culture (rc), 10) education (ed), 11) restaurants and hotels (rh), and 12) miscellaneous goods and services (ot).

and subsequently is balanced with respect to the MRIO structure using the bipartitive balancing RAS algorithm (for a full explanation, see Distefano and D'Alessandro (2023)).

Household consumption in real terms (i.e., net of price inflation) is formalised as a behavioural equation linking expenditure on each good to three components: habit formation (captured by lagged consumption), the income effect (disposable income deflated by the price of the good), and the substitution effect (relative prices across goods). The estimation relies on a panel dataset comprising 30 household groups—defined by five income quintiles across six regions—and GLS regressions are applied separately to each COICOP consumption category. The full specification of the equation and the definition of variables are provided in Appendix A.3.

Regional household disposable income is derived by allocating national disposable income across regions in proportion to their value added,

$$YD_{r,t} = \frac{VA_{r,t}}{VA_t} YD_t, \tag{9}$$

where $VA_{r,t}$ denotes the value added of region r. Within each region, disposable income is further disaggregated by quintile according to the initial income distribution,

$$YD_{r,q,t} = \gamma_q YD_{r,t}, \tag{10}$$

where γ_q denotes the initial income quintile share.

Prices of consumption goods are obtained from national industry prices using a consumption–industry bridge matrix and are assumed to be homogeneous across regions. The same bridge matrix is applied to convert real household consumption by COICOP categories into real household consumption by industry. For consistency with the regional input–output module, household consumption of the South and Islands is aggregated into a single regional account.[3]

3.3 Climate damage

To capture the differentiated impacts of climate change across macro-regions, we incorporate regional temperature projections into the model. This extension allows us to derive region-specific damage coefficients. Within this framework, rising temperatures reduce productivity by directly affecting the technical coefficients matrix $\mathbf{A}$ of the MRIO. Increasing temperatures lead to a decline in productive efficiency, which in turn generates higher demand for intermediate inputs to offset damages caused by extreme events. To account for these impacts, we adopt the methodology proposed by Distefano, D'Alessandro, et al. (2025), whereby the intermediate input matrix is updated under conditions of climate damage as follows:

[3]The consumption–industry bridge matrix is a weight matrix indicating, for each unit of a specific good, the percentage contribution of each industry producing it.

$$\mathbf{Z} = \mathbf{Y}^T \mathbf{A} \mathbf{D}, \tag{11}$$

where $\mathbf{D}$ denotes the climate damage matrix (95×95),

$$\mathbf{D} = \begin{bmatrix} \mathbf{D}_{NW,NW} & \mathbf{D}_{NW,NE} & \cdots & \mathbf{D}_{NW,South} \\ \mathbf{D}_{NE,NW} & \mathbf{D}_{NE,NE} & \cdots & \mathbf{D}_{NE,South} \\ \vdots & \vdots & \ddots & \vdots \\ \mathbf{D}_{South,NW} & \mathbf{D}_{South,NE} & \cdots & \mathbf{D}_{South,South} \end{bmatrix}. \tag{12}$$

For each pair of inter-regional intermediate good transactions from region r to region s, $\mathbf{D}_{r,s} = diag(\frac{1}{1-\Lambda_{1,s,t}}, \frac{1}{1-\Lambda_{2,s,t}}, \cdots, \frac{1}{1-\Lambda_{19,s,t}})$, the industry-specific climate damage multiplier, $\Lambda_{j,s,t}$, depends on the temperature of the intermediate good destination region, which is governed by a Beta distribution to account for extreme climate events (Desmet et al., 2015 and Burzynski et al., 2018) as in Campigotto et al. (2022). In particular, the agriculture sector is more sensitive to temperature change than the other sectors, which makes the south region more vulnerable to climate change in the model, because they are mainly specialised in agricultural production.

The temperature of the five macro regions are computed as the average (size weighted) of the projections of 20 Italian provinces based on the data from the Copernicus Climate Data Store (CDS) in our baseline scenario. In our RCP 6.0 scenario shown in the next section, the regional temperatures are computed based on the *near-surface air temperature* (across the four scenarios) from the CMCC-CM2-SR5 model, a coupled atmosphere–ocean general circulation model developed by the *Centro Euro-Mediterraneo sui Cambiamenti Climatici*, which is part of the CMIP6 framework used by the IPCC in its Sixth Assessment Report (AR6, 2021).

4 Results

Following the presentation of the model structure and its regional extensions, this section reports a simulation exercise that serves as a proof of concept for the REWIND framework. The aim is to demonstrate how climate damages are incorporated into the model and how the multi-spatial architecture captures their differentiated regional and aggregate impacts. To this end, we conduct a comparative analysis between two stylised scenarios: a Baseline without climate damages and a climate change scenario in which damages are explicitly activated. This exercise highlights the capacity of REWIND to account for spatial heterogeneity and to trace the propagation of shocks through interregional linkages. Although the simulation may appear simple, the process of creating the model involved significant effort. This included data collection and integration, extending the architecture to encompass five macro areas, calibrating the consumption function at the regional level, and calculating spatial-specific temperature projections. Therefore, the aim is to present this novel REWIND model and demonstrate its usefulness for regionally tailored policy. Additionally, we chose to keep the scenario simple to facilitate the reader's understanding of the model's main contribution and potential.

In the *Baseline* scenario, climate damages are not considered. Regional temperatures are fixed at the twelve-year average observed in the reference period (2013). Moreover, technological change is not regionalised but evolves according to the dynamics of the national technical coefficients matrix **A**, applied uniformly across industries. In contrast, the *Climate Change* scenario introduces damages consistent with the Representative Concentration Pathway 6.0 (RCP 6.0), starting from 2025. RCP 6.0 represents a medium-to-high emissions trajectory developed by the IPCC, characterised by delayed and moderate mitigation measures. It stabilises radiative forcing at 6.0 W/m^2 above pre-industrial levels by 2100, leading to an expected global average temperature increase of approximately 3°C. This setting provides a robust test of the model's ability to incorporate climate-induced productivity losses and to simulate their economic and spatial consequences. In the model, atmospheric temperature projections are generated for each macro-region following RCP 6.0, as described in 3.3. These projections affect precipitation patterns and a climate damage coefficient that reduces productivity and, consequently, regional output. In practical terms, lower productivity implies that more inputs are required to produce the same level of output. This raises the relative weight of intermediate goods in production while simultaneously increasing costs for firms, thereby reducing revenues, value added, and ultimately gross domestic product (GDP). Climate damages are activated from 2025 onwards and capture the adverse effects of climate change on the productivity of production factors in sectors exposed to extreme weather conditions, as previously described.

For a robustness check and sensitivity analysis, we run 500 simulations in which selected parameters affecting technological innovation and climate damage are treated as stochastic. Technological innovation remains endogenously determined, but its parameters are varied according to a Normal distribution, influencing the intermediate-input and labour-saving technology (D'Alessandro, André Cieplinski, et al., 2020). Climate change parameters follow a Beta distribution and increase the required amount of intermediate inputs across industries for a given output. From these simulations, we compute the median trajectory and a confidence interval to reduce the influence of stochastic noise and avoid arbitrary outcomes associated with numerical simulations (Distefano, D'Alessandro, et al., 2025). The simulations start from 2019, consistent with the MRIO data described in Section 3.1, and incorporate two exogenous shocks: the COVID-19 pandemic in 2020 and 2021 (see Table A1.3 in the Appendix) and the Italian National Recovery and Resilience Plan (PNRR) in 2022. The former is constructed based on the Bank of Italy's projections for variations in consumption, investment, exports, and imports.[4] The latter increases government expenditure and subsidies to firms by sectors in six mission plans.[5]

[4] Further information available on https://www.bancaditalia.it/pubblicazioni/proiezioni-macroeconomiche/2020/index.html. Accessed 30/08/2025.

[5] Further information available on https://www.italiadomani.gov.it/content/sogei-

4.1 On spatial disaggregation

To assess the role of regional climate damages, we compare aggregate output losses under the RCP 6.0 scenario with those under the baseline, both in the multi-spatial and national models (i.e., using the EUROGREEN model). The results, reported in Figure 2, illustrate that incorporating regional heterogeneity leads to marked under-estimation of production losses. This difference highlights the importance of spatial granularity. By revealing how uneven regional impacts accumulate into amplified national damages, the multi-spatial framework provides a more accurate and robust basis for assessing climate impacts.

The trajectories shown in Figure 2 correspond to the median across the 500 simulation runs, with confidence intervals constructed from the median absolute deviation scaled by a factor of 1.5. This approach provides a robust measure of dispersion around the central tendency, allowing us to capture variability in the simulated outcomes. In 2030, aggregate output losses reach approximately 7% in the multi-spatial model, compared to about 5% in the national model. Thereafter, the multi-spatial trajectory briefly converges with the national one around 2038, before diverging again as the differentiated regional impacts accumulate over time. This non-linear pattern highlights how regional heterogeneity, particularly the uneven exposure to climate shocks, amplifies aggregate effects in ways that a national model cannot capture. Ultimately, despite the temporary convergence in trajectories, cumulative output losses remain larger in the multi-spatial model due to the deeper downturns experienced in the preceding years, and the gap between the two approaches widens markedly from the mid-2030s onwards. Beyond the production side, this suggests fiscal consequences that a national model may overlook, which should be considered in public finance analysis. These aggregate findings provide the rationale for moving beyond the national perspective, motivating a closer examination of the regional dimension of climate damages. This is addressed in the following maps of value-added losses by macro-region, shown in Figure 3.

Figure 3 shows the value-added losses by macro-region in 2030, 2040, and 2050 under the RCP 6.0 scenario. While all regions are negatively affected by climate change, the magnitude of the impact varies according to spatial heterogeneity. The Northwest experiences the highest losses, reaching approximately -11.6% by 2050, followed by the South at around -10%. These differences reflect the underlying regional productive structures and sectoral sensitivities. Although all regions experience significant value-added losses, two distinct patterns stand out. The South, with a high share of agricultural activity, is particularly affected due to the direct sensitivity of agriculture to temperature rise and extreme events. In contrast, the Northwest, despite being less agriculture-intensive, shows the largest losses overall. Manufacturing-intensive and accounting for the largest portion of national value added, the Northwest becomes the central transmission node through which productivity shocks reverberate across interregional and intersectoral demand

ng/it/it/home.html. Accessed 30/08/2025.

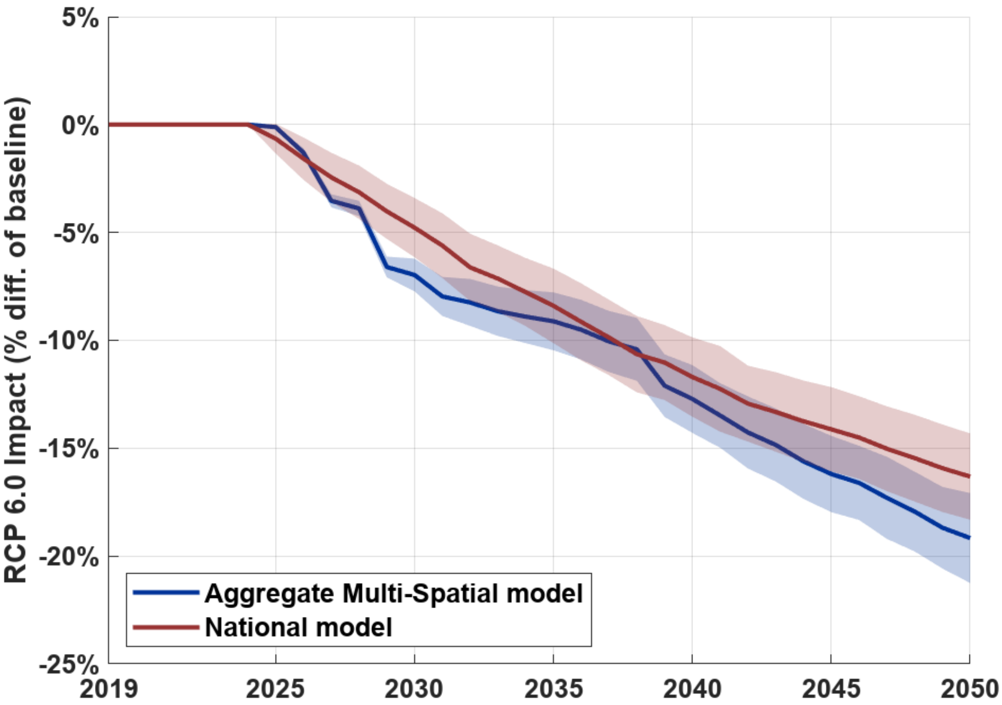


Figure 2: Aggregate Output loss: Multi-Spatial vs National. Yearly percentage difference of national output under the climate scenario RCP 6.0 with respect to the Baseline. The red line refers to the national-scale EUROGREEN model, while the blue line refers the the Multi-Spatial REWIND model in which the national output is given by the sum of macro-regional output.

chains. These results illustrate that climate damages are shaped not only by direct sectoral sensitivity but also by a region's centrality within the broader economic network.

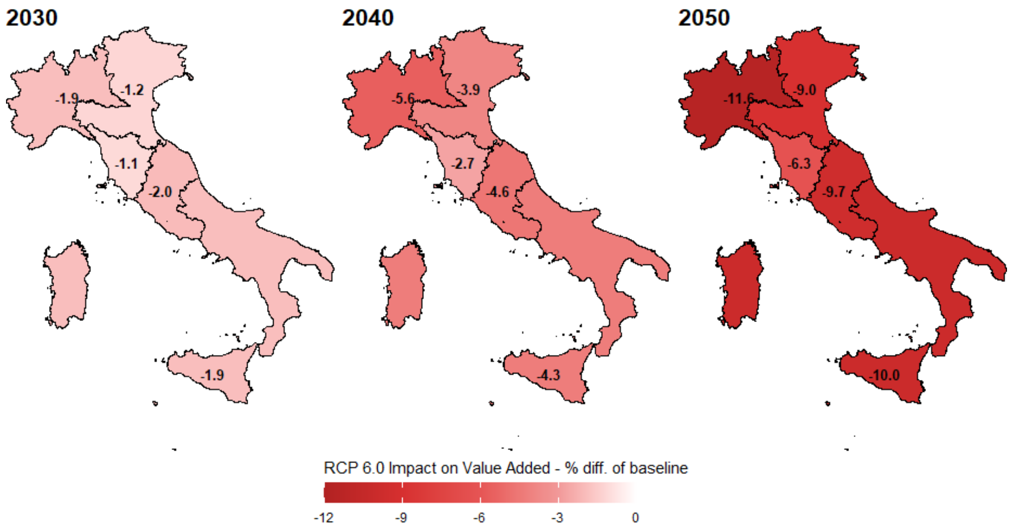


Figure 3: Value Added loss by macro-region. Percentage difference in value added due to the climate damage under the RCP 6.0 scenario, by macro-region, with respect to the Baseline.

4.2 Multi-sectoral and multi-spatial focus

The productivity shocks induced by climate damages call for a closer examination of how intermediate goods flows are affected. Table 1 reports the percentage differences in intermediate goods transactions (i.e., the $Z^{dom}_{95,95}$ matrix) between the RCP 6.0 and the baseline scenario for three selected sectors—agriculture, manufacturing, and trade—across the years 2030, 2040, and 2050. These sectors are chosen because agriculture is the most sensitive to climate damage, manufacturing is the most important in terms of output, and trade is the largest services sector.

Table 1: Intermediate goods transaction for selected sectors. Percentage difference of intermediate demand under climate scenario RCP 6.0 with respect to the Baseline.

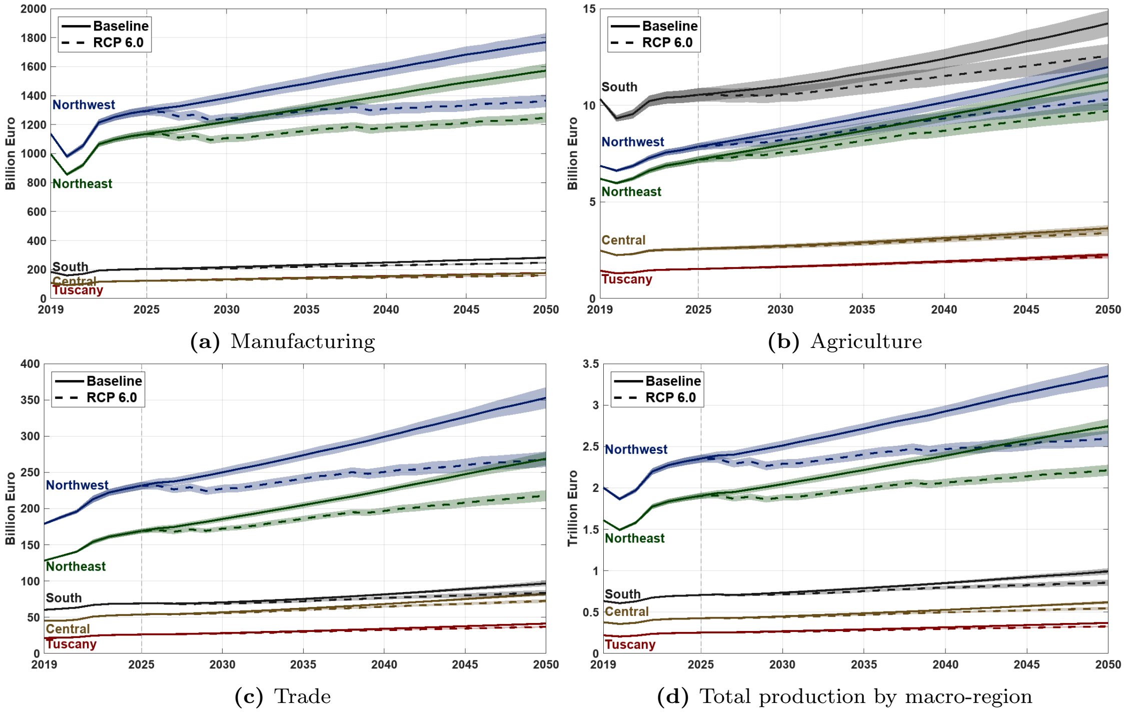
	NW			NE			TOSC			CEN			SOUTH		
Year	*agri*	*manuf*	*trade*	*agri*	*manuf*	*trade*	*agri*	*manuf*	*trade*	*agri*	*manuf*	*trade*	*agri*	*manuf*	*trade*
2030	-42.8%	-18.7%	-17.2%	-40.4%	-17.2%	-15.0%	-5.5%	-6.1%	-4.5%	-15.3%	-3.7%	-2.5%	-14.6%	-5.9%	-3.9%
2040	-64.3%	-31.5%	-29.7%	-61.9%	-28.9%	-25.8%	-8.3%	-12.2%	-10.3%	-24.9%	-8.1%	-6.7%	-22.5%	-12.1%	-9.1%
2050	-74.9%	-39.3%	-40.1%	-72.2%	-35.9%	-34.8%	-12.0%	-20.1%	-20.7%	-30.3%	-13.7%	-16.0%	-27.8%	-19.6%	-20.0%

In this Table, rows correspond to the simulation years, while columns indicate the destination region of the intermediate goods. The origin is not broken down by region but aggregated, since climate damages are introduced locally as productivity shocks and therefore affect production in the destination region. This setup illustrates how regional demand for intermediate goods adjusts when productivity declines: on the one hand, more inputs are required to maintain a given level of output; on the other, the overall contraction in value added reduces the total volume of transactions. The Table thus illustrates how inter-regional demand for intermediate goods is reshaped under climate stress, providing insight into the channels through which local productivity shocks propagate and ultimately generate the differential regional impacts observed in value added.

The results in Table 1 highlight heterogeneous effects across sectors and regions, though some clear patterns emerge. Agriculture is consistently the most affected sector, reflecting its high sensitivity to climate change, but the magnitude of losses varies across regions. The Northwest and Northeast register the largest overall contractions, not only because their damage coefficients are higher—derived directly from regional temperature projections under RCP 6.0 and the associated construction of the climate damage functions—but also because of their structural position in the economy. As the main manufacturing-intensive regions and the largest contributors to national value added, they act as transmission nodes: productivity shocks in other regions reduce demand for intermediate inputs, which in turn depresses value added in the Northwest and Northeast. Tuscany shows a distinct profile: by 2040 and 2050, losses in manufacturing and trade surpass those in agriculture, making it the only region where agriculture is not the most affected sector. Finally, the greater agricultural intensity of the South and Central regions implies that climate shocks there reduce both the demand for intermediate inputs from the Northwest and Northeast, as well as final demand through income losses. These combined effects explain why the Northwest and Northeast, despite being less agriculture-intensive, experience the most substantial overall declines in intermediate goods transactions.

The regional patterns discussed above motivate a closer analysis of the temporal dynamics of output at the sectoral levels. Figure 4 depicts the evolution of real output at both national and sectoral levels under the baseline and RCP 6.0 scenarios across the five macro-regions. Focusing on manufacturing (Panel 4a), agriculture (Panel 4b), and trade (Panel 4c) allows us to disentangle how sectoral composition interacts with regional vulnerability to climate impacts. This sectoral perspective sheds light on the mechanisms through which climate damages propagate within and across regions, ultimately shaping the distribution of aggregate losses in the Italian economy. In the following figures, the solid line represents the baseline scenario and the dashed line the RCP 6.0 scenario.

Consistent with the previous results, the Northwest and the Northeast show the largest output levels and climate losses (Panel 4d). These regions also grow the fastest, reflecting their manufacturing intensity and higher productivity, characteristic of more industrialised areas. However, for the same reasons, they register the largest climate-related losses, as productivity shocks propagate through interregional and intersectoral linkages and affect demand. This pattern echoes the aggregate results discussed above, while the regional breakdown now reveals how these mechanisms unfold across space and sectors. It is necessary to note, however, that



(a) Manufacturing **(b)** Agriculture

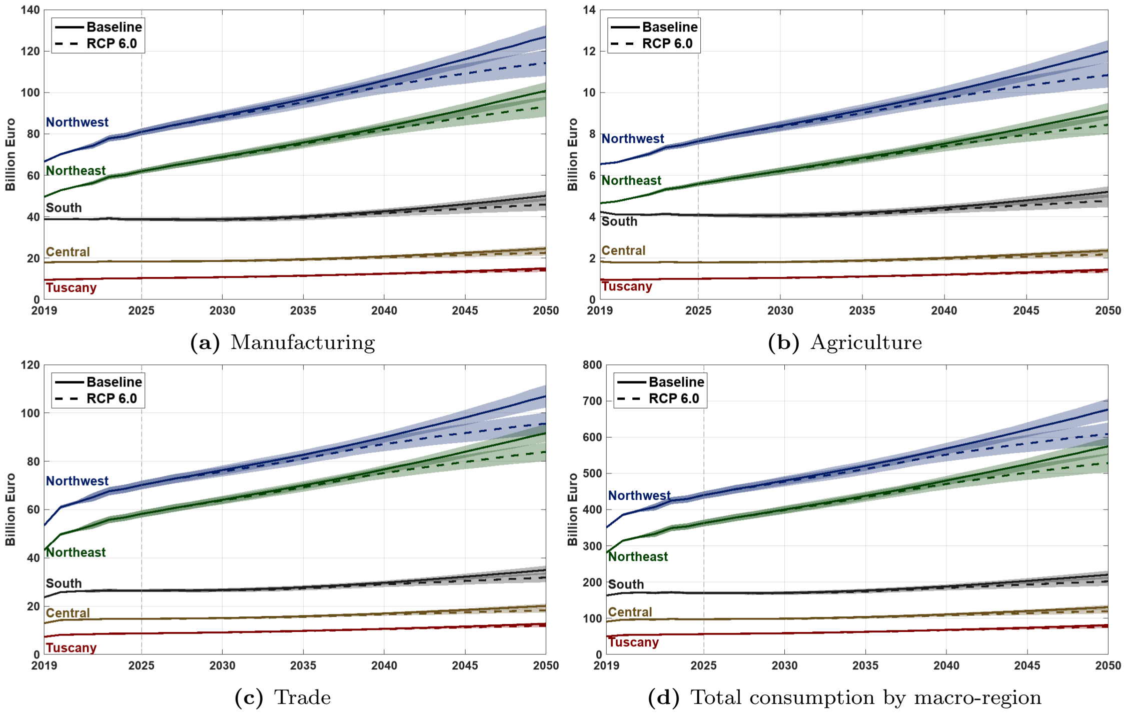
(c) Trade **(d)** Total production by macro-region

Figure 4: Real output for selected sectors. Spatial comparison of total output, by macro-area, under the Baseline and the climate RCP 6.0 scenario (dotted lines) for three selected sectors: (a) Manufacturing, (b) Agriculture, and (c) Trade. Panel (d) shows the overall output at the regional level under the two scenarios.

since many mechanisms continue to follow national-level dynamics, the emphasis here is less on the absolute values of the simulations and more on the dynamics they reveal. This aspect becomes accessible precisely through the multi-spatial structure.

Turning to the sectoral dimension, the South stands out with the largest agricultural output. Given agriculture's direct exposure to climate shocks, damages in this sector exert strong spillover effects on the rest of the regional economy, which helps explain why aggregate value added in the South is among the most affected. In manufacturing, the figures highlight the wide distance separating the Northwest and Northeast from the other regions. This gap underscores not only the tendency for the north-south divide in Italy to widen, but also its role as a shock absorber of value-added losses originating elsewhere in the economy. Finally, services—here represented by trade—are also most affected in the Northwest and Northeast, reflecting the contraction in household demand following the decline in productivity and income.

Building on this, we turn to household consumption, another dimension explicitly modelled at the regional level. Figure 5 mirrors the structure of the output analysis, reporting total consumption by region (Panel 5d) as well as consumption in agriculture (Panel 5b), manufacturing



(a) Manufacturing **(b)** Agriculture **(c)** Trade **(d)** Total consumption by macro-region

Figure 5: Real household consumption for selected sectors. Spatial comparison of total consumption, by macro-area, under the Baseline and the climate RCP 6.0 scenario (dotted lines) for three selected sectors: (a) Manufacturing, (b) Agriculture, and (c) Trade. Panel (d) shows the overall output at the regional level under the two scenarios.

(Panel 5a), and trade (Panel 5c). This parallel structure allows us to examine how climate damages, transmitted through output and income, ultimately translate into regional consumption patterns across sectors.

The transmission channel from productivity shocks to household consumption operates primarily through income: regions with larger losses in value added tend to experience more substantial reductions in consumption. However, in a multi-spatial setting, interregional consumption flows diffuse these impacts across space, making the relative intensity of the climate shock on consumption more uniform across regions. What remains differentiated are the absolute levels of consumption, which mirror the distribution of output and value added—highest in the Northwest and Northeast, followed by the South, Central, and Tuscany. While these results largely reproduce the output patterns, the regional consumption structure provides a foundation for future extensions, where incorporating region-specific demographic, labour market and price system dynamics will allow for a more complete assessment of how climate shocks transmit from production to household demand.

5 Concluding remarks

This paper presents REWIND, a novel Multi-Spatial Integrated Assessment Model (MS-IAM) that extends the Italian EUROGREEN model by incorporating regional heterogeneity within a coherent national framework. The model builds on the tradition of Ecological Macroeconomics while advancing a line of research that has so far received limited attention: a multi-spatial integrated assessment model. Despite the growing interest in climate change impacts, most existing IAMs operate at the global or national level, thereby overlooking spatial disparities and the interactions between local and aggregate dynamics. This leaves an important gap in understanding how climate damages propagate across regions, how regional vulnerabilities compound at the national scale, and how national policies may generate uneven effects across space. By explicitly incorporating subnational dynamics, REWIND takes a step toward closing this gap. It contributes to the development of tools capable of capturing the geography of climate impacts with greater accuracy and policy relevance.

The multi-spatial structure allows us to trace how regional and sectoral trajectories evolve, highlighting differences in both growth patterns and climate-induced impacts. The comparison between the regionalised and national versions of the model underscores the importance of spatial granularity. Aggregate models, by construction, smooth over localised variations in climate impacts, thereby limiting the capacity to represent the uneven geography of damages. By contrast, a multi-spatial framework explicitly incorporates regional heterogeneity, enabling a more accurate assessment of how differentiated climate shocks impact economic dynamics and how these effects accumulate at the national level. In this way, regionalisation does not simply refine the detail of the analysis, but enhances its robustness and relevance for understanding the economic consequences of climate change.

It should be emphasised that, at this stage, several mechanisms in the model continue to follow national-level dynamics. For example, imports are computed using constant import share coefficients derived from historical real data. Exports are modelled based on a constant price elasticity and an exogenous, industry-specific growth rate. Labour force dynamics incorporate an exogenous trend by skill level, reflecting developments in educational attainment over time. All workers are assumed to be employed under full-time contracts. Similarly, government expenditure on final demand evolves according to an exogenous trend calibrated from historical data. These assumptions help reduce the number of free parameters in the model and ensure consistency with observed macroeconomic patterns while acknowledging the limits of representation inherent in any modelling exercise.

For this reason, the focus was creating a modelling framework capable of integrating spatial aspects and multi-scale dynamics. The strength of this approach lies precisely in providing a structure that can be progressively expanded. Beyond the economic core, the model already incorporates energy and environmental modules, which opens the possibility of extending the analysis to capture how climate shocks and transition policies reverberate not only through production, income, and household demand, but also across the labour market, resource use, technological change, and ecological pressures. While some modules may be expanded to a multi-spatial setting in future extensions, others—such as finance and government—are reasonably kept at the national level, as long as they remain fully integrated with regional dynamics. In this way, the model offers a foundation upon which a wide range of policies and scenarios can be tested in a genuinely multi-systemic perspective.

In parallel, developing the REWIND model involved an extensive effort in data collection, harmonisation, and analysis to calibrate parameters and initial conditions. This empirical foundation supports the behavioural assumptions embedded in each submodule and ensures consistency across simulations. However, as with any model, simplifications are necessary. Despite its detailed structure and broad variable coverage, REWIND remains a stylised representation of the real economy. Given the high level of complexity and the number of parameters involved, some features are treated as exogenous in order to keep the model tractable and ensure the robustness of the simulations. These challenges are further amplified in the multi-spatial setting, where the inclusion of five regions increases the number of equations, parameters, and interdependencies across all submodules. As a result, the model's construction and calibration become considerably more complex, requiring careful management to maintain internal consistency and tractability.

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A Appendix

A.1 Tables

Table A1.1: EUROGREEN model in a nutshell. List of all the modules together with a recap of the main assumptions and feedback effects. The full documentation is available at doi.org/10.1038/s41893-020-0484-y.

Module	*Main assumptions*	*Feedback*
Demography	Four age cohorts and three skill groups by education (low, middle and high). Demographic exogenous trends provided by ISTAT projections.	It affects labour force participation rate and educational skill composition.
Prices	Prices depends on the markup and unit cost of production, which include unit labour cost, unit intermediate cost, unit capital depreciation cost. The price markup depends on the difference between current capacity utilisation rate and normal capacity utilisation rate.	Generates an upward slopping Philips curve. Technological improvements reduce prices.
Profits and VA	Accounting equations follow SNA.	It affects the maximum level of private indebtedness and then the level of future investments.
Consumption	Average propensity to consume extrapolated by non-linear algorithm into household income categories by income level, gender, skill, employment status, pensioner and capitalist. Consumption share between COICOP depends on price elasticity and income elasticity.	Consumption depends on income and substitution effects between goods. Final demand determines the overall sectoral output through the Leontief inverse.
Input-Output	The Input–Output module follows a demand-led framework with no substitutability between inputs, unlike neoclassical models based on optimization and flexible factor use. Technical coefficients define inter-sectoral input requirements and evolve endogenously over time, reflecting changes driven by innovation. The model also allows for output to be constrained by capacity utilisation.	It affects labour demand and employment, VA, emissions, GDP growth and public revenues (via taxation).

Table A1.1 continued from previous page

Module	*Main assumptions*	*Feedback*
Investments	Demand-led determination of investment based on deviations from the capacity utilisation from the desired rate (Post-Keynesian/Sraffian). Financial constraint to investment based on the Equity-to-Liabilities Ratio (ELR) is rooted in Post-Keynesian/Kaleckian/Minskyan macroeconomic theory of investment behaviour and financial fragility.	It affects final demand, capital stock accumulation, and financial indebtedness.
International Trade	Imports are computed using constant import share coefficients derived from historical real data. Exports are modelled based on a constant price elasticity and an exogenous, industry-specific growth rate.	Gross domestic product and trade balance.
Finance	The value of total national wealth is divided depending on the skill level, used as a proxy of propensity to make financial investments. Also, capitalists are included. Low-skill individuals hold only bank deposits, middle-skill individuals hold also public bonds, while high-skill individuals and Capitalists make also investments in Equities. Allocation of assets according to a simplified Tobin's portfolio choice depending on the rate of return.	It impacts income distribution, inequality and wealth taxation.
Labour	Wage evolution depends on labor productivity growth rate, employment levels, and inflation. Since it depends on prices, it is affected by the markup. Employment by industry is determined by how much labour is required to produce the planned output, and hence depends on labour productivity, as well as hours worked.	It has an impact on income distribution, working hours, (un)employment, consumption and inequality.
Energy	Five main energy sources: solid, liquid, gas, nuclear and renewable. Exogenous share composition depending on scenarios.	Energy demand depends on total output and technological innovations (which affects energy efficiency). It determines the level of GHG emissions.

Table A1.1 continued from previous page

Module	*Main assumptions*	*Feedback*
Carbon Emissions	Coefficient of CO2 emissions are calculated for each fossil source and GHG is derived in proportion to CO2 levels.	It does not have feedback in the economy but is influenced by innovations and energy efficiency changes.
Technology	The dynamics of innovation contain a stochastic element influencing the accessibility and efficiency advancements of novel technologies. Each industry will adopt the most cost-effective technology, resulting in savings in labour and/or intermediate resources.	It determines the dynamics of the Leontief technical coefficients, labor productivity, and energy efficiency gains.
Government	It includes all the sources of revenue (income tax, corporate income and financial tax, VAT, labour and carbon tax) and expenditures (subsidies, wages, investments, and consumption) to determine the public deficit and debt, also considering the interest rate on bonds.	It impact production and consumption through taxes and subsidies and via direct policy intervention under given scenarios.

Table A1.2: List of sectors of REWIND Model

Sector no.	Sector name	Nace Rev. 2 code
1	Agriculture, forestry and fishing	A
2	Mining and quarrying	B
3	Manufacturing	C (excl. C19)
4	Coke and refined petroleum products	C19
5	Electricity, gas, steam and air conditioning supply	D
6	Water supply	E
7	Construction	F
8	Wholesale and retail trade	G
9	Transportation and storage	H
10	Accommodation and food service activities	I
11	Information and communication	J
12	Financial and insurance activities	K
13	Real estate activities	L
14	Professional, scientific, technical, administrative and support service activities	M, N
15	Public administration and defence	O
16	Education	P
17	Human health and social work activities	Q
18	Arts, entertainment and recreation	R
19	Other	S, T, U

Table A1.3: Exogenous shocks from the Covid-19 pandemic from 2019 to 2020.

Covid shocks	$\Delta\%$
investments	-12.40
consumption	-8.84
export	-15.4
import	-17.3

Authors' own elaboration. Data are provided by the EUROSTAT GDP and main components.

A.2 Calibration

The empirical calibration of parameters and initial values for the Italian economy is based on official data, providing a consistent and coherent foundation for assessing the feasibility of carbon tax measures. To estimate the unknown parameters, we used official data from 2010 to 2020 (if available) and applied the optimisation function provided by Vensim SDD. We employed the multi-objective parameter optimization mode available in Vensim SDD, which automates the calibration process through repeated simulations. Technical details are available at: `https://vensim.com/optimization/#model-calibration.` The calibration process aimed to align the model outputs with observed data for key variables.

Table A2.1: Main parameters for calibration and sensitivity analysis.

Parameter	***Value***	***Equation or definition***	***Note***
p_0^{T2}	*0.5*	Probability of emergence of a labour productivity (λ) gains innovation	The innovation process is modelled in four steps. First, new technologies are discovered. Second, the magnitude of $\Delta\lambda$ and $\Delta a_{i,j}$ coefficients (i.e. the extent of the innovations) is determined. Third, a choice is made on whether to adopt one of the new technologies or not, based on a min cost rule. Fourth, the chosen technology is implemented. Calibration based on EU Klems and WIOD Rev. 1, 1995–2009 data for Italy.
p_0^{T3}	*0.5*	Probability of emergence of a material efficiency gain innovation, which affects technical coefficients ($a_{i,j}$)	
p_0^{T4}	*0.25*	Probability of emergence of a win-win innovation, which improves labour productivity and material efficiency	

Table A2.1 continued from previous page

Parameter	***Value***	***Equation or definition***	***Note***
δ	*0.3*	$Div_i = \delta \cdot (\Pi_i - Inv_i)$	Total dividends as a residual of profits net to new investments. δ is defined as: (dividends + buybacks - stock issuances) / (net income + depreciation - capital expenditure + new debt - debt repaid). Data is available at: https://pages.stern.nyu.edu/~adamodar/pc/datasets/divfundEurope.xls (05/01/2021 update). Investment (Inv) is derived from OECD.Stat, Table 8A: capital formation by activity. Available at: https://stats.oecd.org/Index.aspx?DataSetCode=SNA_TABLE8A.
$\overline{\eta}$	*0.03*	$\eta(t) = \eta(t-1) \cdot [1 - \overline{\eta}(uc - uc^N)]$	η is the markup and $\overline{\eta}$ is a measure of the sensitivity to capacity over-utilisation. Initial industry-specific markups ($m_{i,0}$) are approximated based on Christopoulou and Vermeulen (2012, Appendix C) using Eurostat correspondence tables (https://ec.europa.eu/eurostat/web/nace-rev2/correspondence_tables). The value for initial (2010) inflation is taken from OECD data (https://data.oecd.org/price/inflation-cpi.htm). Other parameters are calibrated to 2010–2019/20 data. Normal utilization capacity (uc^N) is taken from Setterfield and Avritzer (2020, p. 909).
uc^N	*0.8*	Eq. above	Normal utilization capacity values are approximated following **setterfield2020hysteresis**.
$(g'_{agr}, g''_{agr}, g'''_{agr})$	*(-2.24, 0.308, -0.0073)*	Eq. above, these values refer to the agricultural sector.	In the model a distinction is made between agricultural and non-agricultural activity. Estimates are taken from Desmet et al., 2015.
$(g'_{j'}, g''_{j'}, g'''_{j'})$	*(0.30, 0.08, -0.0023)*	Eq. above, these values refer to all the other sectors $j \neq$ *agric.*	

The regional household consumption function parameters are estimated based on GLS regressions shown in section 3.2.

Table A2.2: Main parameters of regional household consumption (selective)

Parameters	Definition	Value	95% confidence interval
$\alpha^l_{fo,NE}$	Long-run regional effect of North East to food and beverage consumption	-0.026	[-0.049, -0.003]
$\alpha^l_{fo,Sud}$	Long-run regional effect of South to food and beverage consumption	0.107	[0.071, 0.143]
$\alpha^l_{fo,Isole}$	Long-run regional effect of Islands to food and beverage consumption	0.087	[0.057, 0.116]
$\beta_{fo,1}$	Short-run income effect to food and beverage consumption	0.179	[0.067, 0.29]
$\beta_{fo,5}$	Long-run income effect to food and beverage consumption	0.349	[0.286, 0.412]
$\alpha_{at,NE}$	Long-run regional effect of North East to alcohol	-0.053	[-0.079, -0.028]
$\alpha_{at,Sud}$	Long-run regional effect of South to alcohol	0.121	[0.091, 0.151]
$\alpha_{at,Isole}$	Long-run regional effect of Islands to alcohol	0.102	[0.073, 0.132]
$\beta_{at,1}$	Short-run income effect to alcohol and tobacco consumption	0.214	[0.098, 0.33]
$\beta_{at,5}$	Long-run income effect to alcohol and tobacco consumption	0.391	[0.331, 0.452]
$\alpha^s_{cf,Isole}$	Short-run regional effect of Islands to clothing and footwear consumption	-0.065	[-0.114, -0.016]
$\alpha^l_{cf,NE}$	Long-run regional effect of North East to clothing and footwear consumption	0.032	[0.006, 0.058]
$\alpha^l_{cf,Sud}$	Long-run regional effect of South to clothing and footwear consumption	0.095	[0.059, 0.131]
$\alpha_{cf,Isole}$	Long-run regional effect of Islands to clothing and footwear consumption	0.066	[0.035, 0.096]
$\beta_{cf,1}$	Short-run income effect to clothing and footwear consumption	0.316	[0.182, 0.45]
$\beta_{cf,5}$	Long-run income effect to clothing and footwear consumption	0.443	[0.372, 0.514]
$\alpha^l_{hb,Sud}$	Long-run regional effect of South to housing, water, electricity and gas consumption	-0.041	[-0.068, -0.015]
$\beta_{hb,1}$	Short-run income effect of housing, water, electricity and gas consumption	0.213	[0.087, 0.339]
$\beta_{hb,5}$	Long-run income effect of housing, water, electricity and gas consumption	0.398	[0.341, 0.455]
$\beta_{fe,1}$	Short-run income effect of furnishing and	0.261	[0.142, 0.381]

	equipment consumption		
$\beta_{fe,5}$	Long-run income effect of furnishing and equipment consumption	0.395	[0.331, 0.459]
$\alpha^s_{he,Sud}$	Short-run regional effect of South to health consumption	0.033	[0.01, 0.056]
$\alpha^l_{he,NE}$	Long-run regional effect of North East to health consumption	0.067	[0.041, 0.093]
$\beta_{he,1}$	Short-run income effect of health consumption	0.228	[0.105, 0.351]
$\beta_{he,5}$	Long-run income effect of health consumption	0.341	[0.277, 0.404]

A.3 Equations

The estimated consumption equation uses the following notation: $c_{i,r,q,t}$ denotes real household consumption of good i in region r, income quintile q, and time t; $c_{i,r,q,t-1}$ is lagged consumption (habit formation); $YD_{r,q,t}$ is net disposable income; $P_{i,r,t}$ is the price of good i in region r; and $\frac{P_{i,r,t}}{P_{j,r,t}}$ represents the relative price of good i to other goods j.

$$\begin{aligned}\Delta \ln c_{i,r,q,t} = & \sum_{r \neq Centro} (\alpha^s_{i,r} Dum_r) + \sum_{q \neq iii} (\alpha^s_{i,q} Dum_q) + \beta_{i1} \Delta \ln \frac{YD_{r,q,t}}{P_{i,r,t}} \\ & + \sum_{j \neq i} \left(\phi^s_{ij} \Delta \ln \frac{P_{i,r,t}}{P_{j,r,t}} \right) + \beta_{i2} \Bigg[\ln c_{i,r,q,t-1} - \beta_{i3} - \sum_{r \neq Centro} (\alpha^l_{i,r} Dum_r) \\ & - \sum_{q \neq iii} (\alpha^l_{i,q} Dum_q) - \beta_{i4} \ln c_{i,r,q,t-2} - \beta_{i5} \ln \frac{YD_{r,q,t-1}}{P_{i,r,t-1}} - \sum_{j \neq i} \left(\phi^l_{ij} \ln \frac{P_{i,r,t}}{P_{j,r,t}} \right) \Bigg] \end{aligned} \quad \text{(A1.1)}$$

Where $i = fo, at, cf, hb, fe, he, tr, co, rc, ed, rh, ot$ denotes the index of consumption classifications, $r = NW, NE, Tuscany, Centre, South, Islands$ denotes the index of regions, $q = i, ii, iii, iv, v$ denotes the index of income quintiles, $\alpha^s_{i,r}$ and $\alpha^l_{i,r}$ captures the heterogeneity across regions in the short run and long run, respectively, $\alpha^s_{i,q}$ and $\alpha^l_{i,q}$ captures the heterogeneity across income quintiles in the short run and long run, respectively, $\beta_{i1} > 0$ and $\beta_{i5} > 0$ denotes the short-run and long-run elasticity of consumption to disposable income, respectively, ϕ^s_{ij} and ϕ^l_{ij} denotes the short-run and long-run substitution effect, respectively, $-1 < \beta_{i2} < 0$ denotes the long-run correction parameter of household consumption, β_{i3} denotes the propensity to consume in average, and $0 < \beta_{i4} < 1$ captures consumption habit formation.