Review of macroeconomic approaches to modelling Wellbeing, Inclusion, and Sustainability

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WISE HORIZONS

IMPRINT

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ABOUT WISE HORIZONS

The WISE Horizons project, funded by the European Union, seeks to accelerate systemic change beyond the dominant economic paradigm towards one that prioritises wellbeing, inclusion, and sustainability (WISE). This work aims to create a unifying theoretical framework which synthesises the current beyond-growth literatures and initiatives. This synthesis provides WISE metrics, a WISE accounting framework and WISE models for evidence-based policymaking and narratives.

The resulting WISE data, available for up to 180 countries will be provided in a special database, which includes long-term time series (going back to the 19th century) as well as contemporary data relevant to policy and media. These datasets will be used to analyse historical patterns and policy trade-offs as well as win-win opportunities.

The project will deliver nine partial policy models, which provide a vision of 2050, from the perspective of wellbeing, inclusion, and sustainability. The topics covered include living within planetary boundaries, sustainable wellbeing, the circular economy, the welfare state, productivity and the environment, gender inequalities and tax policy etc. Two integrated WISE models will also be created including a model of the Sustainable Development Goals.

The metrics, accounts, models, and visions of 2050 will be developed using various co-creation “labs” to be held in Brussels and online. The participants will be chosen from the WISE Stakeholder Network which is a “network of networks” of a global community of policymakers, researchers, activists, among others. At least five events will be organised to gather feedback from the various stakeholders in order to create a vision of the future and the necessary policies to achieve wellbeing, inclusion, and sustainability.

REVIEWS OF METRICS, MODELS AND POLICIES

This document is part of a series of three reviews carried out at the beginning of the WISE Horizons project (which started on January 1st, 2023). This report provides a synthesis of macroeconomic modelling approaches to Wellbeing, Inclusion, and Sustainability (Deliverable 1.2).

There are also two other reviews in this series. Firstly, a synthesis of Beyond-GDP metrics for Wellbeing, Inclusion and Sustainability including a deep-dive into EU metrics and their role in governance (Deliverable D1.1). Secondly, there is a review of policies worldwide to see how these policy frameworks are linked to the WISE dimensions (Deliverable D1.3). All three reports can be read in isolation, but this report on Beyond-GDP metrics provides a more comprehensive discussion of the underpinnings of the WISE conceptual framework.

The three reports will be foundational for the WISE theoretical framework that will be published at the end of 2023. See the www.wisehorizons.world website for the other reviews as well as all the latest reports of the WISE Horizons project.

EXECUTIVE SUMMARY

In response to the urgent global challenges of climate change and rising inequality, the need to re-evaluate our traditional economic models and adopt new approaches focused on sustainability, wellbeing, and inclusion has become evident. The current economic paradigms, based on equilibrium thinking and GDP-centric measurements, have proven inadequate in addressing the intricate interplay between economic, social, and environmental dimensions. As we embark on a transformative journey towards a sustainable and equitable future, it is crucial to adopt diverse modelling approaches to provide policymakers and stakeholders with informed decision-making tools.

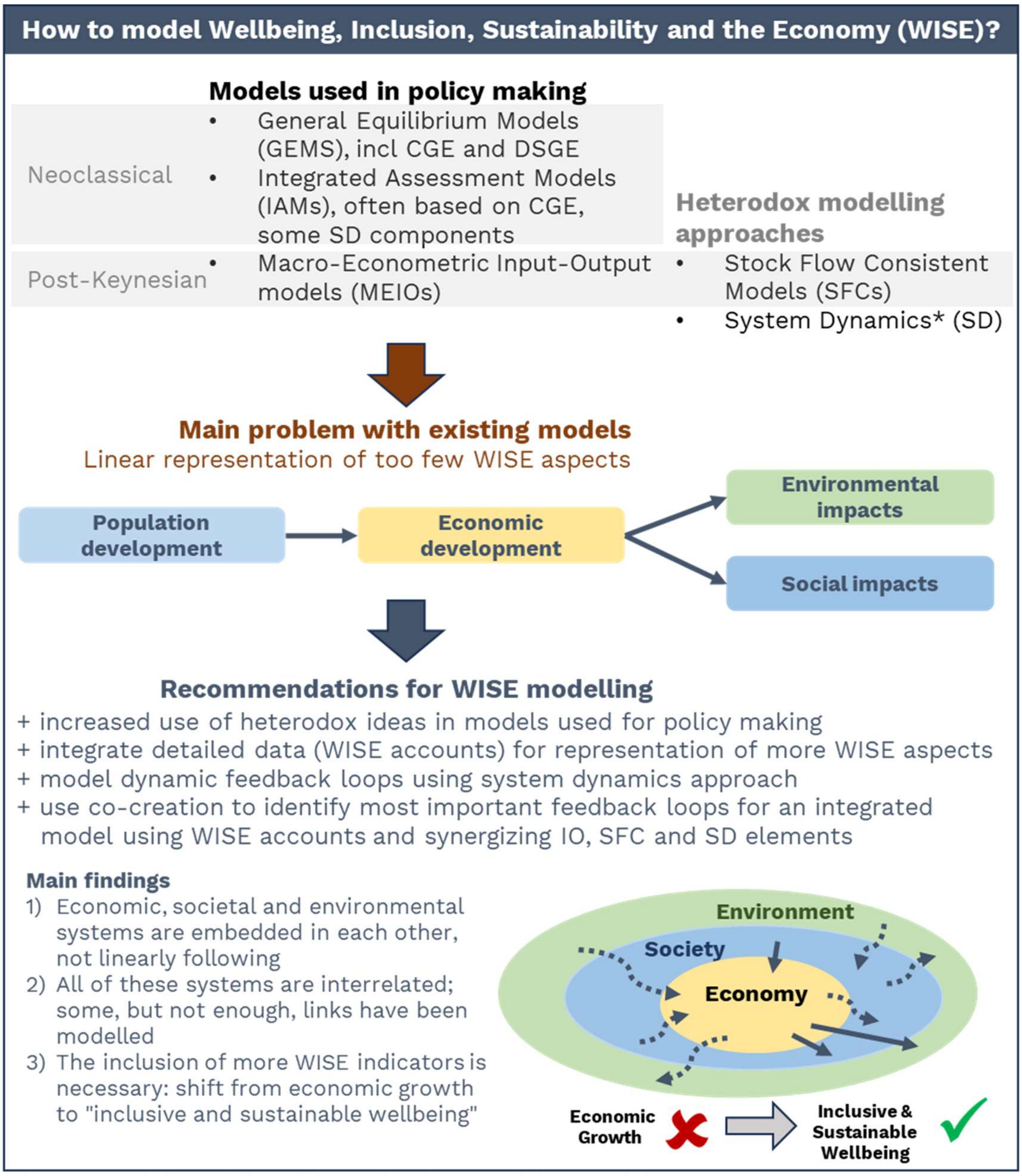
This report delves into the analysis of five different macroeconomic model types (general equilibrium models, macro-econometric & input-output models, stock-flow-consistent models, integrated assessment models, and system dynamics models), evaluating their respective strengths and weaknesses to propose an integrated framework that encompasses the multifaceted nature of our world. A key recommendation is to improve existing models by enhancing their dynamics and feedback loops between dimensions and systems, thus better reflecting the interactions and effects of different social and economic policies. Striking a balance between complexity and transparency is essential, ensuring that models remain flexible and capable of linking with models with greater detail but narrower focus.

The report emphasizes the incorporation of WISE accounts (detailed data on Wellbeing, Inclusion, Sustainability, and Economy that will be collected and harmonized during the project) into macroeconomic models as an opportunity to overcome the challenge of data availability, which poses a significant obstacle in modelling endeavours. Robust and reliable data sources are crucial to the success of any model and require continual improvement in data collection processes.

To broaden our understanding of the dynamics of WISE dimensions and the potential impacts of policies, integrating alternative perspectives, such as heterodox economics, can offer valuable insights. Co-creating quantitative analysis with stakeholders enhances ownership and uptake of the models and may help with bridging the gap between research and policy implementation.

Furthermore, an integrated modelling framework that accounts for the non-linear interactions between human and earth systems is necessary to properly assess policies tackling 21st century challenges in the context of WISE dimensions. This integrated model should draw upon the data of WISE accounts and synergize elements of Input-Output models, System-Dynamics, and Stock-Flow consistent models to provide a structured tool for policymakers and researchers in shaping a sustainable and inclusive future.

Figure ES1: Modelling Wellbeing, Inclusion, Sustainability, and the Economy (WISE)



How to model Wellbeing, Inclusion, Sustainability and the Economy (WISE)?

	Models used in policy making	**Heterodox modelling approaches**
Neoclassical	• General Equilibrium Models (GEMS), incl CGE and DSGE • Integrated Assessment Models (IAMs), often based on CGE, some SD components	
Post-Keynesian	• Macro-Econometric Input-Output models (MEIOs)	• Stock Flow Consistent Models (SFCs) • System Dynamics* (SD)

Main problem with existing models

Linear representation of too few WISE aspects

Recommendations for WISE modelling

+ increased use of heterodox ideas in models used for policy making
+ integrate detailed data (WISE accounts) for representation of more WISE aspects
+ model dynamic feedback loops using system dynamics approach
+ use co-creation to identify most important feedback loops for an integrated model using WISE accounts and synergizing IO, SFC and SD elements

Main findings

1) Economic, societal and environmental systems are embedded in each other, not linearly following
2) All of these systems are interrelated; some, but not enough, links have been modelled
3) The inclusion of more WISE indicators is necessary: shift from economic growth to "inclusive and sustainable wellbeing"

*System Dynamics is a modelling technique, not based on any particular economic theory

1. INTRODUCTION

1.1 The WISE dimensions

Current measures for assessing national and societal progress are heavily based on economic indicators, specifically one indicator "Gross domestic product" (GDP) and its related "Gross domestic product per capita" (GDP per capita). However, there is growing recognition that economic measures alone are inadequate in capturing the development of societies. Solely focusing on economic growth and economic measures can lead to misplaced priorities in society. Rather, economic growth can be seen as a means to achieve broader socio-political goals, such as poverty alleviation and stable employment (if at all relevant).

The concept of "Beyond GDP" has gained significant momentum, even at the highest level of global politics, with the endorsement of the UN's Secretary General. The main idea is to incorporate aspects of well-being, inclusion, and sustainability into the measurement of societal progress and development. This project emphasizes the interconnectedness of these dimensions, collectively referred to as Wellbeing, Inclusion, Sustainability, and the economy (WISE). Table 1 below, provides a description of the dimensions (for more information please see (Jansen et al., 2023)).

Our objective is to review and assess various approaches for modelling one or more dimensions of WISE. We seek to identify key aspects in the models that should be considered when developing an integrated WISE framework. By considering the various perspectives offered by different models, we can incorporate the most robust and relevant elements into the design of our integrated framework. This will ensure that our modelling approach captures the intricacies and interdependencies of the WISE dimensions, leading to more accurate and meaningful assessments of societal progress.

Table 1: Definition of WISE dimensions (Jansen et al., 2023)

Term	Wellbeing	Inclusion	Sustainability
Slogan	Wellbeing today	Wellbeing for all	Wellbeing in the future
Definition	Relates to wellbeing of the current generation.	Relates to the distribution of wellbeing[4]	Relates to the wellbeing of future generations
Clarification	Wellbeing is a multidimensional concept which encompasses both experienced wellbeing and factors such as social relations, mental health, and living standards.	Inclusion is a multidimensional concept which encompasses the distribution of wellbeing determinants and opportunities across spatial scales (within countries, between countries, and globally) and social groups (gender, race, background, etc.).	Sustainability is a multidimensional concept which encompasses social and economic conditions for future wellbeing, such as education and infrastructure, as well as environmental conditions, such as planetary boundaries.
Associations	Happiness, quality of life, prosperity, welfare, life satisfaction, flourishing, fulfilment,	Equality, fairness, equity, opportunities, minorities, poverty, social floors, subsistence, (global) disparities	Resilience, long term, wealth, planetary boundaries, natural limits, resources, natural capital, human capital, social capital,
Typical policy domains	Health, social connections, housing, air pollution	Poverty, Gender and racial disparities, global north-south divide,	Climate change, biodiversity, aging society, Research and Development, Infrastructure

1.2 Why is modelling important in the WISE context?

A core methodological approach in assessing WISE economies is macroeconomic modelling, for the following reasons:

1. There is a need to identify trade-offs and synergies between the WISE dimensions and economic considerations when considering different policy options. This includes analysing the generalised multidimensional impacts of WISE policies on a set of relevant metrics.
2. It is important to identify the most promising leverage points in the current socio-economic system to bring about a social-ecological transformation.
3. It is important to build a nuanced understanding of the intricate interlinkages between the WISE dimensions.
4. There is a need to identify the most effective environmental policies and how to counteract their potentially negative impacts on wellbeing and inclusion.

This is important as many environmental policies (such as carbon taxes) can be regressive in nature, depending on how they are structured.

5. Policymakers need evidence to inform ex-ante policy evaluation. This need for evidence-based policy is crucial for/in/with longer-term challenges. Highlighting the difference between business-as-usual policy pathways with post-growth pathways and related policies reveals a different vision of the future.
6. These models can help to bridge the gap between science and policy by communicating complex ideas in a quantified and structured manner.

There exist many models that inform society and policymakers regarding possible future developments at the national and global level, as well as strategies to influence them. The practice of modelling society can be traced back to the Malthusian Theory of Population (Landreth & Colander, 2002), which highlighted the significance of demographic, health/life expectancy and production capacity factors to assess possible societal futures. These factors continue to play a central role in economic modelling as knowledge on population development is not only important for consumption, but also on the production side regarding labour availability and qualification. Currently, there are diverse models employed to simulate society, with some primarily focusing on economic aspects. Examples include computational general equilibrium models and macro-econometric simulation models. While these models concentrate on economic dynamics, there are others that explicitly incorporate the linkages between the economy and the environment. For instance, integrated assessment models are employed to evaluate the influence of human activities on climate change. However, it is important to note that most models do not adequately account for the reciprocal relationship between environmental damage and its impact on the economy.

For assessing the WISE dimensions and policies that can potentially influence WISE outcomes, it is important to utilize models that consider:

1. A detailed, but comprehensive representation of the **population** (including the number of people and characteristics such as education, health status and time use) and the **economy** that includes a large number of industrial sectors and economic actors. These economic and societal developments cover different aspects related to **wellbeing** .

2. Global coverage as well as disaggregation/heterogeneity of agents within countries in the model, to ensure that they can well reflect **inclusion**, that is the distribution of wellbeing.
3. The possibility for medium-to-long-term policy simulation analysis, for linking today's actions to the wellbeing of future generations (**sustainability**). Here a consideration of the natural environment is important as well as other aspects that will affect future generations (infrastructure, innovation, human capital etc).

Thus, the 'ideal' macroeconomic model which incorporates and considers the WISE dimensions is built on the principle of disaggregation and a plethora of agents/industries within the economy, as well as the longitudinal nature of policy: how does the 'here' and 'now' relate to 'then' and 'there' for each actor in the economy?

1.3 Reading Guide

After we set the scope of this review in the next section, we review different types of macroeconomic models that are relevant for simulating policies and assessing impacts related to WISE in Section 3. To that end we give an introduction including a short historical account and a general description of each of the model types, a short account on model theory, method, and main concepts, including strength and weaknesses. We end the description of each model type with its relevance for modelling WISE, drawing on individual pieces of research to show how well WISE dimensions can be considered. This is followed by a discussion and recommendations.

2. SCOPE

In this review, we focus primarily on empirical economic models that are used by international organisations, governments, and in academia for policy simulation and impact analysis. Before elaborating on the scope of this review, some terminological clarifications are necessary. We answer the question "**What is macroeconomics and what are economic models?**" using two quotes from international organizations that rely heavily on macro-economic modelling for simulating potential policy outcomes:

"Macroeconomics focuses on the performance of economies – changes in economic output, inflation, interest and foreign exchange rates, and the balance of payments." (World Bank, 2022)

"An economic model is a simplified description of reality, designed to yield hypotheses about economic behavior that can be tested. An important feature of an economic model is that it is necessarily subjective in design because there are no objective measures of economic outcomes. Different economists will make different judgments about what is needed to explain their interpretations of reality." (Ouliaris, 2011)

"Analytic work begins with material provided by our vision of things, and this vision is ideological almost by definition. It embodies the picture of things as we see them, and wherever there is any possible motive for wishing to see them in a given rather than another light, the way in which we see things can hardly be distinguished from the way in which we wish to see them. The more honest and naïve our vision is, the more dangerous is it to the eventual emergence of anything for which general validity can be claimed." (Schumpeter, 2006, p.40)

The World Bank's definition of macroeconomics primarily emphasizes traditional economic metrics to assess the overall health and functioning of an economy. In contrast, the European Society of Ecological Economics offers a more comprehensive definition of economics, including macroeconomic modelling, as *"Advancing and understanding of the relationships among, ecological, social, and economic systems for the mutual wellbeing of nature and people"* (O'Neill, 2021).

In a broader sense, to move away from a monetary measurement of wellbeing, it is useful to consider the economy as a *"set of activities that uses resources to meet human needs or wants"* (Mair, 2020) .That is departing from the vision of economy as money oriented towards a definition of systems of production that can be structured to satisfy and provide wellbeing for society, as described by feminist and ecological economists (Gibson-Graham, 2006; Raworth, 2017). Theses definitions acknowledges the need to advance our understanding of the relationships between systems and the significance of maintaining a balance that supports both nature and human societies. In the context of WISE dimensions, the latter definition is more appropriate as it prioritizes a holistic approach that considers the broader implications of economic activities on human and earth systems.

Economic models can be divided into two classes, theoretical and empirical. Theoretical models are based on stylized representations of interdependencies between economic agents and their actions. These interactions are often based on stylized facts such as those from Kaldor (1961). Even though these models are based on a set of equations, if no empirical data are used, only qualitative assessments of how one variable impacts other variables in the system can be provided. In contrast, empirical models parametrize the system of equations using observed data. Interdependencies can be either modelled based more on theory (as for example in general equilibrium models) or based more on empirically observed relationships (as for example in macro-econometric models). Empirical models always give numerical results. However, the modeller and the user of the results should be careful not to take the exact numerical results as being "true", see quotes above by Schumpeter (2006) and Ouliaris (2011).

Let us now turn to the question how the modelling approaches assessed here have been selected. For this review, we select modelling approaches based on the following considerations:

i. Model types must, in principle, be able to project medium- to long-term policymaking pathways and their impacts on economic, social, and environmental variables.
ii. Model types must be able to capture the development of the society and economy at the global level, i.e., include the possibility of international trade relations.
iii. Model types need to fulfil the requirements for macroeconomic models as defined by (Hardt & O'Neill, 2017, p. 200), that is: “(1) describe the total monetary economy in mathematical terms; (2) include different groups of agents or sectors, typically households, firms, and the government; and (3) aggregate the economy at the level of a nation-state or region”.
iv. Model types conceptualise the economic system from a top-down perspective (the 'policy maker' perspective), thus excluding bottom-up approaches such as agent-based modelling (ABM) techniques. As WISE modelling focuses on long term projections and scenario analysis, top-down approaches offer an holistic understanding of trends without delving into

individual details that require large individual data information and/or high computational complexity.

v. Considering the complexity of economic systems at a detailed level is crucial for understanding economic development (Hidalgo & Hausmann, 2009; Ricardo Hausmann et al., 2005). As the sustainability or green transition will impact the structure of global society and economic system, it is important to capture the effects of this structural change at the most detailed level possible. Therefore, model types need to be able to represent the economy at a more detailed level, such as for example separating at least 7 UN SNA main aggregates economic activities, but preferably also interindustry dependencies.

Models using input-output tables, supply-and-use tables, or social accounting matrices easily fulfil requirement v (see Box 1 for a definition of these methods). Many macroeconomic models used for policy simulation and impact assessment use these approaches and it is therefore that we concentrate our review on model types that generally utilize these, or where an integration is straightforward.

Based on the criteria above as well as other recent model reviews, such as Proctor (2023), we have identified five types of models that can be used for macro-economic policy simulation and impact assessment and review these in more detail[3]:

1. General equilibrium models
2. Macro-econometric (input-output) models
3. Stock-flow consistent models
4. Integrated assessment models (IAMs)
5. System dynamics models (SDs)

We note that only the first three are macroeconomic modelling approaches in the narrow sense. The fourth approach, IAMs, can be split into two broad classes: cost-benefit-analysis (CBA) and process-based. CBA IAMs such as DICE or FUND do not have detailed, technical components on how systems and cycles are defined, whereas complex process-based IAMs such as MESSASGE, IMAGE and others have technical components. For our purposes, process-based IAMs satisfy all the

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[3] A list of all models reviewed can be found in the Appendix.

requirements above. We will refer to process-based IAMs simply as IAMs from now on. IAMs usually combine a macroeconomic model (often a CGE or partial equilibrium model) with climate, water, agricultural or other physical models, for assessing different economic drivers of climate change and climate change policies in an integrated way (as noted above, these models usually do not have the feedback of environmental damage on the economy).

System Dynamics (SD) models are not rooted in a particular economic theory, but rather constitute a technique for modelling complex systems of any kind. Nevertheless, the SD approach is most often applied in heterodox economics such as in post-Keynesian economics. It should, however, be noted that SD approaches can also be applied in more mainstream economics settings, for instance using neoclassical assumptions on agents' behaviour.

Box 1 - Definition of statistical terms (OECD, 2008)

The **System of National Accounts (SNA)** consists of a coherent, consistent, and integrated set of macroeconomic accounts, balance sheets and tables based on a set of internationally agreed concepts, definitions, classifications and accounting rules. The System of National Accounts 1993* has been prepared under the joint responsibility of the United Nations, the International Monetary Fund, the Commission of the European Communities, the OECD and the World Bank.

Supply and Use Tables (SUT) are in the form of matrices that record how supplies of different kinds of goods and services originate from domestic industries and imports and how those supplies are allocated between various intermediate and final uses, including exports.

An **Input-Output Table (IOT)** is a means of presenting a detailed analysis of the process of production and the use of goods and services (products) and the income generated in that production; they can be either in the form of (a) supply and use tables or (b) symmetric input-output tables.

A **Social Accounting Matrix (SAM)** is a means of presenting the SNA accounts in a matrix which elaborates the linkages between a supply and use table and institutional accounts. A typical focus of a SAM on the role of people in the economy may be reflected by, among other things, extra breakdowns of the household sector and a disaggregated representation of labour markets (i.e., distinguishing various categories of employed persons).

Note by the authors:

* The definitions above are taken from the OECD's Definition of Statistical Terms. The most recent version of the classification system for the SNA is from 2008 (United Nations et al., 2009). It is currently being substantially revised towards including many more aspects and considering wellbeing and sustainability (UN DESA, 2023). The new SNA guidelines are expected to be published in 2025.

The table below gives an overview on how past SNA revisions expanded to respond to the context of the time and how modellers started using these SNA data and what it meant for modelling. This is not a full historical overview but shows that the development of the SNA and macro-economic models are linked in important ways.

Context	**Edition**	**Data Innovation**	**Modelling innovation**
First global standard	SNA1953		
Empirical macro-models	SNA 1968	SUTs/IOTs introduced	IO, CGE and other macro-economic models
Sustainability & environment and inequality	SNA 1993	Satellite Accounts such as Environmental Accounts and the SAM	Single country environmental IO analysis and inequality using SAM
Globalization	SNA 2008	Global IO databases	Global Value Chains, Environmental Footprints
Beyond-GDP	SNA2025	Wellbeing and sustainability and inequality	To be determined. WISE Horizons project aims to develop a number of WISE models.

Source: (Hoekstra, 2019) *and based on discussions with Rutger Hoekstra 2023*

It is worth noting that the reviews for each model type may vary slightly due to the inherent nature and characteristics of the models themselves. For further information on how and where we gathered information on each model type, please refer to the corresponding section in the Appendix.

3. OVERVIEW OF MACROECONOMIC MODELLING APPROACHES

Policy-relevant macro-economic models are often based on neoclassical economic theory: A body of models that summarize and expand the marginalist conception of the economic system [except for financial market modelling] (Hicks, 1932, 1934; Stigler, George J, 1941). The ideas of the neoclassical school are formalized in the Arrow-Debreu model (Arrow & Debreu, 1954; Debreu, 1959) and applied in partial and general equilibrium models (GEM) which serves as the nucleus of multiple branches of economics. Partial equilibrium models focus on one specific market at a time while assuming the rest of the economy remains unchanged, while general equilibrium models analyse the whole economic system. Given the narrow scope of partial equilibrium models, we exclude them from our review and analysis. The main characteristics and assumptions of this “nucleus” for the dominating economic paradigm are (Colander, 2000):

1. Rooted in Methodological individualism, society is explained by individual behaviour, external factors (society, institutions) do not affect individual behaviour.
2. Focus on allocation of resources.
3. Resources are scarce and must be allocated “efficiently”.
4. Marginal trade-offs.
5. Formalization of marginalist theory and rationality of agents.
6. Perfect foresight / perfect information (which allows the maximization over time)
7. Utility maximization of agents adds to maximum welfare of society, there is no uncertainty.
8. Perfect markets: perfect competition (price takers) and market clearance (prices and quantities adjust)
9. The idea of the existence of a general equilibrium in a decentralized economic system.
10. Say’s Law: Keynes defined it as the idea that Supply creates its own demand (Keynes, 1936), although this definition has been contested as it only contains a part of the propositions of the “Law of Markets” (Baumol, 1999)

The evolution of macroeconomic modelling can be attributed in part to the pioneering work of Jan Tinbergen, the first Nobel laureate in economics. Tinbergen championed the application of mathematical models to comprehend and address economic complexities, laying the groundwork for macroeconomic modelling and policy analysis (Heijdra & Ter Weel, 2019). His notable achievements encompassed the development of structural economic models designed to represent the fundamental relationships underpinning economic systems. Additionally, he was the architect of the first macro-econometric model, a significant milestone that effectively established economic policymaking as a science (Morgan, 2019).

However, over the course of the second half of the 20th century, macroeconomic modelling underwent a notable transformation that led it away from Tinbergen's early approach. These changes were marked by an emphasis on the roots of general equilibrium theory; the last 50 years of economic modelling dealt with relaxing these assumptions (Stiglitz, 2000). These assumptions can be philosophically interrogated, but many are convenient for mathematical tractability. That is, assumptions such as a general equilibrium makes the model(s) mathematically solvable. This way of modelling economies and their application for evaluating policy options became dominant at the end of the 1970s, mainly because of what is known as the Lucas critique; introduced by Robert Lucas, it challenged the Keynesian approach of macroeconomic modelling and policy evaluation, which was dominant at the time. The Lucas critique emerged during a specific period characterized by significant macroeconomic events such as the oil price shocks and the breakdown of the Bretton Woods system. It highlights the limitations of relying on statistical relationships and historical data to make policy decisions, particularly in the context of changing economic conditions. Lucas argued that economic agents are forward-looking and will adjust their behaviour in response to policy changes. This forward-looking behaviour creates a feedback mechanism that can invalidate the estimated relationships between policy variables and economic outcomes (De Vroey, 2010).

This new “macroeconomic thinking and modelling” continued in the 1980s as "New Keynesian" economists incorporated elements of the New Classical and Real Business Cycle (RBC) frameworks into their models. These models aimed to capture market imperfections and rigidities by introducing features like monopolistic competition and various forms of rigidity, all while maintaining representative-agent and rational-expectations micro foundations.

A major development in macroeconomic theory was the emergence of Dynamic Stochastic General Equilibrium (DSGE) models, which formed the basis of the New Neoclassical Synthesis. These models combined the core principles of RBC theory with additional elements such as monopolistic competition, nominal imperfections, and monetary policy rules to account for various types of "imperfections," "frictions," and "inertias." However, DSGE models faced criticism for their excessive reliance on ad hoc adjustments and their assumptions regarding the rationality of representative agents. The assumption that agents were highly sophisticated in making future allocation decisions but constrained by sticky prices and backward-looking behaviour in consumption choices appeared disconnected from the realities of the economy (Dosi & Roventini, 2019).

In response to the limitations of general equilibrium-based models, alternative macroeconomic approaches gained prominence, particularly following the 2008 financial crisis. Among these approaches, three paradigms gained relevance, each offering a distinct perspective on understanding and modelling economic systems. The first one, complexity economics, views the economy as a complex, adaptative, and dynamic system recognizing the diversity of agents' behaviours, adaptability, non-linearities, and the emergence of patterns as fundamental features (Arthur, 2021). The second approach, Post-Keynesian, economics emphasizes the role of uncertainty, financial instability, and effective demand in shaping economic outcomes. It challenges the assumptions of rational expectations and market efficiency, advocating for the importance of government intervention and addressing issues like income distribution and financial fragility. Similarly, the third approach, Kaleckian economic models focus on the relationship between income distribution, investment, and economic growth, highlighting the role of power relations and income shares in shaping macroeconomic dynamics. These alternative models gained traction because they provided more nuanced explanations of economic complexity and its interaction with the financial system. They considered the inherent uncertainty, non-equilibrium dynamics, and institutional factors that play a crucial role in shaping economic outcomes. By recognizing the limitations of general equilibrium-based models and embracing these alternative approaches, economists sought to develop more comprehensive frameworks that could capture the intricacies of real-world economic phenomena and inform more effective policy responses.

Table 2 below summarizes the main theoretical characteristics of the three macroeconomic model types that we review in more detail below: general equilibrium models, specifically computable generable equilibrium (CGE) models, macro-econometric (input-output) models and stock-flow-consistent (SFC) models. IAMs and SD models are not macroeconomic models per se as discussed before and are not considered in this table as they could be combined with any of the underlying economic theories.

Table 2: Summary of characteristics of macro-economic modelling approaches (adapted from Table 2 in Mercure et al., (2019) & Pollitt & Mercure.,(2018))

	CGE approach	Macro-econometric approach	SFC approach
General underlying economic theory	Neoclassic	Post-Keynesian	Post-Keynesian
Model type	Optimisation	Simulation	Simulation
Degree of uncertainty	Perfect knowledge	Fundamental uncertainty	Fundamental uncertainty
Human behaviour	Optimising (RARE representative agent with rational expectations)	Derived from past data (rather SAFE than RARE)	Individuals are SAFE (sectoral average with flexible expectations), and not RARE
Price adjustment	Fully flexible	Sticky	Sticky
Money supply	Fixed in real terms	Endogenous (or exogenous, but flexible)	Endogenous (or exogenous, but flexible)
Output determined by	Supply-side factors	Aggregate demand	Aggregate demand
Impacts of regulation	Usually negative	Either positive or negative	Either positive or negative

3.1 General Equilibrium Models (GEMs)

3.1.1 Introduction and historical account

General equilibrium models, both computable general equilibrium (CGE) models and dynamic stochastic general equilibrium (DSGE) models have been widely used in policy simulation and analysis for the past century. **Computable general equilibrium**

(CGE) models are usually based on social accounting matrices and use nested constant-elasticity-of-substitution production functions. CGE models exist for almost all countries in the world. Among the first global CGE models used for policy analysis are the GTAP model (Hertel, 1997) and the MONASH model (Dixon & Rimmer, 2001). The European Commission uses GEM-E3 (Capros et al., 2013) and RHOMOLO (Lecca et al., 2018) models, among others.

Dynamic stochastic general equilibrium (DSGE) models combine econometric modelling with neoclassical economic theory. Many central banks of financial institutions around the world rely on these models for forecasting and business cycle analysis as monetary policy is explicitly modelled. Among the impact assessment models used by the European Commission, there are two multi-country DSGE models: IO-DSGEM (European Commission. Directorate General for Communications Networks, Content and Technology. et al., 2021) and QUEST (Ratto et al., 2009). However, IO-DSGM is particularly tailored to one policy question and cannot be generally used for macroeconomic or WISE policies. While QUEST has been developed by DG ECFIN and is mostly applied to fiscal and monetary policies, it has also been used for the analysis of WISE-relevant issues such as CO2 emissions and innovation in green sectors (Conte et al., 2010), energy sectors (Varga et al., 2021), and income distribution (Roeger et al., 2019).

Given the general focus of DSGE models on monetary and fiscal policy, we will concentrate on CGE models for the remainder of this section. Nonetheless, we will discuss the relevant aspects of the QUEST model. The OECD utilizes three CGE model variants: ENV-LINKAGES (Château et al., 2014), ENV-Growth (OECD, 2013) and METRO-Trade (OECD, 2023), with emphasis on detailed environmental assessments, economic growth projects, and trade analysis, respectively. A former version of the ENV-Linkages model, for example was used to assess economic impacts of the Shared Socioeconomic Pathways for climate change (Dellink et al., 2017).

Box 2 – Computable General Equilbrium (CGE) Models

Computable general equilibrium (CGE) models have been most extensively used for economic and policy analysis among the different model types reviewed here. Their complexity ranges from less than ten to several hundred equations. In their simplest and purest form, they follow the neoclassical Arrow-Debreu model as explained above, calibrated to fit the empirical data for the country for one year, usually the most recent year for which System of National Account data are available. More comprehensive models utilize detailed social accounting matrices or supply-and-use tables. The natural environment, e.g. energy or other raw materials, can be included as production inputs similar to labour and capital. Constant-elasticity-of-substitution functions are the most common form to represent production in CGE models. The objective is to find the optimal allocation of resources available in the economy

Box 3 – Stochastic Dynamic General Equilibrium (DSGE) Models

Dynamic stochastic general equilibrium models combine econometric modelling with neoclassical economic theory. The new generation DSGE is closer to New-Keynesian rather than neoclassical economic theory. The main difference is that these allow for market inefficiencies such as imperfect competition and sticky prices. Uncertainty is usually quantified with the help of Bayesian estimation. However, DSGE models have a rigorous foundation in microeconomics regarding utility and profit optimization. They are most often used by central banks or other financial institutions for forecasting and assessing effects of fiscal and monetary policy on the economy. As they are based on time series data, data requirements for DSGE models are significantly higher than for CGE models, which are usually calibrated for one year. As with all economic models, model formulations may vary from a few basic equations that represent the economy at an aggregated level, to several hundreds of equations specifying many details and relations between economic agents.

3.1.2 Theoretical substance and methodology, strengths, and weaknesses

CGE models in their purest form use the standard Arrow-Debreu framework obeying neoclassical assumptions, as described above. That is, no uncertainty, perfect information and perfect markets, rational agents with maximizing behaviour, there exists an equilibrium, and externalities are generally discarded. These models are characterized by the following key aspects (Burfisher, 2016):

Equilibrium: CGE models seek to find an equilibrium point where all economic agents are satisfied with their production and consumption levels, employment, savings, and investments. Producers optimize their input and output levels to maximize efficiency, while consumers maximize their utility by choosing the most satisfying bundle of goods within their budget constraints.

Macroeconomic Constraints: CGE models incorporate macroeconomic constraints, such as ensuring that aggregate supply equals aggregate demand, in a production function that generally only considers labour and capital as factor, which are fully utilised and therefore there is no unemployment or capital misallocation, and national savings equal investment spending. These constraints help maintain consistency and balance within the model.

Static Nature: Many CGE models are static, single-period models that provide a before-and-after comparison of the economy when subjected to shocks or policy changes. They analyse the redistribution of resources and the winners and losers resulting from these changes. However, static models do not capture the adjustment path or the potential dislocation and unemployment that may occur during the transition.

Fixed Factor Supplies: Standard CGE models assume fixed supplies of factors of production, such as labour and capital, unless explicitly changed as part of the model experiment. While they allow for medium-run adjustments in employment and wages, they do not capture long-run changes in factor productivity, labour force size, or capital accumulation.

In policymaking, CGE models are used to assess the impacts of various policy interventions, such as tax reforms, trade liberalization, or changes in regulations. They provide insights into the potential effects on production, consumption, employment, income distribution, and overall economic welfare. However, it's important to note that CGE models have limitations, including:

Simplified Assumptions: CGE models make simplifying assumptions about economic behaviour and interactions. Being the representative agent is one key weakness as this assumption does not fully capture the complexities and dynamics of real-world economies, leading to potential limitations in their predictive power.

Lack of Adjustment Path: Static CGE models do not capture the adjustment process or the time it takes for the economy to reach a new equilibrium. They may overlook the potential costs and dislocations associated with the transition, which can have important societal implications.

Data Requirements: CGE models require extensive data on economic parameters, input-output relationships, and behavioural responses. Obtaining and updating such data can be challenging and may introduce uncertainties in the model results.

Sensitivity to Assumptions: CGE model outcomes can be sensitive to the assumptions made regarding the structure of the model, parameter values, and behavioural responses. Sensitivity analysis is crucial to assess the robustness of the results and the uncertainty associated with different assumptions.

Different implementations of these assumptions exist, and some relax one or two of them. One example for this is the GEM-E3 model which relaxes the constraint on the perfect labour market and allows for unemployment. These assumptions and restrictions are significant impediments as the world faces environmental crises that drive large-scale non-equilibrium adjustments.

3.1.3 WISE representation in individual models

The extension of these models to include wellbeing, inclusion, and sustainability representations varies widely. While almost all models have one or more employment indicators (which can be related to wellbeing), wellbeing/inclusion indicators such as distribution of income and wealth across different household types or poverty rates are present in only a subset of the models (GEM-E3, RHOMOLO, EU-EMS, EUROMOD, MAGNET, GTAP-CGE, MONASH). According to MIDAS[4] , only one model, EUROMOD, specifies differences in impacts on women and men. For models based on GTAP (e.g. GTAP-CGE, MONASH, ENV-LINKAGES, METRO-Trade), employment data disaggregated according to gender and skill level by industry exists[5], so that effects on jobs typically held by high-, medium-, or low-skilled women or men can be assessed. As models usually cover a wide range of countries, global inequalities (inclusion), regarding the different impact areas of

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[4] https://web.jrc.ec.europa.eu/policy-model-inventory/explore/impact-types/fundamental-rights/

[5] https://datacatalog.worldbank.org/search/dataset/0038490

wellbeing can be assessed. However, subjective wellbeing measures[6] such as life satisfaction, happiness, work-life-balance, or related aspects such as time use are not part of any model. Nevertheless, research on the QUEST model clearly points to that a further incorporation of social and environmental variables is technically possible (Diefenbacher et al., 2020; Gran et al., 2019).

Regarding sustainability, the long-term assurance of wellbeing, the representation of the natural environment is important. Here, the most common measures available in the models are emissions and energy use (GEM-E3, QUEST, MAGNET, the OECD's ENV model and its variants). Only MAGNET with a more explicit modelling of changes in land-use and waste production, treatment, disposal, and recycling has additional environmental impact assessment possibilities. The use of data on different biotic and abiotic materials was not mentioned for any model. The limited representation of these other environmental aspects (land use, waste, materials) can be explained by the difficulty of linking these to the aggregated economic flows that are represented in the models (Rosendahl et al., 2021). More details for each model, including which SDGs can be analysed are collected in Table 3 in the Appendix.

3.2 Macro-econometric and Input-Output models

3.2.1 Introduction and historical account

Macro-econometric and input-output models have a long tradition of being used for policy simulation and impact analysis. **Macro-econometric models** represent the entire economy by using equations that combine historical statistics data with economic theory, these models can contain equations ranging from less than ten to several thousand equations. The most well-known global macro-econometric model emerged from project LINK, that linked existing macro-econometric models for individual countries using trade accounts (Klein, 1976). **Input-output analysis** in its most simple static form, consists of one equation in matrix form (the total number of equations depends on the disaggregation of industries in the underlying input-output table), and is traditionally used to assess impacts of changing final demand on production and related measures by industry, such as value added, employment or emissions (Miller & Blair, 2009). Extending macro-econometric models with data

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[6] See (Jansen et al., 2023)

from input-output tables adds industry resolution to the model, and with that allows for different growth paths of both product demand and industry activity levels. In addition, value chains are disaggregated, and inter-industry linkages become visible.

For the United Nation's study "The Future of the World Economy", Wassily Leontief et al. (1977) developed the first **global input-output model**. It aggregated the world into 15 regions and modelled the economy as well as it's interactions with the environment through resource use and pollution with 175 equations per region. The policy scenario analyses include topics such as global food production, inequality, and resource availability for the next 25 years (1980, 1990, and 2000) and served as a basis for the United Nation's General Assembly's work on the International Development Strategy. One of the conclusions was that it is possible to improve livelihood around the world without compromising the environment, a finding that is very much in line with what the WISE concept envisions, while the main obstacles for reaching this are of political, social, and institutional nature. Duchin's work in the 1980's and 1990's, led to a generalization of Leontief's World Model to a World Trade Model (Duchin, 2005), specifically a further endogenization of international trade through a modelling of prices and comparative advantages. Here, the work on modelling technology choices in input-output models (Duchin & Lange, 1995; Wassily Leontief, 1986) proves essential. Also, because this is a requirement for a more detailed modelling of interlinkages with the physical environment.

Box 4 – Macro-econometric models

The textbook example of a macro-econometric model consists of only three equations, two stochastic equations, that can be estimated econometrically, and one identity: 1) the consumption function, where aggregate consumption depends on income (GDP) and, possibly, previous consumption, 2) the investment equation, where investment depends on the interest rate and, possibly, on the difference between this year's and last year's production (GDP), and 3) the demand-side GDP identity, where GDP is equal to the sum of consumption, investment, and government spending. When additionally including wages (stochastic), profits and capital stock (identities), the Klein Model I, it becomes a slightly more encompassing model already (Klein, 1950), still disregarding international trade, i.e. assuming closed economies. But it is possible to include trade also for individual countries, or even link existing macro-econometric models for individual countries using trade accounts as done in Project LINK (Klein, 1976). Many governments (mostly Central Banks and Ministries of Finance) as well as international organizations (e.g. World Bank, OECD or UN) are using macro-econometric models. However, their use is primarily forecasting or long-term projections of economic growth and not impact analysis of policy simulations (Fontagné et al., 2022; Fouré et al., 2013).

Box 5 – Static Input-Output models

Input-output analysis is based on input-output or supply-and-use tables and in its basic form is basically an accounting system, that links final demand to production and different factors of production. Demand-driven impact assessment can be done using a single equation in matrix form. Assuming that production technologies remain constant, changes in final demand by households or government, in investments or exports have direct linear impacts on the industry producing the final goods as well as indirect impacts on those industries producing intermediate goods along the value chain for the final goods. When endogenizing households, induced effects through impacts of changes in household income on final demand can be estimated as well. This type of analysis can be done for single countries or many countries simultaneously, if inter-country input-output tables (often also referred to as multi-regional input-output tables) are used. Environmental as well as social factors can be estimated if those can be linked to industrial production. The most prominent example is carbon dioxide emissions related to production, but also other GHG emissions or employment are often analysed. Some of the global input-output databases have a large range of environmental and socio-economic stressors ranging from GHG emissions, local pollutants, material and land use to different employment categories (skills, age and gender).

The **global macro-econometric input-output models**, E3ME and GINFORS, that are being used by the European Commission nowadays, were first developed at the end of the 1990s and are continuously being updated (Barker, 1999; C. Lutz et al., 2010; Lehr & Lutz, 2019; Mercure et al., 2018; Meyer & Lutz, 2002). Both models can also be classified as energy-economy-environment (E3 models), as they have a representation of the energy sector as well as of some other environmental aspects (e.g. emissions) in physical terms. The European Commission's Joint Research Centre established its own macro-econometrics input-output model for Europe, FIDELIO, about ten to fifteen years ago (European Commission. Joint Research Centre. & WIFO., 2017; Kratena et al., 2013). The most recent version, FIDELIO 3, is from 2019 (European Commission. Joint Research Centre. et al., 2019). There are macro-econometric input-output models for many individual countries, e.g. Germany (Becker et al., 2022), India (Cambridge Econometrics, 2020), countries of members of the INFORM group (Inforum, 2022), or countries for which a Green Jobs Assessment model[7] has been developed (Arsenio et al., 2022; Simas et al., 2022; Wiebe, Andersen, et al., 2021; Wiebe, Simas, et al., 2021).

An important feature of the dynamic input-output models is that even though they are demand-driven, total final demand and its structure are endogenous to the system. For example, household consumption (in total and its structure) generally depends on income, often approximated by total value added, and the relative price levels of goods and services. Here, the biggest difference to CGE models is, that price adjustments do not lead to an immediate equalization of supply and demand.

There also exist a few studies using models based on multi-regional input-output tables for "what-if" scenario analysis, some are dynamic forward looking (Beaufils & Wenz, 2022; Duchin et al., 2016; Duchin & Levine, 2016; Montt et al., 2018; Wang et al., 2021; Wiebe et al., 2018, 2019), while most rely on static input-output analysis, e.g. (Černý et al., 2022; Saget et al., 2020; Vita et al., 2019).

3.2.2 Theoretical substance and methodology, strengths, and weaknesses

The early dynamic input-output models Leontief and Duchin, as well as macro-econometric input-output models (MEIO) are used for the same type of impact and policy simulation analysis as CGE models. The European Commission for example has used MEIO and CGE models side-by-side on a number of occasions: E3ME with GEM-E3 and QUEST as well as GINFORS with EUROMOD, GEM-E3 and QUEST (*Explore MIDAS by Model Combinations*, 2023)[8].

In contrast to General Equilibrium Models (GEMs), that are neoclassical in their theoretical approach, macro-econometric input-output models as well as stock-flow-consistent models (see next section) are flexible and can represent alternative economic frameworks, typically of the post-Keynesian type (Pollitt, 2017). Following

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[7] For a full description of models and analysis see https://www.ilo.org/global/topics/green-jobs/publications/assessments/lang--en/index.htm

[8] Unfortunately, the JRC's own model, FIDELIO, is not part of this overview.

(Keynes, 1921), the most important assumption in macro-econometric input-output models is that there is fundamental uncertainty, and, thus, no perfect information (rather myopic information). This in turn implies that economic agents do not optimize their behaviour, neither in the current nor in future years. Markets do not necessarily clear, and prices are sticky and do not adjust perfectly. (Pollitt et al., 2019) In contrast to Keynes, however, behavioural parameters are estimated econometrically, and thus, these models are subject to the Lucas critique (Lucas, 1976), which questions the applicability of using past behaviour to project future behaviour. However, all models mentioned above are flexible enough to allow to override the estimated parameters, if other - possibly better - qualitative, or quantitative information is available. In addition, all models can easily be run with different specifications for sensitivity analysis.

The models are demand driven and supply (production) adjusts accordingly. It is assumed that supply is smaller or equal to potential supply, so that no constraints on production exist in the short run. As the model is used for policy simulation, it is rather important to let production vary freely and use the results for policy recommendations into which industries need to invest into production capital and what kind of employees (skills and occupations) are necessary to satisfy future demand (Simas et al., 2022; Wiebe, Andersen, et al., 2021; Wiebe, Simas, et al., 2021). But, in this case, the modeler needs to ensure that the results of the policy simulation are still realistic, to avoid credibility problems (Pollitt & Mercure, 2018). It is, however, possible to include factor constraints, and some models do (Pollitt, 2017). An alternative approach to factor constraints is to introduce feedback loops between the environment, but also society and the economy using a system dynamics approach (for more information on system dynamics, see Section 3.4 below).

Even though the models are demand driven, final demand is (at least partially) endogenous to the model, either through econometric equations linking final demand to contemporaneous and/or lagged income from production (GDP), or through using identities from the System of National Accounts, where disposable income is calculated from wage income, capital income, taxes, and transfers (Becker et al., 2022; Capros et al., 2013). The financial sector is represented in different levels of detail, but more implicitly in the general assumptions underlying the model than an actual explicit modelling as done in stock-flow-consistent models. The main difference of macro-econometric input-output compared to CGE models is that any increase in investments can be financed by additional (possibly intergenerational) debt. That means that investments in new technologies, e.g. renewable energy, do not necessarily come at the expense of other investments, but are additional inflows of money into the economy. As markets are not assumed to be in equilibrium, there are both production capacities and workers available for an expansion of economic activity. These additional investments can therefore have a positive effect on the economy. For more information on the modelling of financial markets in different types of macroeconomic models the reader is referred to (Pollitt & Mercure, 2018).

In the context of the WISE accounting framework, models based on multi-regional or inter-country input-output (MRIO / ICIO) tables have a clear advantage: they represent all relations between final demand and final and intermediate goods production around the world as well as externalities of production, providing an accounting system for the entire world that is in line with official SNA data. The two major disadvantages of simple "what-if" IO analyses based on these data are: 1) a very simplistic representation of dynamics compared to the macro-econometric IO models that are already used by the EC, and 2) that many datapoints are not actually known but constructed by various methodologies. This is especially true for trade by importing industry (trade data is generally available by exporting industry/product as well as importing country) and environmental and social extensions. Often, those are only available from official sources at a very aggregated industry level and for very few years. Different estimation methods such as simple shares or linear interpolation or extrapolation are used to fill the gaps. E3ME, GINFORS, and FIDELIO in contrast are based on data that are available from official statistical offices and use economic modelling to link the data. For example, rather than splitting the electricity industry in the input-output table and estimating by energy extensions by detailed industry, they link the economic data to an energy module based on energy balance data in physical terms in the available industry classification, which then uses information on changing prices and energy demand to change the monetary coefficients in the economic part of the model.

3.2.3 WISE representation

The environmental dimension, which is important to ensure that wellbeing is not only ensured for the present, but also for future generations, is represented very well in the macro-econometric input-output (MEIO) models E3ME, FIDELIO, and GINFORS-E regarding energy use and GHG emissions. The models use differentiated prices and include alternative low-carbon energy technologies, so that changes in behaviour regarding energy use can be modelled endogenously. Regarding other environmental aspects such as material use, waste, or land use the MEIO models face the same difficulties as GEMs (Rosendahl et al., 2021) of linking these to the aggregated economic flows that are represented in the models.

While the number of socio-economic and environmental extensions to the inter-country input-output tables by the OECD (OECD-ICIO (OECD, 2021b, 2021a, 2022)) and the European Commission (FIGARO) is still limited, some of the global MRIO databases (e.g. Eora (Lenzen et al., 2012, 2013), EXIOBASE (Stadler et al., 2018), Gloria (Lenzen et al., 2022)) have many environmental extensions in addition to emissions, such as energy, materials, water, land use, and others at detailed industry and country level. However, for the use of these indicators in this type of static input-output analysis (that is for example used to calculate demand-based environmental footprints) it is necessary to link each environmental impact to specific production at the industry level. For some indicators this is easier (e.g. GHG emissions) than for others (e.g. land use). For materials, the difficulty mostly lays in the level of aggregation of material extraction and processing industries that is available in official economic data. The MRIO databases that provide this level of detail are constructed using a variety of estimation and interpolation methods, leading to very different estimates for the same industries/countries across the databases. The users of these data should therefore be aware that large uncertainties exist. In addition, the argumentation of (Rosendahl et al., 2021) of the difficulties of linking certain environmental impacts to economic flows is equally applicable here. Socio-economic indicators such as employment by gender and skill level are generally available as time series in these databases, however the actual data availability from national statistical offices is often restricted to individual years for which household surveys were conducted.

Wellbeing regarding health or educational issues are only indirectly considered as population and demographic development are exogenous drivers of economic development, through its impact on consumption and available labour force (working-age population). They also have a detailed modelling of economic growth and employment including the possibility to analyse impact on jobs in specific sectors, professions, regions, or countries, as well as indirect effects on employment levels. They endogenously model wages, labour costs and prices using different wage setting mechanisms. These models, that use the System of National Accounts (SNA) to link wage and capital income to disposable income and income, face the difficulty of the aggregation of household types in the SNA data. Here, the use of more detailed data as e.g. available in social accounting matrices (SAMs) that are often used as the base for national CGE models, would be useful. But the global nature of the models requires to use data that is available at the same level of aggregation for most countries. Therefore, there are limitations in the current representation of income and consumption by household group, as e.g. has been done for Europe (Cazcarro et al., 2022; Kim et al., 2015). But, just to emphasise, this is not due to theoretical/philosophical principles of the models, it is only due to data availability issues. Here, these models can apply the same techniques as the GEMs, to go from income generation by economic activity to income and consumption by household type. FIDELIO is the model with most advanced consumption modelling, touching on the inclusion dimension at the subnational level by using data on different household types. For the other models, it is only possible to assess inclusion on the global level, by assessing inequalities across countries.

As with General Equilibrium Models (GEMs), none of the models goes deeply into the inequalities across different population group (exception: employment by gender and skill level) and subjective wellbeing measures[9] such as life satisfaction, happiness, work-life-balance, or related aspects such as time use are not represented in any of the models reviewed here. More information on each model can be found in Table 4 in the Appendix. Generally, as GEMs and MEIOs are based on the same economic data, all indicators that are used in one model type can also be incorporated into models belonging to the other model type. In addition, the environmental and socio-economic extensions from the existing MRIO databases can be linked to any of the more dynamic macro-economic models.

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[9] See (Jansen et al., 2023)

3.3 Stock-flow consistent models

3.3.1 Introduction & Historical Account

Stock Flow Consistent (SFC) models are a type of macroeconomic model which seeks to integrate all stocks and flows of an economy into an accounting framework. The model's beginnings can be traced back to 1949, to the work of Morris A. Copeland, who along with the other modellers of the time, was seeking to track the flow of funds, the flow of money. The model itself belongs to the post-Keynesian tradition, and has been developed gradually throughout the years, its biggest leaps being facilitated by the likes of James Tobin in the 1980's, and especially Wynne Godley in the late 1990's, and once more alongside Marc Lavoie in his seminal work in 2007 (Caverzasi & Godin, 2013; Godley & Lavoie, 2007).

This type of models reached its inflection point in the aftermath of the 08' crisis, as it was credited with being able to predict the economic downturn that all the General Equilibrium (GEM) models had missed. An ever-evolving model, Caverzasi and Godin convincingly argue and illustrate how different assets and sectors promptly became integral to SFC work after 2008 (Caverzasi & Godin, 2013): bonds, deposits, equities, loans, and money were the assets that peaked during the aftermath, whereas banks and Nonbank Financial Institutions (NFBI), capitalists, central bank, firms, government, and households all similarly either first appeared in the analysis, or peaked in the early 2010's.

SFC models lend themselves nicely to the study of ecological economics, e.g. Jackson et al. (2016) or Jackson & Victor (2015). Additionally, and perhaps critically, they are inherently malleable, which explains the many variations, whereby Agent-Based Models (ABM), System Dynamics (SD) models, as well as Input-Output (IO) models are often combined or integrated into SFC models, as to compliment standard SFC modelling. The first of its kind and 'massive' SFC-ABM model, EURACE (Agent-based Computational Economics), was constructed in 2008 (now Eurace@Unibi) (Deissenberg et al., 2008), but it is unclear how or whether it has been used beyond academia. In contrast to CGEs, which have a long history of being applied to policy analysis, SFCs in all their forms are indeed mostly constrained to the world of academia. The exception here is the Bank of England (BoE), which has developed its own SFC model (Haldane & Turrell, 2018).

3.3.2 Theoretical Substance & Methodology

SFC models are characterised by their tracking of mainly financial flows and stocks. Their primary advantage is their ability to capture the real and financial sides of the economy. They differ from CGEs and other models in that they are distinctly post-Keynesian, as they fundamentally reject most assumptions in neoclassical economics (Godley & Lavoie, 2007).

More specifically, SFC models adhere to certain assumptions, such as that individuals are SAFE (sectoral average with flexible expectations), and not RARE (representative agent with rational expectations). Similarly, banks are thought to not lend reserves, but rather make loans by simultaneously expanding both sides of their balance sheets, creating an asset of the bank (a loan) and a liability of the bank (a deposit). Banks create credit ex nihilo by creating a liability with a corresponding asset. Money is also seen as possessing a hierarchical nature, whereby currency is a promise to pay gold or settle taxes; deposits are promises to pay currency; securities are promises to pay deposits. Furthermore, unlike other models, SFCs do not assume Say's law or that the economy is in full employment. This is in stark contrast to neoclassical models that assume and then (re-)produce supply-side equilibria, where demand plays a minute and temporal role. But perhaps most importantly, integral to SFC modelling and inseparable from any conclusion and output, is the idea that aggregate demand drives the economy, in stark contrast to CGE models, where supply is the main variable, and the financial sector plays a much smaller role.

Furthermore, Nikiforos & Zezza (2018) identify four main aspects of SFC models (Nikiforos & Zezza, 2018):

1) **Flow consistency**: SFC models remove 'black holes' from the system, as every flow starts from, and must therefore end up, somewhere. One may thus track the flow of money, e.g., in the form of consumption from households to firms, from firms to the government in the form of taxes, from the government to the banks in the form of capital, etc.
2) **Stock consistency**: financial liabilities and assets are 'two sides of the same coin'. Loans are assets for the bank but liabilities for the holder, and in a similar vein, wages and taxes are 'promises to pay' which may be seen as liabilities for firms, but assets for the government and citizens.

3) **Stock-flow consistency**: flows are accompanied by changes in stocks, and as such, assets must therefore increase when net saving is positive, and vice versa.
4) **Quadruple entry**: from the above, it follows that any given transaction necessitates a quadruple entry in accounting: *'For example, when a household purchases a product from a firm, the accounting registers an increase in the revenues of the firm and the expenditure of the household, and at the same time a decrease in at least one asset (or increase in a liability) of the household and correspondingly an increase in at least one asset of the firm'.*

The primary methodological component of SFC models is the emergent balance-sheet and the transactions-flow matrices. These tables typically include all monetary flows[10] and stocks in the economy, whereby each row and column amount to 0, upon the addition and subtraction of liabilities and assets. Assets are represented with a plus sign (+) in front of the variable, liabilities are shown with a minus sign (-), whilst the tables are usually also accompanied by a visualisation of the economy and its workings. Further simulations and changes to the economy, such as consumption shocks or changes in investment behaviour may not impact the universal rule that is the elimination of 'black holes'. Another important aspect is the amount of assets (or liabilities for that matter) that are included in the model. A more comprehensive model may in some instances be more accurate, but one must sacrifice intuition to achieve such goals.

A sacrifice of complexity can also usually be found in modelling behaviour of actors in the economy. Nikiforos and Zezza speak of 5 categories of behavioural assumptions: 1) the choice of a consumption function, an investment function and a government expenditure function, which are usually common across different studies, 2) how '*agents finance their expenditure and possible net borrowing position*', which is modelled linearly, especially for households, as it is a function of their income, 3) the allocation of household wealth, 4) productivity growth, wages and inflation, whereby the first of the three is either constant or absent, whereas inflation and wages are results of conflict between firms and employees, and finally 5) assumptions about the financial system, and more specifically, how monetary policy is conducted and the role of central banks (Nikiforos & Zezza, 2018).

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[10] These flows can be expanded to non-monetary flows such as biophysical and material flows.

3.3.3 Strengths & Weaknesses

SFC models have evolved as a counterweight to the established macroeconomic modelling status quo and have thus been informed by the weaknesses and shortcomings of GEM (CGE or DSGE) models. Theoretically, their primary merit lies in their ability to track all real and financial flows in the economy, an attribute that was so integral to predicting both the seemingly invisible 08' financial crisis, as well as the long-term economic stability that came with the institutional structure of the Euro. What also helps SFC models' relevance in policymaking is the fact that their structure and logic is perfectly compatible and complementary to that of the System of National Accounts (SNA). For example, In Xing et al. (2022), the authors showcase the strengths of SFC models in policymaking, by incorporating carbon taxes for firms into the models, and highlighting how those could incentivise green investments and facilitate the low-carbon transition.

This further illustrates the point that SFC models are quite flexible and able to integrate diverse elements of the economy to provide policy implications. What once was a weakness, is perhaps now a core strength of SFC models. Indeed, ecological economists had long criticized approaches such as SFC models and IO models on the grounds that they focus on the circular flow of exchange value (i.e., money), rather than on the physical throughput of natural resources from which all goods and services are ultimately derived. Nowadays, SFCs are being used increasingly in ecological economics, as it has so seamlessly integrated both IO and ABM models, as well as expanded to account for the environment as a system and as a large set of assets and liabilities (stocks) which is integral to production and the functioning of the economy.

Indeed, the fusion with other types of models and ideas, and the general adaptability of SFC models allows for constant readjustment and betterment of an already successful model. ABMs more specifically offer SFC models an opportunity for more heterogeneity, which the original models lack in their sectoral oversimplification. As Berg et. al note, the same is true of IO models, which can bolster the fields of '*complexity economics, ecological macroeconomics, and ecological econophysics*' (Berg et al., 2015), while they can conjure up interdisciplinary alliances of researchers to tackle large-scale problems like climate change.

But these models also have some drawbacks, notably that, for simplicity sakes, a lot of them are closed economies. It should be noted that Godley and Lavoie did provide ways of having both an open economy, as well as external money (Godley & Lavoie, 2007) which has been extended in other models such as the LOWGROW model for Canada (Jackson & Victor, 2020) or a 2 region (north-south) global SFC model (Leoni et al., 2023). For example, in Nikiforos and Zezza's model, a natural conclusion is that government debt is in fact only a liability for the government and taxpayers, but an asset for households, meaning that future generations will in fact earn proceeds – should the debt not be held by foreign hands (Nikiforos & Zezza, 2018). Similarly, other models assume a zero-sum trade balance. There are also internal shortcomings, such as the pervasive homogeneity found in the aggregation of sectors, which disallows intra-sectoral comparisons.

The Bank of England, in a 2017 working paper, raises both valid, as well as perhaps slightly redundant points in their assessment of SFC models (Haldane & Turrell, 2018). The authors correctly identify a lot of the positive aspects, such as the overlap with the national accounts framework, the disaggregation by sector, the role played by money, credit and the financial system, and the realistic behavioural assumptions, but also criticise the practice for being 'not well-established', and for not adhering to standard economic theory. Perhaps the most relevant of their critiques is the need for large data volumes, but also the fact that the models suffer from the Lucas critique.

3.3.4 WISE representation

To the extent that macroeconomic modelling is even concerned with societal goals and qualitative assessments of one's life, it is understandable that Wellbeing is not part of the SFC modelling literature. This dimension is absent, mostly because the model does not lend itself to integrating and measuring such elements. Though, to our knowledge, there haven't been any SFC models explicitly tackling the issue of wellbeing, it is conceivable that one might find therein policy implications based on different scenarios. For example, in Jacques et. al. (2023), the authors model future population projections, '*as a function of fertility and mortality rates, the former being driven by education level and access to contraception*'.[8] In contrast, there are various ways in which the SFC literature has attempted to address the issue of inclusion (Goda et al., 2017). Godin (2013) may not follow the steps of other ecological economists in integrating the environment into his model, but he is able to simulate how a 'green job Employer of Last Resort' is effectively able to set a target of full employment, alleviate unemployment and poverty, as well as reduce emissions by providing green jobs. Because SFCs track the flow of funds, there is ample potential for measuring the distributional effects of policies through simulations, and researchers have already explored such approaches, e.g., Caiani et al. (2019), Detzer (2018), or Sarkhosh-Sara et al. (2022).

SFC models have gained popularity in ecological economics because of the seamless structure of the balance-sheet and transactions-flow matrices, which allows for physical stock to be assimilated into the accounting framework, has allowed researchers to experiment with the approach as they see fit. Normally, SFC models' output always comes in the form of a balance-sheet and a transaction-flow matrix, but ecological SFC models, which incorporate the laws of thermodynamics, might translate into physical-flow matrices for example, e.g., as seen in (Dafermos et al., 2017).

To incorporate the environment in SFC models, there are two possibilities: 1) considering the physical stocks and flows of resources, such as energy, water, and materials and 2) including environmental constraints in the model, for example in simulations. In achieving the former, one must include environmental stocks and flows as assets and liabilities in the balance-sheet and transactions-flow matrices. For instance, the natural resources extracted and used in the production process can be classified as natural resource assets, and waste emissions can be considered as environmental liabilities. This enables the modelling of the environmental impacts of economic activities and the evaluation of policies aimed at reducing their negative effects. One of the benchmark models that employs this kind of approach is (Berg et al., 2015), a SFCIO model that considers energy and physical stock, as well as the emergent heat as a by-product of the production process. In their demand-driven ecological collapse SFC model, Barth and Richters also include heat (entropy) and biomass in their physical transaction flow-service matrix, thus calculating physical stock as assets and liabilities in the accounting framework (Decker et al., 2019).

The latter is achieved by including environmental constraints in the model, which can be used to simulate the impact of resource depletion or environmental degradation on the economy. For example, if a particular resource becomes scarce, its price will increase, which will impact the economy's production and consumption patterns. This approach can also be used to model the impact of climate change on the economy, by including the effects of extreme weather events, rising sea levels, and other climate-related factors on the economy.

A particularly interesting example in this strand of literature is (Asjad Naqvi, 2015), whereby the author simulates five environmental policies, as well as includes the environment as a sector with the non-renewable resource of X. Naqvi simulates the effects of a) Reduction in consumption expenditure (low or no-growth), b) Damage function, whereby capital stock depreciates with greater environmental degradation, c) High share of renewable energy, i.e., an economy that is effectively able to run on renewables, d) Environmental tax on firms and households, which mirrors b) in that taxes perform a 'damage' function to bring emissions to desired levels, and finally e) Capital and Energy efficiency, whereby direct input costs do not increase.

Naturally, a macroeconomic model like SFC is apt for the task of measuring what matters in the economy. With a post-Keynesian basis, and the rejection of neoclassical frameworks and assumptions, it has attracted a lot of economists of heterodox minds, who see benefit in expanding on previous work and fostering transdisciplinary collaboration to answer questions that economics as a discipline has either ignored or has been incapable of answering by itself.

3.4 Integrated assessment models (IAMS)

3.4.1 Introduction and historical account

Integrated Assessment Models (IAMs) have become increasingly important in informing climate policymaking, particularly in response to the growing visibility of climate change impacts in the real world. This increase in awareness has led policymakers and institutions to demand models that can measure and assess future climate impacts. IAMs are computer simulations that represent the interactions and feedbacks between the socioeconomic system, including climate policies, and the natural system on a long-term scale (van Beek et al., 2020; van Vuuren et al., 2011). These models vary in structure, detail, and type of policy questions they are designed to address.

There are two main types of IAMs: detailed process-based IAMs and highly aggregated cost-benefit IAMs. While the former is the basis for the IPCC's assessments of transformation pathways towards temperature targets, the latter estimates optimal mitigation levels relative to the economic costs of climate impacts, which play a less prominent role in the IPCC but are particularly influential in US climate policy (van Beek et al., 2020).

3.4.2 Theoretical substance and methodology, strengths, and weaknesses

Concerns have been raised about the capabilities of IAMs to capture key elements of the real world and how IAM results and recommendations translate into real mitigation activities. There are six main areas of critique to IAMs (CMCC, 2021):

- **Representation of actor heterogeneity**: IAMs often use a single representative agent to capture behaviour and do not fully represent inequality, social, and distributional impacts. This limited representation of heterogeneity is a trade-off in modelling that can increase uncertainty. Heterogeneity is important because behaviour is uncoordinated and differs between actors, including businesses, governance, and institutions.

- **Technology diffusion and dynamics**: IAMs only partially represent technological change and often do not cover spillovers from sectors in detail. The speed of technology diffusion is not always clear, and there is a need to cover more of the drivers of diffusion speed. In many cases backstop technologies are modelled as large negative emission technologies with unrealistic effects and dynamics, e.g. the case of Carbon Capturing and Storage (CCS).

- **Representation of capital markets and finance**: IAMs often assume perfect capital markets, which may not reflect reality. The allocation of finance between borrowers and banks as creators of finance versus channels for limited savings can be complex. Computable General Equilibrium (CGE) type IAMs could include financing schemes for the repayment of loans, detailed budgeting of debt actors across time, and agents' disposable income, debt accumulation, and debt stability. Demand-driven IAMs consider finance created by demand and include the worthiness of borrowers.

- **Inadequate consideration of the environmental and social impacts of technologies**: IAMs often assume unrealistic decoupling between economic growth and energy/emissions, particularly in developing countries. Lack of feedback loops between society, environment, and economic systems.

- **Over-reliance on techno solutions**: IAMs often do not consider policy feedback mechanisms and may overemphasize techno solutions. They may also favour mitigation for long-term objectives over immediate action, neglecting important trade-offs and synergies with other societal goals.

- **Ad-hoc solutions and arbitrary parameters**: The emphasis on damage functions – the effect of CO2 increases/temperature changes on societies welfare (expressed as GDP) – as a key explainer of the effects of climate change on society can be misleading in policy formulation because it ignores other non-monetary quantifiable impacts. Moreover, the damage functions often used in IAMs lack theoretical and/or empirical foundation together with the parameters involved in such functions (discount rates and risk aversion rates for example) (Pindyck, 2013).

To address these concerns, higher transparency is needed in the explicit documentation of large complex models. IAMs need to focus on technologies and costs shifting towards wider impacts on society, and there should be recognition of model limits, with the interpretation phase as a discrete phase of work. Additionally, IAMs need to include the "possibility" space, which is relevant to diverse voices and perspectives.

3.4.3 WISE representation

In the context of the WISE framework, this review highlights the suitability of Integrated Assessment Models (IAMs) for addressing the sustainability and economic dimensions. IAMs demonstrate a robust capacity to incorporate sustainability considerations, leveraging metrics encompassing greenhouse gas emissions, energy consumption, resource depletion, land use, water usage, and biodiversity loss. Additionally, IAMs encompass traditional economic indicators, including GDP, GDP per capita, and value-added per industry/region/nation, among others.

It should be noted that although originally designed to explore the relationships between the economy and climate, IAMs have the potential to evaluate and model effects represented in the SDGs, the development of more detailed biophysical modules representing earth cycles, together with higher availability of socio-economic data has led to an increase research agenda on IAMs towards the analysis of SDGs in their models, covering further topics related to social wellbeing, environmental, and social justice[11] (Nozaki et al., 2023; Van Soest et al., 2019; Zhou et al., 2020).

Regarding inclusion, the review reveals that selected IAMs integrate social dimensions by utilizing indicators such as poverty rates, gender equality, and access to education and healthcare. However, it is noted that the availability of distributional analysis indicators for assessing the fairness and justice of policy outcomes tends to be limited, predominantly accessible for a reduced number of countries. While IAMs demonstrate strengths in capturing sustainability and economic dimensions, further research and development are warranted to enhance the availability and coverage of indicators pertaining to inclusion and distributional analysis.

Details for each model regarding the representation of the WISE dimensions as well as general model characteristics and coverage can be found in Appendix B. Main characteristics of selected IAMs.

3.5 System Dynamics models

System Dynamics (SD) models are used to analyse the behaviour, interaction, and structure of complex systems over time (Bala et al., 2017; ElSawah et al., 2012; Hardt & O'Neill, 2017). In that regard, SD models can be used to evaluate policy strategies and their impacts in order to inform how a system may be best governed (Bala et al., 2017; Radzicki, 2020). Usually, SD modelling is considered to be a heterodox approach in economics (Crookes & De Wit, 2014), being applied in post-Keynesian, ecological, behavioural, and institutional economics (Radzicki, 2020). And while it is true that neoclassical economists rarely make use of SD modelling techniques, it should be noted that SD models are not per se incompatible with the theoretical basis of neoclassical economics (Crookes & De Wit, 2014).

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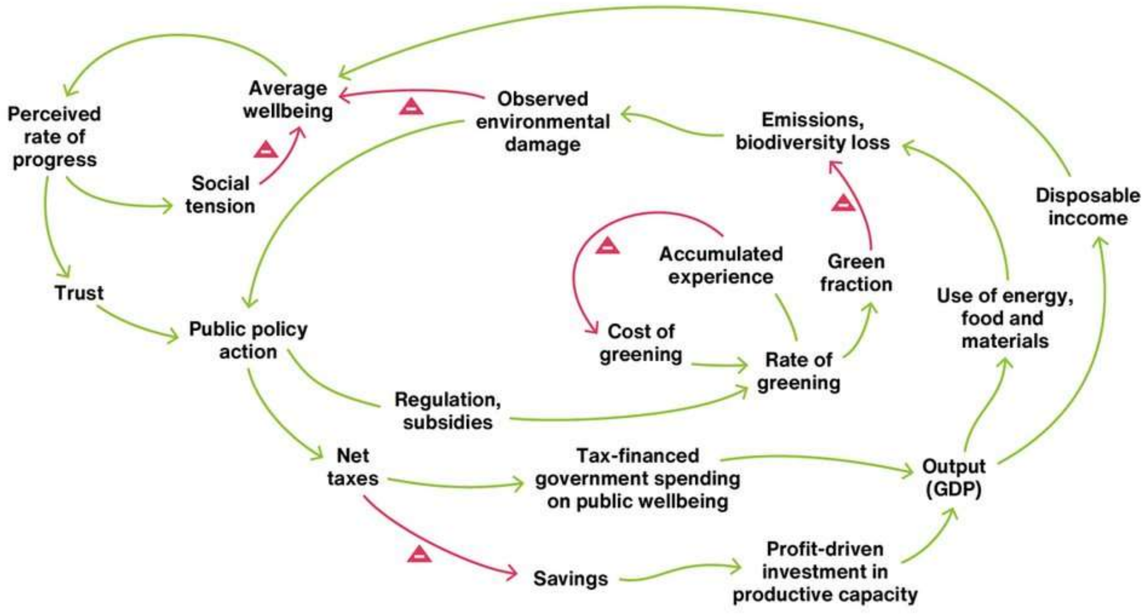
[11] See the developments in EU projects Navigate: https://www.navigate-h2020.eu/, Elevate: https://www.elevate-climate.org/ , and ENGAGE: https://www.engage-climate.org/project/

3.5.1 Introduction and historical account

System Dynamics (SD) models have found extensive application across various academic fields, showcasing their versatility and analytical power. SD models are used in various disciplines such as social sciences, economics, agricultural studies, public policy, and environmental studies (Bala et al., 2017; Coyle, 1996). Despite the capacities of SD models to model different policy scenarios and their effects, our review indicates that they are mostly used in academia rather than in institutionalised policy evaluation exercises. Moreover, SD models can be readily combined with other modelling approaches such as input-output analysis (Cordier et al., 2017; Uehara et al., 2018) as well as agent-based modelling (ABM) (Liu et al., 2020; Uddin et al., 2021).

Historically, SD models were pioneered by Jay W. Forrester in the 1950s with the aim of modelling corporate dynamics and informing managerial decision-making to improve business performance (Forrester, 2007; Radzicki, 2020). In particular, Forrester developed the Industrial Dynamics model to study the behaviour of firms in the manufacturing sector, specifically to explore the causes of business cycles and fluctuations in production and employment (Forrester, 1961). In 1971, Jay Forrester was invited by the Club of Rome to develop a system dynamics model of the socioeconomic system and the interconnected relationships between variables such as population, industrial production, pollution, resources, and food (Forrester, 1971). Forrester’s work then provided the basis for one of the best-known applications of SD models to date (Forrester, 2007), namely the development of the WORLD3 model published in the seminal Limits to Growth report conducted by the Club of Rome (Meadows et al., 1972). Only recently, the WORLD3 model has been updated in the form of the Earth4All model (Dixson-Decleve et al., 2022), a simplified depiction of which can be found in Figure 1.

Figure 1: A simplified depiction of the Earth4All model. Taken from https://earth4all.life/the-science/



3.5.2 Theoretical substance and methodology of SD modelling

System Dynamics is built on the fundamental notion that the dynamic behaviour of a system over time arises from the structure of the system and the co-dependent interactions among system components (ElSawah et al., 2012). System Dynamics focuses on modelling feedback loops and causal relationships to understand how variables change over time in complex systems, often without explicit considerations of monetary flows (Radzicki, 2020; Sterman, 2001). (Stock-) Flow consistent models, in contrast, focus on and emphasize the consistency of monetary flows within an economic system and their impact on macroeconomic variables, with less emphasis on feedback loops.

Let us therefore investigate the components of system dynamics as well as the decision rules that give rise to a system's behaviour. While stocks represent current state or level of a variable, flows describe the rates of change in stocks. Crucially, the accumulation and movement of quantities within the system is governed by feedback loops that determine the dynamic relationships between variables. Here, feedback loops involve the transmission of information from one component of the system to another, which affects the rates of flow and generates subsequent actions within the system in a continuous and dynamic manner (Bala et al., 2017; Coyle, 1996; Radzicki, 2020). Lastly, it should be noted that the feedback loops in

SD models may also capture time delays, that is a lag between actions and their effects (Bala et al., 2017).

Notably, feedback loops can be classified into two main types, positive and negative feedback loops. Positive feedback loops are essentially reinforcing and can thus contribute to both the accumulation and the decline of a given stock (Coyle, 1996; Radzicki, 2020). Population growth exemplifies a positive feedback loop, as a bigger population leads to more births per year which again increases the population in continuous reinforcing manner (Bala et al., 2017). Conversely, negative feedback loops can be described as self-regulating or goal-seeking, as they are geared towards maintaining a desired state. When a discrepancy between the actual and desired state of a variable is detected, corrective action is triggered to close that gap. An example of a negative feedback system is a temperature control system in a room, where a thermostat maintains a set temperature by activating and deactivating a heater (Bala et al., 2017; Coyle, 1996; Radzicki, 2020).

Another crucial characteristic of SD models is their ability to model non-linearities. First, non-linearities imply that the relative significance of feedback loops within a system can be subject to endogenous change, thus allowing for possibility of the structure of the system to develop in an evolutionary manner over time (Radzicki, 2008). Secondly, SD models allow for an integration of limiting factors; hence, stocks and flows can be modelled in a way that it is impossible for them to exceed or fall below certain maximum and minimum levels (Radzicki, 2008, 2020).

Now that we have elaborated on the theoretical concepts that underlie SD models, let us turn to the methodology used for constructing SD models. The first step to be taken towards the construction of a SD model is to identify a problem or question “that is stated in dynamic form by a time-series graph of a variable(s) that is behaving problematically or in a way that is not well understood” (Radzicki, 2008, p. 162). The way in which the variable behaves over time is referred to as the reference mode and or reference mode behaviour (Bala et al., 2017; Radzicki, 2008).

Subsequently, a so-called dynamic hypothesis is formulated, which seeks to explain the reference mode behaviour endogenously, utilising causal loop diagrams as well as stock-flow diagrams to conceptualise the feedback loops that give rise to the system’s behaviour (Bala et al., 2017; Radzicki, 2008). The next step is then to test the dynamic hypothesis drawing on observed data for the reference mode as well as simulated data produced by the model (Bala et al., 2017; Radzicki, 2008). The dynamic hypothesis is then adjusted so that the model is capable of generating results in line with the reference mode (ElSawah et al., 2012).

Lastly, the modeller develops a numerical model. Here, the dynamic hypothesis is translated into stock-flow form and differential equations are specified to describe the change rates of stocks. The behaviour of the system and its components over time can then be simulated using a simulation engine (ElSawah et al., 2012), drawing on software such as POWERISM, VENSIM, and STELLA (Bala et al., 2017).

3.5.3 Strengths & Weaknesses of SD models

System Dynamics models – like all modelling approaches – come with certain strengths and weaknesses that must be taken into account when considering the choice of model to be used for scientific enquiry.

Strengths and advantages of SD models include (Crookes & De Wit, 2014; ElSawah et al., 2012):

- Ability to model complex system dynamics accurately using non-linear relationships, delays, and feedback loops
- Facilitate system understanding and promote system thinking skills in both modelers and end-users
- Ease of communicating the structure of the model to various audiences via easily comprehensible causal loop diagrams
- High degree of flexibility, allowing for interdisciplinary collaboration and facilitation of stakeholder involvement
- Well-suited even in cases of poor data availability, for instance when extensive time series data on economic variables is lacking

Weaknesses and drawbacks of SD models include (Crookes & De Wit, 2014; ElSawah et al., 2012):

- Advanced skills and substantial resources are required.
- Challenging to find detailed and calibrated SD models for comparison.

- Transition from dynamic hypothesis to quantitative simulation model is not straightforward, as it involves defining variables, relationships, and making assumptions and simplifications that introduce uncertainty.
- Integrating SD with other modelling techniques complicates the analysis of sensitivities and uncertainties in the integrated models.
- Balancing model complexity with the ability to gain meaningful insights is challenging.
- SD modelling is less structured compared to traditional modelling approaches and thus requires the researcher to possess a quite advanced theoretical understanding of the system under study to effectively develop the model.

3.5.4 WISE dimensions in SD modelling

Let us now turn to the question how well the WISE dimensions can be modelled using SD models. For this purpose, we will confine our review here to discussing a non-exhaustive selection of analyses that apply SD models within the broad realm of ecological macroeconomics, as this seems to be the most relevant scientific field in the WISE context.

One of the first SD models developed in the field of ecological economics is the LOWGROW model by (Victor & Rosenbluth, 2007). The model is used to simulate a no-growth pathway under which the Canadian economy would be able to reduce unemployment, alleviate poverty and simultaneously reduce greenhouse gas emissions. In a similar vein, (Bernardo & D’Alessandro, 2016) construct a model to assess the impacts of focussing investments in low-carbon sectors on economic variables such as GDP, debt-to-GDP ratio, employment, wages, and income distribution. While both models cover all of the three WISE dimensions, it is evident that wellbeing considerations are only present in terms of employment and the wage it generates. Similarly, inclusion is primarily targeted in terms of income distribution and monetary poverty.

A more recent study is the analysis undertaken by Đula et al. (2021). Here, the authors use SD modelling to evaluate the impacts of several well-known degrowth policy proposals such as basic and maximum income as well as a job guarantee. The study is interesting insofar as it not only models the impacts of these policies on jobs, employment, and income but also on the Human Welfare Index, which integrates life expectancy, education, and GDP into a single metric. In that way, the study employs a more nuanced and multidimensional understanding of wellbeing, which is of course crucial in the WISE context.

Lastly, we would like to highlight three of the most intricate and extensive models employing SD elements to date, both of which also incorporate aspects of other model types, such as IO analysis. First, the MEDEAS model constitutes an IAM modelling framework to simulate the impacts of transition policies. MEDEAS includes several modules, the majority of which deal with sustainability-related elements such as energy, minerals, land use, water, and emissions but lacks a similarly extensive consideration of wellbeing and inclusion elements (Capellán-Pérez et al., 2020). Second – and related to MEDEAS –, the pymedeas model explores pathways towards a zero-carbon economy on the global and EU level, taking into account environmental limits, the impacts of climate change, as well as the raw material availability (Solé et al., 2020). Third, the EUROGREEN model constitutes a dynamic macrosimulation tool to assess and compare the outcomes of transition pathways such as green growth and degrowth. For their analysis, the authors cover impacts on variables such as GHG emissions, income distribution, unemployment, and public deficits. Moreover, the authors employ a mesoscale approach, making it possible to delineate household groups along the lines of characteristics such as gender, skill, and employment status (D'Alessandro et al., 2020).

From this non-exhaustive review, it becomes apparent that SD models currently do not capture the multidimensionality of the three WISE dimensions. When it comes to wellbeing, most models only cover objective dimensions such as employment, education, and life expectancy. While a crucial element of wellbeing, the impact on subjective wellbeing (e.g. life satisfaction, happiness) is only present in the eart4all model, their measure of average wellbeing index (AWI), takes into account the perception of perceived progress which indirectly relies on subjective valuation of wellbeing (Dixson-Decleve et al., 2022). In terms of inclusion, SD models seem to be primarily focused on simple measures of income distribution, such as the GINI index. The EUROGREEN model is an exception here, as its mesoscale approach in principle allows for an analysis of more granular forms of inequalities between different social groups. For instance, the EUROGREEN model has been employed to investigate the effects of working time reduction and universal income schemes on gender disparities pertaining to income and time use (Cieplinski et al., 2023).

On a more critical note, we note that the issue of wealth inequalities has been addressed in a few of the SD models reviewed here. It is wort noting the EUROGREEN model which differentiates between income groups and asset classes to address changes in wealth. Although not explicitly calculated in the form of an Index, EUROGREEN provides the data and results to infer changes in wealth as a result of different scenarios in the future. Lastly, sustainability is the WISE dimension that is explored in most depth by the models. In particular, the MEDEAS model captures a multitude of environmentally relevant variables that go beyond the simple focus on climate and emissions. Nevertheless, a further integration of Planetary Boundary variables (e.g. biodiversity) (Steffen et al., 2015) seems to be a meaningful way forward. Beyond the environmental dimension of sustainability, the LOWGROW as well as the EUROGREEN model show that it is furthermore possible to model impacts on debt-to-GDP ratios and public deficits, respectively, and thus assess fiscal sustainability implications of policy pathways.

4. DISCUSSION

There are some important lessons in this review, but perhaps a main outcome is the fact that no single model type, let alone model, is perfect and suits all the WISE aspects indiscriminately. Research suggests that *"from forecasting, there is evidence that combining two or more models leads to greater predictive power than using one model alone"* (Haldane & Turrell, 2018), something we have ourselves identified in every step of the way. This can also be observed in the impact assessment done by and for the European Commission, where often several models are utilized to complement each other in answering the same policy question[12]. Nonetheless, some models are much more capable and especially flexible for representing large scale structural changes that are required for a sustainability transition (McCarthy et al., 2018)[13] or in integrating the various WISE aspects.

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[12] https://web.jrc.ec.europa.eu/policy-model-inventory/explore/models/models-ia-combinations

[13] "..., certain types of macroeconomic model are more appropriate for assessing the transition than others, notably due to their accounting of interactions between sectors and macroeconomic feedbacks."

In the following we will discuss three major points that are relevant to WISE modelling and the WISE Horizons project in general:

1. The representation of the WISE dimensions in existing models
2. Model characteristics relevant for representing WISE
3. How can we model WISE policies and their impacts on WISE indicators with the existing models and what do we need to develop?

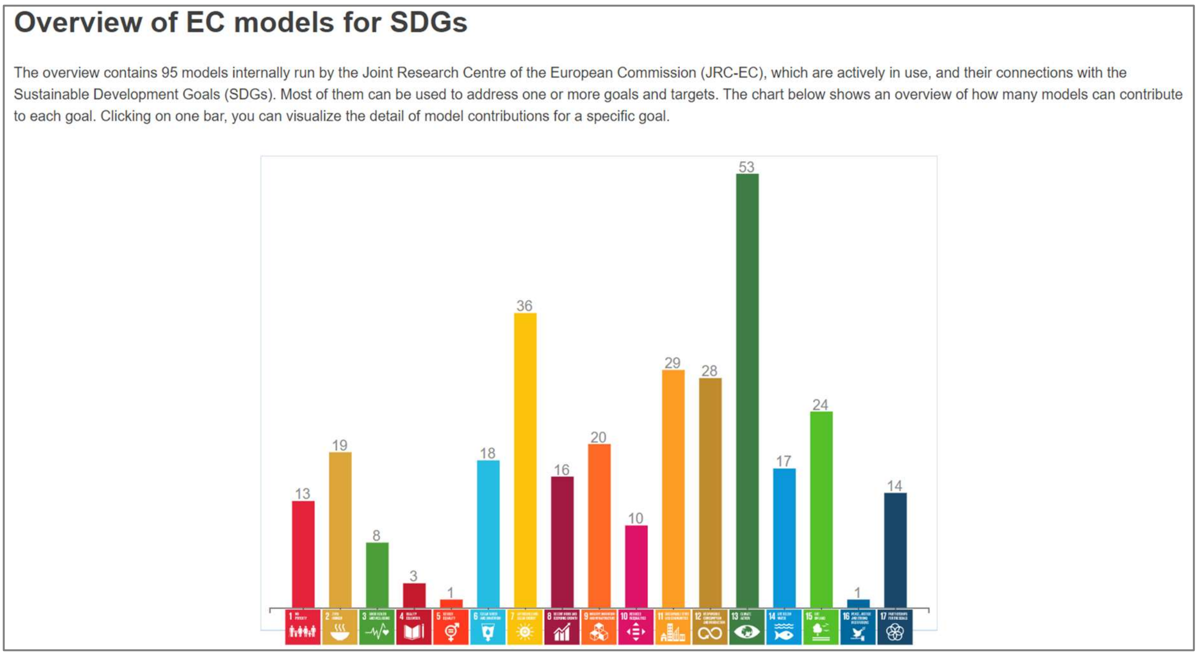
4.1 Representation of WISE in existing models

At the first glance wellbeing and inclusion seem to be well covered in macro-economic models, especially as many explicitly incorporate general health status through population development, and some, at least indirectly, consider educational aspects by modelling labour force availability. Aggregated inequality and poverty outcomes can be estimated through impacts on employment. However, details on how economic structural change influences inequality outcomes is difficult to assess with the current models. Here, it is not a lack of theory, modelling philosophy or flexibility in the models, but rather a lack of data at the global level, that links changes in detailed economic activities (as presently modelled in all the reviewed model types to a lesser or larger extend), to employment and income differentiated by household type (age, skills, occupation, gender, wealth). In addition, the current SNA system (EC et al., 2009), while recognizing the importance of unpaid household work as well as ecosystem services, does not actually account for these "in systematic measurements of economic activity" (Mair, 2020). In this context, for example time use accounts could be linked to how people employed in different parts of the economy spend their days. This in turn, together with information on health status and education possibilities would allow for estimating wellbeing more comprehensively than currently done. The possibilities are vast, but the data are a limitation. Wellbeing and inclusion measures are often disaggregated along different dimensions than economic activity and environmental impact data.

For modelling sustainability, that is wellbeing in the future, the macroeconomic modelling analyses are most concerned with estimating environmental repercussions. However, most models lack the endogenous feedback loops between earth system (environment) and the human system (often reduced to the economy) [more on that later, see Section 4.2]. Still, the environment is also only represented in a very limited way, as it is reduced to energy-related impacts such as GHG emissions. None of the comprehensive medium-to-long-term policy simulation macro-economic models reviewed in the MIDAS database covers any of the other environmental impact categories "Efficient Use Of Resources (Renewable & Non-Renewable)", "Land use", "Soil quality or resources", " Waste Production / Generation / Recycling", "Water Quality And Resources", see Table 3 and Table 4 in Appendix A. These are well represented in partial models or in integrated assessment models, both of which only have an aggregate representation of the economy.

Sustainability, of course, does not only refer to environmental issues, but also economic and social sustainability needs to be addressed. Here, the United Nation's Sustainable Development Goals (SDGs) and their targets and indicators can help us identify how sustainability impacts in general can be quantified in the models. The knowssdgs website of the European Commission's Joint Research Centre provides an overview of how the different SDG indicators are represented in the models, see Figure 2. The dominance of energy (SDG 7) and climate (SDG 13) related issues becomes immediately obvious. Gender equality (SDG 5), education (SDG 4), and health (SDG 3) issues are clearly underrepresented. Table 3 and Table 4 in the Appendix summarize the SDG representation in the reviewed macro-economic models. The distribution of SDGs covered is very much in line with the overall model sample as shown in Figure 2. One reason for the distribution of the indicator representation is related to the inherent structure of macro-economic models, both General Equilibrium Models, Macro-Econometric Input-Output models and Stock-Flow-Consistent models, but also Integrated Assessment Models. Given the current nature and coverage of these models, it is currently only possible to directly estimate SDG indicators from the model, that can be linked to economic activities. Especially easy are indicators that are related to industrial production, such as SDG indicators 8.2.1 *"Annual GDP growth rate per employed person"* or 9.4.1 *"CO2 emissions per unit of value added"*. In the eaSi-system project (Wiebe et al., 2021) we differentiate between indicators that can be directly estimated from the data available in macroeconomic models, denoted with "indicator" in the middle column (Type) of the table in Figure 3, indicators where we can approximate the impact, "proxy" indicators, and indicators where we can use qualitative reasoning for the general size and direction of impacts, "base" indicators.

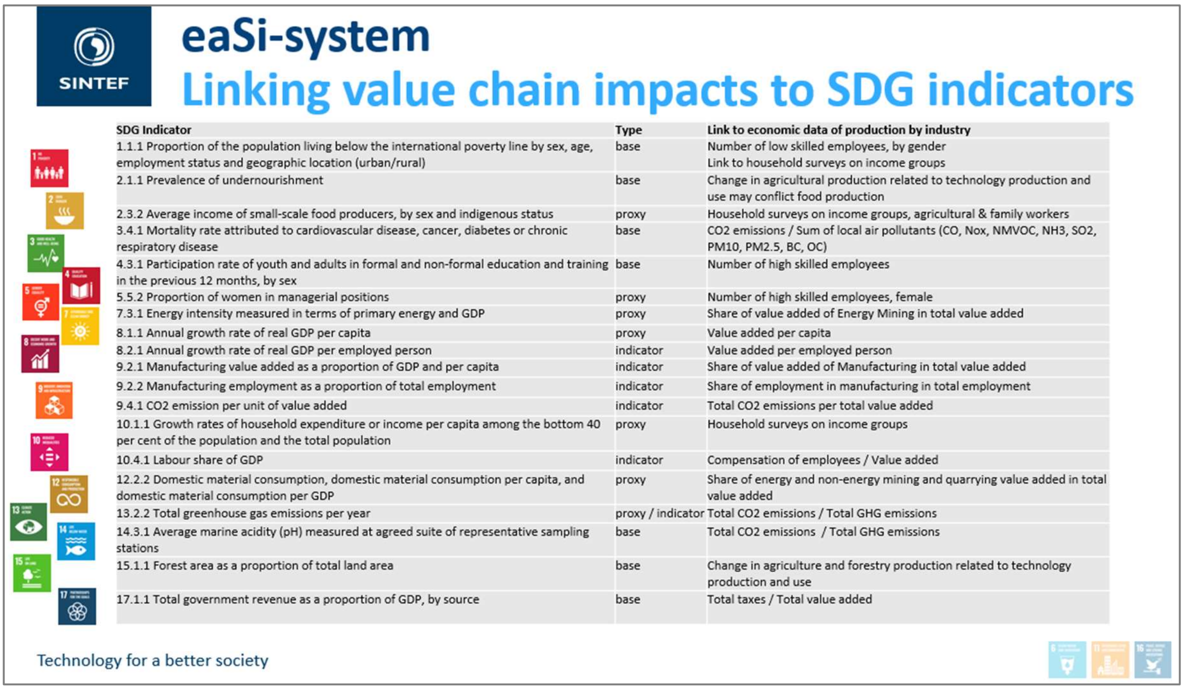
Figure 2: SDG representation in impact assessment models used by the European Commission. Source: Screenshot (April 27, 2023) from https://knowsdgs.jrc.ec.europa.eu/



Overview of EC models for SDGs

The overview contains 95 models internally run by the Joint Research Centre of the European Commission (JRC-EC), which are actively in use, and their connections with the Sustainable Development Goals (SDGs). Most of them can be used to address one or more goals and targets. The chart below shows an overview of how many models can contribute to each goal. Clicking on one bar, you can visualize the detail of model contributions for a specific goal.

Figure 3: Linking value chain impacts to SDG indicators
Source: unpublished work (by authors) from eaSi-system project



eaSi-system

Linking value chain impacts to SDG indicators

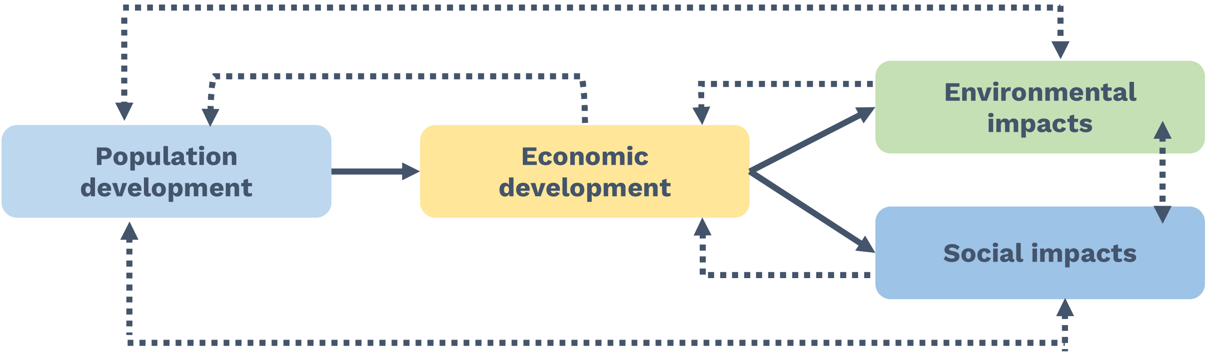
SDG Indicator	Type	Link to economic data of production by industry
1.1.1 Proportion of the population living below the international poverty line by sex, age, employment status and geographic location (urban/rural)	base	Number of low skilled employees, by gender Link to household surveys on income groups
2.1.1 Prevalence of undernourishment	base	Change in agricultural production related to technology production and use may conflict food production
2.3.2 Average income of small-scale food producers, by sex and indigenous status	proxy	Household surveys on income groups, agricultural & family workers
3.4.1 Mortality rate attributed to cardiovascular disease, cancer, diabetes or chronic respiratory disease	base	CO2 emissions / Sum of local air pollutants (CO, Nox, NMVOC, NH3, SO2, PM10, PM2.5, BC, OC)
4.3.1 Participation rate of youth and adults in formal and non-formal education and training in the previous 12 months, by sex	base	Number of high skilled employees
5.5.2 Proportion of women in managerial positions	proxy	Number of high skilled employees, female
7.3.1 Energy intensity measured in terms of primary energy and GDP	proxy	Share of value added of Energy Mining in total value added
8.1.1 Annual growth rate of real GDP per capita	proxy	Value added per capita
8.2.1 Annual growth rate of real GDP per employed person	indicator	Value added per employed person
9.2.1 Manufacturing value added as a proportion of GDP and per capita	indicator	Share of value added of Manufacturing in total value added
9.2.2 Manufacturing employment as a proportion of total employment	indicator	Share of employment in manufacturing in total employment
9.4.1 CO2 emission per unit of value added	indicator	Total CO2 emissions per total value added
10.1.1 Growth rates of household expenditure or income per capita among the bottom 40 per cent of the population and the total population	proxy	Household surveys on income groups
10.4.1 Labour share of GDP	indicator	Compensation of employees / Value added
12.2.2 Domestic material consumption, domestic material consumption per capita, and domestic material consumption per GDP	proxy	Share of energy and non-energy mining and quarrying value added in total value added
13.2.2 Total greenhouse gas emissions per year	proxy / indicator	Total CO2 emissions / Total GHG emissions
14.3.1 Average marine acidity (pH) measured at agreed suite of representative sampling stations	base	Total CO2 emissions / Total GHG emissions
15.1.1 Forest area as a proportion of total land area	base	Change in agriculture and forestry production related to technology production and use
17.1.1 Total government revenue as a proportion of GDP, by source	base	Total taxes / Total value added

Technology for a better society

4.2 Model characteristics relevant for representing WISE

What all models and model types (except System Dynamics models), have in common is the linearity regarding the WISE dimensions as shown in Figure 4 below. Population development (which is determined by demographics and health) drives consumption in the economic models. Population and education together determine the availability of workers, that can be economically active, which is also an important factor in macroeconomic models. Health and educational issues are part of "wellbeing", so that even if population development is not an exhaustive measure of wellbeing it is still part of it, and it is exogenous to the macroeconomic models. Indicators related to sustainability and inclusion, in contrast, as seen above, are modelled as outcomes of economic development. **Feedbacks both from the sustainability and inclusion dimensions to the economy, and of all three of these back to wellbeing are generally omitted in the models reviewed here, but crucial for considering all WISE dimensions and their interplay.**

Figure 4: Simplified representation of current linear interactions (→) between WISE dimensions in macro-economic models, and generally omitted feedback loops (◂··▸) that are crucial for considering all WISE dimensions and their interplay. Source: Authors' own visualization of findings.



These complex interdependencies also make it very unlikely that there is a general equilibrium of the economic system, let alone of the entire societal-environmental system (Arthur, 2021). In addition, as pointed out by (McCarthy et al., 2018), the world cannot be modelled in an equilibrium given the large structural changes ahead.

Nonetheless, some details of GEMs are important and relevant, for example the modelling of inclusion and wellbeing as outcome indicators of policy simulations, as for example in GEM-E3. The modelling approaches of GEM-E3 (neo-classical CGE) and E3ME (post-Keynesian MREIO), both models frequently used by the European

Commission, have been extensively compared (Pollitt, 2017; Pollitt & Mercure, 2018; Rademaekers et al., 2018). The same holds to a lesser extend for EU-EMS (GEM) and GINFORS (MEIO). FIDELIO is unfortunately not part of MIDAS and the comparisons, even though it has been developed by the European Commission's Joint Research Centre and, thus, is expected to have been used extensively, especially for energy and household analyses. Especially the latter, household modelling, is important in the WISE context, and the FIDELIO approach could be considered in other models for a better representation of both wellbeing and inclusion. Energy-economy linkages are most detailed in the other two MEIO models (E3ME and GINFORS), as they combine detailed economic energy demand with detailed data on energy production and use, as available in energy balances (IEA, 2023). The relations between the different variables in these models are estimated econometrically.

The representation of international trade is based on detailed bilateral trade data at the product level for many of the GEM and ME(IO) and dynamic IO models, using different functional forms for relating prices (product prices, and, possibly, transport costs, taxes, tariffs, regulations, or trade agreements) to quantities and direction of trade. However, trade is only one of four major transnational channels of climate change impacts (Davis et al., 2016) and other sustainability impacts. While the "people" and "finance" channels are generally not represented in the reviewed models, some of the IAMs represent selected biophysical cross-border flows, such as the effect of increased GHG emissions on global temperature change and their effect on society via damage functions, as explained in Section 3.4. IAMs are developed for estimating the effect of the economy on the environment and climate and are extensively used by IPCC for climate policy analysis. They also use population and education projections for driving the aggregated economic development based on neoclassical economic models, and they also generally lack feedback loops. Regarding aggregated representation of the economy and restricting CGE assumptions, insights and approaches from macro-econometric input-output models can help. As for the macro-economic models (GEM, MEIO, SFCs), IAMs could also benefit from system dynamics approaches for modelling feedback loops between all WISE dimensions. Here, the MEDEAS model (Capellán-Pérez et al., 2020; Solé et al., 2020), is a good example.

A key focal point of the different typologies of models reviewed is that their divergences bear upon the main WISE dimensions, such as how they address household-level inequalities and dynamics between environment and society. IAMs, characterized by their predominantly aggregated nature, face inherent limitations when confronted when tackling structural inequalities. Conversely, CGE and Macroeconomic IO models, although not originally designed for such aspects, have the potential to accommodate these features.

Stock-Flow consistent models (SFC) and System Dynamic (SD) models emerge as distinctive features that can be integrated into macroeconomic IO models and some CGE models. SFCs foundation lies on the incorporation of flow relationships, while SD offers a specific way tailored to dynamic equations. Though methodological complexities may arise about integrating these models, they have the potential to solve some of the challenges in modelling WISE dimensions while maintaining the nature of macroeconomic models, which opens the door for progressive integrations. In this perspective, SFCs and SDs can be characterized as supplementary typologies to the Macroeconomic models reviewed here, enriching economic modelling within the WISE project and beyond.

4.3 How can we model WISE policies and their impacts on WISE indicators with the existing models and what do we need to develop?

Building on these reflections, it becomes apparent that when it comes to modelling WISE policies and their impacts there is no need to reinvent the wheel. Rather, a sensible way forward is to build on the extensive work that has already been done on macroeconomic modelling and identify suitable pathways for further development. In a nutshell, we conclude that a simple, comprehensible, and transparent model constitutes the most promising option to model the interrelations between the economy, society, and the natural environment. Crucially, a model that integrates all WISE dimensions should comprise the feedback links between the various elements of the WISE accounts.

The envisioned integrated WISE model can potentially adopt characteristics and elements from all model types under review here. In terms of economic theory, the model can draw on more mainstream type of insights (e.g. from national and global CGE models) as well as from heterodox approaches such as post-Keynesian economics (as mostly employed in MEIO as well as SFC models). Such flexibility in terms of modelling the behaviour of agents and interrelations between system elements is crucial to best align the theoretical underpinnings of the model with empirical observations. Moreover, the WISE model can benefit from emulating the high level of consistency present in IO and SFC models when it comes to tracking transactions as well as their capacity to balance simplicity with a sufficient extent of detail and complexity. While input-output models are mostly concerned with the flows within the economic system and to and from the environment (e.g. in terms of material extraction or pollution) and society (e.g. wages), stock-flow-consistent models are also keeping track of available stocks, not only in terms of capital stocks in the economy, but also in terms of nature and society.

Lastly – and possibly most importantly –, the WISE model should incorporate elements from SD modelling, in particular the ability to simulate feedback loops, non-linear dynamics, as well as limiting factors, which present themselves as pivotal preconditions to model the intricate interconnections between stocks and flows of wellbeing, inclusion, and sustainability. However, this is probably easier said than done. During the project we will sketch out ways of modelling WISE using elements from IO and SFC (for a detailed modelling of flows and stocks in the economy) and SD (for capturing interlinkages and feedback loops between economy, society, and the environment) in more detail and aim to implement these based on the WISE accounts.

Box 6 – WISE accounts

During the WISE Horizons project, we will create an interdisciplinary WISE accounting framework which includes the most important Beyond-GDP metrics (see review of metrics) and is could be the empirical foundations for the novel WISE models that this review envisages. The WISE accounting framework will not start from scratch: it is more an integration of existing conceptual accounting framework (System of Environmental-Economic Accounts (SEEA), human capital, labour accounts, demographic accounts, time use accounts) and empirical global databases such as WIOD, EXIOBASE, EORA, ICIO, FIGARO.

The WISE accounts will be based on the sustainable development systems models that views planet, society and economy as connected and embedded systems. We will also take on board the interdisciplinary stock-flow accounts and evaluation methodologies. A first version of the conceptual aspects of the WISE accounts will be developed as part of the development of the WISE theoretical framework. See www.wisehorizons.world for an update, which is expected at the end of 2023.

5. RECOMMENDATIONS

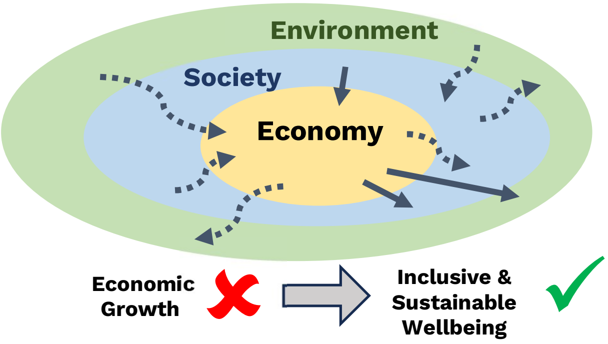
The need to explore alternative models that move beyond the general equilibrium framework becomes especially crucial when analysing sustainability, wellbeing, and inclusion within an alternative paradigm for macroeconomics. This paradigm views the economy as a non-linear and evolving system, recognizing that higher levels of disaggregation can give rise to new phenomena, statistical regularities, and novel structures.

Recognizing the economy as a complex and evolving system (Arthur, 2021) allows for a more comprehensive understanding of factors that contribute to individual and societal wellbeing. It acknowledges that traditional economic indicators such as GDP may not capture the full complexity of human welfare. By incorporating a broader set of indicators and considering the interplay between social, economic, and environmental factors, policymakers can design more inclusive policies that prioritize the wellbeing of diverse populations.

Figure 5: Main findings for WISE modelling of economic, societal and environmental systems and their interplay
Source: Authors' own visualization of findings.

Main findings for WISE modelling

1) Economic, societal and environmental systems are embedded in each other, not linearly following
2) All of these systems are interrelated; some, but not enough, links have been modelled
3) The inclusion of more WISE indicators is necessary: shift from economic growth to "inclusive and sustainable wellbeing"



When for example considering the impact of climate change, these systems perspectives become highly relevant. The notion of self-organized criticality[14] highlights how imbalances can accumulate within the economic system over time, leading to the emergence of tipping points (Dosi & Roventini, 2019). Seemingly

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[14] Self-organized criticality is a concept in physics regarding an observed phenomenon in complex dynamic systems that produces power-law distributed avalanche sizes (Bak & Chen, 1990; Hoffmann & Payton, 2018). In economics, it has been borrowed to explain the macroeconomic fluctuations: *"many small independent shocks to different sectors of the economy need no cancel out in the aggregate, due to the presence of significantly non-linear, strongly localized interactions between different parts of the economy"*(Scheinkman & Woodford, 1994).

innocuous shocks can trigger significant shifts, underscoring the need to consider non-linear dynamics and the potential for abrupt and unexpected changes in economic systems. By adopting models that account for these complexities, policymakers and researchers can better understand the interactions between the economy and the environment, informing strategies to address and mitigate the effects of climate change.

Our recommendations for working with and developing models for WISE policy and impact analysis therefore are:

Improve Existing Models: One recommendation is to enhance the existing models that are currently in use for policy analysis. These models can be refined and updated to better capture the dynamics and complexities of the real world. The focus on improvement should revolve around the incorporation of WISE accounts, striking a balance between complexity and transparency. It is crucial to ensure that it is not a black box and remains flexible enough to link to the results of the partial models.

Specifically, we suggest improving macroeconomic simulation models already used by international organisations and governance bodies to assess and evaluate policies and their impacts. For instance, it is quite possible to integrate WISE aspects and their main interdependencies into existing models used by the DGs of the European Commission. Here, we would like to especially mention the models, such as GEM-E3, E3ME, FIDELIO, GINFORS, or QUEST, as well as the OECD's ENV-family models, that already have various aspects of WISE modelled. While the WISE Horizons project cannot incorporate the necessary changes in the models directly (as the models are not open source), our contribution here can be ideas and detailed recipes of how to link a number of WISE aspects to these economic models.

Embrace Heterodox Models in Institutionalized Policy Evaluation: In addition to enhance existing models, it is recommended to incorporate heterodox models in the process of institutionalized policy evaluation (Kaufmann et al., 2023; Proctor, 2023). Heterodox models offer alternative perspectives and frameworks that can complement prevailing approaches, providing valuable insights and a more comprehensive understanding of policy impacts. Models such as those based on MRIO (Multi-Regional Input-Output) data for global value chains, SFC (Stock-Flow

Consistent) for comprehensive accounting, and SD (System Dynamics) for capturing feedback loops should be considered.

As also identified by our twin-project ToBe[15], the MEDEAS modelling framework (Capellán-Pérez et al., 2020) and related pymedeas model (Solé et al., 2020) provide suitable starting points for extension in the context of the WISE modelling, especially due the intricate modelling of the interconnections between the economy and the natural environment including the consideration of biophysical limits. These can be combined with the Eurogreen model (D'Alessandro et al., 2020) which seems to be particularly strong on the modelling of the economy thus being able to model impacts on wellbeing- and inclusion-related issues such as employment and income distribution, respectively.

To maximize the effectiveness and adoption of any model, it is recommended to engage in a **co-creation process** of quantitative analysis. This means involving stakeholders in the development and application of the models, enhancing their ownership and uptake. Additionally, efforts should be made to improve communication, dissemination, and exploitation of the results. This can be achieved through activities like assessing the needs of stakeholders, co-creating a user-friendly website, and organizing follow-up meetings to engage with stakeholders.

However, it is important to acknowledge that one of the **biggest limitations** in further developing and utilizing these models for WISE analysis is data availability. Obtaining accurate and up-to-date data at the desired level of detail for the models can be challenging. Efforts should be made to improve data collection processes and ensure that the models are supported by robust and reliable data sources.

In summary, in the context of our WISE Horizons project, we envision a comprehensive and integrated model that builds upon the WISE accounts, synergizing Input-Output (IO), Stock-Flow Consistent (SFC), and System Dynamics (SD) elements as its foundation. We aim to encompass a wide array of economic, social, and environmental factors, providing a holistic representation of the complex interactions within the global economic system in this model, while keeping its structure relatively simple. We envision to use IO representation of detailed

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[15] https://doi.org/10.3030/101094211 & https://toberesearch.eu/

economic flows, together with SFC and SD elements to consider stock-flow interactions within and between the economic, social, and environmental systems. This will be achieved by using the WISE accounts as an empirical base that determines the relations between the different elements, enabling us to distinguish between results being driven from theoretical choices and empirical data. By amalgamating these diverse elements, our integrated model will leverage the power of available data, showcasing its potential to offer nuanced insights into the dynamics of wellbeing, inclusion, sustainability, and economic development. This multidimensional approach will enable policymakers and stakeholders to explore a variety of policy scenarios, assess potential impacts, and make informed decisions to foster a more equitable, resilient, and sustainable future for societies across the globe.

6. REFERENCES

Arsenio, F., Alexandri, E., Kiss-Dobronyi, B., Suta, C.-M., Chewpreecha, U., & Harsdorff, M. (2022). *Modelling and comparing the employment impacts of COVID-19 crisis and recovery policies in Indonesia*. ILO.

Arthur, W. B. (2021). Foundations of complexity economics. *Nature Reviews Physics*, *3*(2), Article 2. https://doi.org/10.1038/s42254-020-00273-3

Asjad Naqvi. (2015). *Modeling Growth, Distribution, and the Environment in a Stock-Flow Consistent Framework*. https://doi.org/10.13140/RG.2.1.1907.4402

Bak, P., & Chen, K. (1990). Self-Organized Criticality. *SCIENTIFIC AMERICAN*.

Bala, B. K., Arshad, F. M., & Noh, K. M. (2017). *System Dynamics: Modelling and Simulation*. Springer Singapore. https://doi.org/10.1007/978-981-10-2045-2

Barker, T. (1999). Achieving a 10% Cut in Europe's Carbon Dioxide Emissions using Additional Excise Duties: Coordinated, Uncoordinated and Unilateral Action using the Econometric Model E3ME. *Economic Systems Research*, *11*(4), 401–422. https://doi.org/10.1080/09535319900000029

Baumol, W. J. (1999). Retrospectives: Say's Law. *Journal of Economic Perspectives*, *13*(1), 195–204. https://doi.org/10.1257/jep.13.1.195

Beaufils, T., & Wenz, L. (2022). A scenario-based method for projecting multi-regional input–output tables. *Economic Systems Research*, *34*(4), 440–468. https://doi.org/10.1080/09535314.2021.1952404

Becker, L., Bernardt, F., Bieritz, L., Mönnig, A., Parton, F., Ulrich, P., & Wolter, M. I. (2022). *INFORGE in a Pocket* (GWS-KURZMITTEILUNG 2022/2). GWS.

Berg, M., Hartley, B., & Richters, O. (2015). A stock-flow consistent input–output model with applications to energy price shocks, interest rates, and heat emissions. *New Journal of Physics*, *17*(1), 015011. https://doi.org/10.1088/1367-2630/17/1/015011

Bernardo, G., & D'Alessandro, S. (2016). Systems-dynamic analysis of employment and inequality impacts of low-carbon investments. *Environmental Innovation and Societal Transitions*, *21*, 123–144. https://doi.org/10.1016/j.eist.2016.04.006

Burfisher, M. E. (2016). *Introduction to computable general equilibrium models* (Second Edition). Cambridge University Press.

Caiani, A., Russo, A., & Gallegati, M. (2019). Does inequality hamper innovation and growth? An AB-SFC analysis. *Journal of Evolutionary Economics*, *29*(1), 177–228. https://doi.org/10.1007/s00191-018-0554-8

Cambridge Econometrics. (2020). *E3-India: Technical model manual*. https://www.camecon.com/how/e3-india-model/

Capellán-Pérez, I., Blas, I. de, Nieto, J., Castro, C. de, Javier Miguel, L., Carpintero, Ó., Mediavilla, M., Fernando Lobejón, L., Ferreras-Alonso, N., Rodrigo, P., Frechoso, F., & Álvarez-Antelo, D. (2020). MEDEAS: A new modeling framework integrating global biophysical and socioeconomic constraints. *Energy & Environmental Science*, *13*(3), 986–1017. https://doi.org/10.1039/C9EE02627D

Capros, P., Van Regemorter, D., Paroussos, L., Karkatsoulis, P., Fragkiadakis, C., Tsani, S., Charalampidis, I., Revesz, T., Perry, M., Abrell, J., Ciscar, J. C., Pycroft, J., & Saveyn, B. (2013). *GEM-E3 model documentation.* (Vol. JRC83177). Publications Office of the European Union. https://data.europa.eu/doi/10.2788/47872

Caverzasi, E., & Godin, A. (2013). *Stock-Flow Consistent Modeling Through the Ages* (SSRN Scholarly Paper 2196498). https://doi.org/10.2139/ssrn.2196498

Cazcarro, I., Amores, A. F., Arto, I., & Kratena, K. (2022). Linking multisectoral economic models and consumption surveys for the European Union. *Economic Systems Research*, *34*(1), 22–40. https://doi.org/10.1080/09535314.2020.1856044

Černý, M., Bruckner, M., Weinzettel, J., Wiebe, K., Kimmich, C., Kerschner, C., & Hubacek, K. (2022). *Employment effects of the renewable energy transition in the electricity* *sector: An input-output approach* (SSRN Scholarly Paper 4013339). https://doi.org/10.2139/ssrn.4013339

Château, J., Dellink, R., & Lanzi, E. (2014). *An Overview of the OECD ENV-Linkages Model: Version 3*. OECD. https://doi.org/10.1787/5jz2qck2b2vd-en

Cieplinski, A., D'Alessandro, S., Dwarkasing, C., & Guarnieri, P. (2023). Narrowing women's time and income gaps: An assessment of the synergies between working time reduction and universal income schemes. *World Development*, *167*, 106233. https://doi.org/10.1016/j.worlddev.2023.106233

CMCC (Director). (2021, May 26). *Critical reflection of Integrated Assessment Models (IAMs) scenarios*. https://www.youtube.com/watch?v=7noSsOccanc

Conte, A., Labat, A., Varga, J., & Žarnic, Ž. (2010). *What is the growth potential of green innovation?: An assessment of EU climate policy options*. European Commission. https://data.europa.eu/doi/10.2765/42348

Cordier, M., Uehara, T., Weih, J., & Hamaide, B. (2017). An Input-output Economic Model Integrated Within a System Dynamics Ecological Model: Feedback Loop Methodology Applied to Fish Nursery Restoration. *Ecological Economics*, *140*, 46–57. https://doi.org/10.1016/j.ecolecon.2017.04.005

Coyle, R. G. (1996). *System Dynamics Modelling: A practical approach*. Springer US. http://gen.lib.rus.ec/book/index.php?md5=16cfd8bce9a21009dd3b4a05955340d1

Crookes, D. J., & De Wit, M. P. (2014). Is System Dynamics Modelling of Relevance to Neoclassical Economists? *South African Journal of Economics*, *82*(2), 181–192. https://doi.org/10.1111/saje.12038

Dafermos, Y., Nikolaidi, M., & Galanis, G. (2017). A stock-flow-fund ecological macroeconomic model. *Ecological Economics*, *131*, 191–207. https://doi.org/10.1016/j.ecolecon.2016.08.013

D'Alessandro, S., Cieplinski, A., Distefano, T., & Dittmer, K. (2020). Feasible alternatives to green growth. *Nature Sustainability*, *3*(4), 329–335. https://doi.org/10.1038/s41893-020-0484-y

Davis, M., Benzie, M., & Barrott, J. (2016). *Transnational climate change impacts: An entry point to enhanced global cooperation on adaptation?* Stockholm Environment Institute. https://www.jstor.org/stable/resrep02803

De Vroey, M. R. (2010). Lucas on the Lucasian Transformation of Macroeconomics: An Assessment. *SSRN Electronic Journal*. https://doi.org/10.2139/ssrn.1694579

Decker, S., Elsner, W., & Flechtner, S. (Eds.). (2019). *Principles and Pluralist Approaches in Teaching Economics: Towards a Transformative Science* (1st ed.). Routledge. https://doi.org/10.4324/9781315177731

Deissenberg, C., Van Der Hoog, S., & Dawid, H. (2008). EURACE: A massively parallel agent-based model of the European economy. *Applied Mathematics and Computation*, *204*(2), 541–552. https://doi.org/10.1016/j.amc.2008.05.116

Dellink, R., Chateau, J., Lanzi, E., & Magné, B. (2017). Long-term economic growth projections in the Shared Socioeconomic Pathways. *Global Environmental Change*, *42*, 200–214. https://doi.org/10.1016/j.gloenvcha.2015.06.004

Detzer, D. (2018). Inequality, emulation and debt: The occurrence of different growth regimes in the age of financialization in a stock-flow consistent model. *Journal of Post Keynesian Economics*, *41*(2), 284–315. https://doi.org/10.1080/01603477.2017.1387499

Diefenbacher, H., Gechert, S., Rietzler, K., Gran, C., Neumann, K., Linsenmeier, M., Oehlmann, M., & Zieschank, R. (2020). *Analyse einer Integration von Umweltindikatoren und alternativen Wohlfahrtsmaßen in ökonomische Modelle* (189/2020). Umweltbundesamt. https://www.umweltbundesamt.de/publikationen/analyse-einer-integration-von-umweltindikatoren

Dixon, P., & Rimmer, M. (2001). *Dynamic general equilibrium modelling for forecasting and policy: A practical guide and documentation of MONASH.* (Emerald Group Publishing Limited).

Dixson-Decleve, S., Gaffney, O., Ghosh, J., Randers, J., Rockström, J., & Stoknes, P. E. (2022). *Earth for All: A Survival Guide for Humanity*. New Society Publishers. http://gen.lib.rus.ec/book/index.php?md5=345D5AAA97FE909092019108C5F96730

Dosi, G., & Roventini, A. (2019). More is different ... And complex! The case for agent-based macroeconomics. *Journal of Evolutionary Economics*, *29*(1), 1–37. https://doi.org/10.1007/s00191-019-00609-y

Duchin, F. (2005). A world trade model based on comparative advantage with m regions, n goods, and k factors. *Economic Systems Research*, *17*(2), 141–162. https://doi.org/10.1080/09535310500114903

Duchin, F., & Lange, G.-M. (1995). The choice of technology and associated changes in prices in the U.S. economy. *Structural Change and Economic Dynamics*, *6*(3), 335–357. https://doi.org/10.1016/0954-349X(95)00023-G

Duchin, F., & Levine, S. H. (2016). Combining Multiregional Input-Output Analysis with a World Trade Model for Evaluating Scenarios for Sustainable Use of Global Resources, Part II: Implementation. *Journal of Industrial Ecology*, *20*(4), 783–791. https://doi.org/10.1111/jiec.12302

Duchin, F., Levine, S. H., & Strømman, A. H. (2016). Combining Multiregional Input-Output Analysis with a World Trade Model for Evaluating Scenarios for Sustainable Use of Global Resources, Part I: Conceptual Framework. *Journal of Industrial Ecology*, *20*(4), 775–782. https://doi.org/10.1111/jiec.12303

Đula, I., Videira, N., & Größler, A. (2021). Degrowth dynamics: Modelling policy proposals with system dynamics. *Journal of Simulation*, *15*(1–2), 93–129. https://doi.org/10.1080/17477778.2019.1646108

EC, IMF, OECD, UN, & World Bank. (2009). *System of National Accounts 2008*. European Commission, International Monetary Fund, Organisation for Economic Co-operation and Development, United Nations and the World Bank. http://unstats.un.org/unsd/nationalaccount/docs/SNA2008.pdf

ElSawah, S., Haase, D., van Delden, H., Pierce, S., ElMahdi, A., Voinov, A. A., & Jakeman, A. J. (2012). *Using system dynamics for environmental modelling: Lessons learnt from six case studies*. 2012 International Congress on Environmental Modelling and Software Managing Resources of a Limited Planet, Sixth Biennial Meeting, Leipzig, Germany.

European Commission. Directorate General for Communications Networks, Content and Technology., Garbasso, G., Bianchini, D., & Tortis, M. (2021). *Study to support the impact assessment for the revision of the eIDAS regulation: Final report*. Publications Office. https://data.europa.eu/doi/10.2759/671740

European Commission. Joint Research Centre., Reynes, F., Rocchi, P., & Salotti, S. (2019). *FIDELIO 3 manual: Equations and data sources*. Publications Office. https://data.europa.eu/doi/10.2760/219417

European Commission. Joint Research Centre. & WIFO. (2017). *FIDELIO 2: Overview and theoretical foundations of the second version of the fully interregional dynamic econometric long term input output model for the EU 27*. Publications Office. https://data.europa.eu/doi/10.2760/313390

Explore MIDAS by model combinations. (2023). https://web.jrc.ec.europa.eu/policy-model-inventory/explore/models/models-ia-combinations

Forrester, J. W. (1961). *Industrial Dynamics*. The M.I.T Press.

Forrester, J. W. (1971). *World Dynamics* (2nd ed.). Pegasus Communications. http://gen.lib.rus.ec/book/index.php?md5=80627eb7293f322b81e2e62739b5f8b3

Forrester, J. W. (2007). System dynamics—A personal view of the first fifty years. *System Dynamics Review*, *23*(2–3), 345–358. https://doi.org/10.1002/sdr.382

Gibson-Graham, J. K. (2006). *A postcapitalist politics* (U of Minnesota Press).

Goda, T., Onaran, Ö., & Stockhammer, E. (2017). Income Inequality and Wealth Concentration in the Recent Crisis: Income Inequality and Wealth Concentration in the Recent Crisis. *Development and Change*, *48*(1), 3–27. https://doi.org/10.1111/dech.12280

Godley, W., & Lavoie, M. (2007). *Monetary economics: An integrated approach to credit, money, income, production and wealth*. Palgrave Macmillan.

Gran, C., Gechert, S., & Barth, J. (2019). *Growth, Prosperity and the environment: Integrating environmental and social indicators into QUEST* (4; ZOE Discussion Papers). ZOE Institute for Future-fit Economies.

Haldane, A. G., & Turrell, A. E. (2018). An interdisciplinary model for macroeconomics. *Oxford Review of Economic Policy*, *34*(1–2), 219–251. https://doi.org/10.1093/oxrep/grx051

Hardt, L., & O'Neill, D. W. (2017). Ecological Macroeconomic Models: Assessing Current Developments. *Ecological Economics*, *134*, 198–211. https://doi.org/10.1016/j.ecolecon.2016.12.027

Heijdra, B. J., & Ter Weel, B. (2019). Jan Tinbergen: Engineering a Better World: Celebrating Fifty Years of Nobel Prizes in Economics. *De Economist*, *167*(3), 215–219. https://doi.org/10.1007/s10645-019-09348-8

Hertel, T. W. (1997). *Global trade analysis: Modeling and applications* (Cambridge university press).

Hidalgo, C. A., & Hausmann, R. (2009). The building blocks of economic complexity. *Proceedings of the National Academy of Sciences*, *106*(26), 10570–10575. https://doi.org/10.1073/pnas.0900943106

Hoekstra, R. (2019). *Replacing GDP by 2030: Towards a common language for the well-being and sustainability community* (First Edition). Cambridge University Press.

Hoffmann, H., & Payton, D. W. (2018). Optimization by Self-Organized Criticality. *Scientific Reports*, *8*(1), 2358. https://doi.org/10.1038/s41598-018-20275-7

IEA, I. E. (2023). *World energy balances* [Doi:https://doi.org/10.1787/data-00512-en]. https://www.oecd-ilibrary.org/content/data/data-00512-en

Inforum. (2022). *Inforum: Economic Forecasting and Analysis*. https://inforumecon.com/about-us/

Jackson, T., & Victor, P. A. (2015). Does credit create a 'growth imperative'? A quasi-stationary economy with interest-bearing debt. *Ecological Economics*, *120*, 32–48. https://doi.org/10.1016/j.ecolecon.2015.09.009

Jackson, T., & Victor, P. A. (2020). The Transition to a Sustainable Prosperity-A Stock-Flow-Consistent Ecological Macroeconomic Model for Canada. *Ecological Economics*, *177*, 106787. https://doi.org/10.1016/j.ecolecon.2020.106787

Jackson, T., Victor, P. A., & Naqvi, Asjad. (2016). Towards a Stock-Flow Consistent Ecological Macroeconomics. *Econstor*. https://www.econstor.eu/bitstream/10419/146611/1/856194174.pdf

Jansen, A., Hoekstra, R., Kaufmann, R., & Gerer, A. (2023). *A synthesis of Beyond-GDP metrics for Wellbeing, Inclusion and Sustainability: Including a deep-dive into EU metrics and their role in governance.* (Final Version of WISE Horizons Deliverable 1.1.).

Kaldor, N. (1961). Capital Accumulation and Economic Growth. In D. C. Hague & F. A. Lutz (Eds.), *The Theory of Capital: Proceedings of a Conference held by the International Economic Association*. Palgrave Macmillan UK. https://doi.org/10.1007/978-1-349-08452-4

Kaufmann, R., Barth, J., Steffens, L., Le Lannou, L.-A., Gerer, A., & Kiecker, S. (2023). *Mainstreaming wellbeing and sustainability in policymaking: Technical and governance levers out of the institutional GDP lock-in*. ZOE-Institute for Future-fit Economies. https://zoe-institut.de/wp-content/uploads/2023/03/ZOE_Mainstreaming-wellbeing-and-sustainability-in-policymaking.pdf

Keynes, J. M. (1921). *A treatise on probability*. Dover Publications.

Keynes, J. M. (1936). The General Theory of Employment, Interest and Money. *The General Theory of Employment, Interest and Money*.

Kim, K., Kratena, K., & Hewings, G. J. D. (2015). The Extended Econometric Input–Output Model with Heterogeneous Household Demand System. *Economic Systems Research*, *27*(2), 257–285. https://doi.org/10.1080/09535314.2014.991778

Kirsten S. Wiebe, Fabian R. Aponte, & Nikki Luttikhuis. (2021, February 16). *eaSi-system—Framework for systematic SDG impacts assessment*. SINTEF. https://www.sintef.no/en/projects/2020/easi-system-framework-for-systematic-sdg-impacts-assessment/

Klein, L. R. (1976). Project LINK: Linking National Economic Models. *Challenge*, *19*(5), 25–29. https://doi.org/10.1080/05775132.1976.11470258

Kratena, K., Streicher, G., Temurshoev, U., De, A. H. A., Arto, O. I., Mongelli, I., Neuwahl, F., Rueda-Cantuche, J. M., & Andreoni, V. (2013, June 5). *FIDELIO 1: Fully Interregional Dynamic Econometric Long-term Input-Output Model for the EU27*. JRC Publications Repository. https://doi.org/10.2791/17619

Landreth, H., & Colander, D. (2002). *History of economic thought.: Vol. 4th edition*. Houghton Mifflin Company.

Lecca, P., Barbero Jimenez, J., Christensen, M., Conte, A., Di Comite, F., Diaz Lanchas, J., Diukanova, O., Mandras, G., Persyn, D., & Sakkas, S. (2018). *RHOMOLO V3: A spatial modelling framework.* (Vol. JRC111861). Publications Office of the European Union. https://data.europa.eu/doi/10.2760/671622

Lenzen, M., Geschke, A., West, J., Fry, J., Malik, A., Giljum, S., Milà i Canals, L., Piñero, P., Lutter, S., Wiedmann, T., Li, M., Sevenster, M., Potočnik, J., Teixeira, I., Van Voore, M., Nansai, K., & Schandl, H. (2022). Implementing the material footprint to measure progress towards Sustainable Development Goals 8 and 12. *Nature Sustainability*, *5*(2), Article 2. https://doi.org/10.1038/s41893-021-00811-6

Lenzen, M., Kanemoto, K., Moran, D., & Geschke, A. (2012). Mapping the Structure of the World Economy. *Environmental Science & Technology*, *46*(15), 8374–8381. https://doi.org/10.1021/es300171x

Lenzen, M., Moran, D., Kanemoto, K., & Geschke, A. (2013). Building Eora: A Global Multi-Region Input–Output Database at High Country and Sector Resolution. *Economic Systems Research*, *25*(1), 20–49. https://doi.org/10.1080/09535314.2013.769938

Leoni, D., Jackson, A., & Jackson, T. (2023). *Post Growth and the North-South Divide: A post-Keynesian stock-flow consistent analysis.* [CUSP Working Paper No. 38]. Guildford: Centre for the Understanding of Sustainable Prosperity.

Liu, D., Zheng, X., & Wang, H. (2020). Land-use Simulation and Decision-Support system (LandSDS): Seamlessly integrating system dynamics, agent-based model, and cellular automata. *Ecological Modelling*, *417*, 108924. https://doi.org/10.1016/j.ecolmodel.2019.108924

Lucas, R. E. (1976). Econometric policy evaluation: A critique. *Carnegie-Rochester Conference Series on Public Policy*, *1*, 19–46. https://doi.org/10.1016/S0167-2231(76)80003-6

Lutz, C., Meyer, B., & Wolter, M. I. (2010). The global multisector/multicountry 3-E model GINFORS. A description of the model and a baseline forecast for global energy demand and CO<SUB align=right>2 emissions. *International Journal of Global Environmental Issues*, *10*(1/2), 25. https://doi.org/10.1504/IJGENVI.2010.030567

Lutz, U. L., Christian. (2019). Macro-econometric and structural models. In *Routledge Handbook of Energy Economics*. Routledge.

Mair, S. (2020). Neoliberal economics, planetary health, and the COVID-19 pandemic: A Marxist ecofeminist analysis. *The Lancet Planetary Health*, *4*(12), e588–e596. https://doi.org/10.1016/S2542-5196(20)30252-7

McCarthy, A., Dellink, R., & Bibas, R. (2018). *The Macroeconomics of the Circular Economy Transition: A Critical Review of Modelling Approaches* (OECD Environment Working Papers 130; OECD Environment Working Papers, Vol. 130). https://doi.org/10.1787/af983f9a-en

Meadows, D. H., Meadows, D. L., Randers, J., & III, W. W. B. (1972). *The Limits to Growth*. Signet. http://gen.lib.rus.ec/book/index.php?md5=e2f8ee41f32a56faafa7c8f2e9ba4439

Mercure, J.-F., Knobloch, F., Pollitt, H., Paroussos, L., Scrieciu, S. S., & Lewney, R. (2019). Modelling innovation and the macroeconomics of low-carbon transitions: Theory, perspectives and practical use. *Climate Policy*, *19*(8), 1019–1037. https://doi.org/10.1080/14693062.2019.1617665

Mercure, J.-F., Pollitt, H., Edwards, N. R., Holden, P. B., Chewpreecha, U., Salas, P., Lam, A., Knobloch, F., & Vinuales, J. E. (2018). Environmental impact assessment for climate change policy with the simulation-based integrated assessment model E3ME-FTT-GENIE. *Energy Strategy Reviews*, *20*, 195–208. https://doi.org/10.1016/j.esr.2018.03.003

Meyer, B., & Lutz, C. (2002). Endogenized trade shares in a global model. In K. Uno (Ed.), *Economy-Energy-Environment Simulation* (Vol. 20, pp. 69–80). Kluwer Academic Publishers. https://doi.org/10.1007/0-306-47549-9_4

Miller, R. E., & Blair, P. D. (2009). *Input-Output Analysis: Foundations and Extensions* (2nd ed.). Cambridge University Press.

Montt, G., Wiebe, K. S., Harsdorff, M., Simas, M., Bonnet, A., & Wood, R. (2018). Does climate action destroy jobs? An assessment of the employment implications of the 2-degree goal. *International Labour Review*, *157*(4), 519–556. https://doi.org/10.1111/ilr.12118

Morgan, M. S. (2019). Recovering Tinbergen. *De Economist*, *167*(3), 283–295. https://doi.org/10.1007/s10645-019-09346-w

Nikiforos, M., & Zezza, G. (2018). Stock-Flow Consistent Macroeconomic Models: A Survey. In R. Veneziani & L. Zamparelli (Eds.), *Analytical Political Economy* (pp. 63–102). John Wiley & Sons, Ltd. https://doi.org/10.1002/9781119483328.ch4

Nozaki, N., Ai, Z., Hanasaki, N., Iizumi, T., Kiguchi, M., Kim, W., Oki, T., Rimba, A. B., Tokuda, D., & Hirabayashi, Y. (2023). Side effects of climate mitigation and adaptation to sustainable development related to water and food. *Environmental Research Letters*, *18*(8), 081005. https://doi.org/10.1088/1748-9326/ace922

OECD. (2008). *OECD Glossary of Statistical Terms*. Organisation for Economic Co-operation and Development. https://www.oecd-ilibrary.org/economics/oecd-glossary-of-statistical-terms_9789264055087-en

OECD. (2021a). *Carbon dioxide emissions embodied in international trade—OECD* [dataset]. https://www.oecd.org/sti/ind/carbondioxideemissionsembodiedininternationaltrade.htm

OECD. (2021b). *OECD Inter-Country Input-Output (ICIO) Tables—OECD* [dataset]. https://www.oecd.org/sti/ind/inter-country-input-output-tables.htm

OECD. (2022). *Employment and Global Value Chains (GVCs)—OECD* [dataset]. https://www.oecd.org/sti/ind/trade-in-employment.htm

OECD. (2013). *THE OECD ENV-GROWTH MODELLING FRAMEWORK*. https://www.oecd.org/environment/indicators-modelling-outlooks/Flyer%20ENV-Growth%20model%20-%20version%2025%20Sept%202013.pdf

OECD. (2023). *METRO trade model—OECD*. https://www.oecd.org/trade/topics/metro-trade-model/

O’Neill, D. (Director). (2021). *What is Ecological Economics?* [Video]. https://www.youtube.com/watch?v=vUF7s4Bp_ok&t=71s&ab_channel=DanO%27Neill

Ouliaris, S. (2011, June). Back to Basics: What Are Economic Models? *Finance and Development | F&D*, *48*(2), 46–47.

Pindyck, R. S. (2013). Climate Change Policy: What Do the Models Tell Us? *Journal of Economic Literature*, *51*(3), 860–872. https://doi.org/10.1257/jel.51.3.860

Pollitt, H. (2017). Capacity constraints and macroeconomic performance. *European Commission, Directorate-General for Energy, Contract No. ENER/A4/2015-436/SER/S12.716128*.

Pollitt, H., Lewney, R., & Mercure, J.-F. (2019). Conceptual differences between macro-econometric and CGE models. *Proceedings of the 27th International Input-Output Conference*. https://www.iioa.org/conferences/27th/papers/files/3597_20190430081_IIOApaperE3MEsession.pdf

Pollitt, H., & Mercure, J.-F. (2018). The role of money and the financial sector in energy-economy models used for assessing climate and energy policy. *Climate Policy*, *18*(2), 184–197. https://doi.org/10.1080/14693062.2016.1277685

Proctor, J. C. (2023). Expanding the possible: Exploring the role for heterodox economics in integrated climate-economy modeling. *Review of Evolutionary Political Economy*. https://doi.org/10.1007/s43253-023-00098-7

Rademaekers, K., Svatikova, K., Vermeulen, J., Smit, T., & Baroni, L. (2018). *Environmental potential of the collaborative economy: Final report and annexes.* European Commission. Directorate General for the Environment. https://data.europa.eu/doi/10.2779/518554

Radzicki, M. J. (2008). Institutional Economics, Post-Keynesian Economics, and System Dynamics: Three Strands of. In R. Garnett & J. Harvey (Eds.), *Future Directions for Heterodox Economics* (pp. 156–184). University of Michigan Press.

Radzicki, M. J. (2020). System Dynamics and Its Contribution to Economics and Economic Modeling. In B. Dangerfield (Ed.), *System Dynamics: Theory and Applications* (pp. 401–415). Springer US. https://doi.org/10.1007/978-1-4939-8790-0_539

Ratto, M., Roeger, W., & Veld, J. I. ’T V. (2009). QUEST III: An estimated open-economy DSGE model of the euro area with fiscal and monetary policy. *Economic Modelling*, *26*(1), 222–233. https://doi.org/10.1016/j.econmod.2008.06.014

Raworth, K. (2017). *Doughnut Economics: Seven Ways to Think Like a 21st-Centruy Economist*. Penguin Random House.

Ricardo Hausmann, Jason Hwang, & Dani Rodrick. (2005). What you exports matters. *NBER Working Paper Series*, *11905*. https://www.nber.org/system/files/working_papers/w11905/w11905.pdf

Roeger, W., Varga, J., Veld, J. in ’t, & Vogel, L. (2019). *A model-based assessment of the distributional impact of structural reforms.* Directorate-General for Economic and Financial Affairs. https://data.europa.eu/doi/10.2765/426394

Rosendahl, K. E., Bjørndal, M. H., Fæhn, T., Knallbekken, S., Madlien, A., Sørensen, E., & Tomasgard, A. (2021). *Makromodeller til bruk i klimaanalyser* (M–2110; Rapport Fra Teknisk Beregningsutvalg for Klima). oppnevnt av Regjeringen 15. juni 2018.

Saget, C., Vogt-Schilb, A., & Luu, T. (2020). *El empleo en un futuro de cero emisiones netas en América Latina y el Caribe*. https://doi.org/10.18235/0002509

Sarkhosh-Sara, A., Nasrollahi, K., Azarbayejani, K., & Jamalmanesh, A. (2022). Testing Piketty’s Hypothesis in Analyzing Factors Affecting Income Inequality in Iran: Stock-Flow Consistent (SFC) Approach. *Iranian Economic Review*, *26*(3). https://doi.org/10.22059/ier.2022.89092

Scheinkman, J. A., & Woodford, M. (1994). Self-Organized Criticality and Economic Fluctuations. *The American Economic Review*, *84*(2), 417–421.

Schumpeter, J. A. (2006). *History of economic analysis*. Routledge.

Simas, M., Wiebe, K. S., Sodersten, C. J., & Harsdorff, M. (2022). *Social and Employment Impacts of Climate Change and Green Economy Policies in Türkiye*. ILO, UNDP.

Solé, J., Samsó, R., García-Ladona, E., García-Olivares, A., Ballabrera-Poy, J., Madurell, T., Turiel, A., Osychenko, O., Álvarez, D., Bardi, U., Baumann, M., Buchmann, K., Capellán-Pérez, Í., Černý, M., Carpintero, Ó., De Blas, I., De Castro, C., De Lathouwer, J.-D., Duce, C., … Theofilidi, M. (2020). Modelling the renewable transition: Scenarios and pathways for a decarbonized future using pymedeas, a new open-source energy systems model. *Renewable and Sustainable Energy Reviews*, *132*, 110105. https://doi.org/10.1016/j.rser.2020.110105

Stadler, K., Wood, R., Bulavskaya, T., Södersten, C.-J., Simas, M., Schmidt, S., Usubiaga, A., Acosta-Fernández, J., Kuenen, J., Bruckner, M., Giljum, S., Lutter, S., Merciai, S., Schmidt, J. H., Theurl, M. C., Plutzar, C., Kastner, T., Eisenmenger, N., Erb, K.-H., … Tukker, A. (2018). EXIOBASE 3: Developing a Time Series of Detailed Environmentally Extended Multi-Regional Input-Output Tables. *Journal of Industrial Ecology*, *22*(3), 502–515. https://doi.org/10.1111/jiec.12715

Steffen, W., Richardson, K., Rockström, J., Cornell, S. E., Fetzer, I., Bennett, E. M., Biggs, R., Carpenter, S. R., Vries, W. de, Wit, C. A. de, Folke, C., Gerten, D., Heinke, J., Mace, G. M., Persson, L. M., Ramanathan, V., Reyers, B., & Sörlin, S. (2015). Planetary boundaries: Guiding human development on a changing planet. *Science*, *347*(6223), 1259855. https://doi.org/10.1126/science.1259855

Sterman, J. D. (2001). System Dynamics Modeling: Tools for Learning in a Complex World. *California Management Review*, *43*(4), 8–25. https://doi.org/10.2307/41166098

Stiglitz, J. E. (2000). The Contributions of the Economics of Information to Twentieth Century Economics. *The Quarterly Journal of Economics*, *115*(4), 1441–1478.

Uddin, M. N., Wang, Q., Wei, H. H., Chi, H. L., & Ni, M. (2021). Building information modeling (BIM), System dynamics (SD), and Agent-based modeling (ABM): Towards an integrated approach. *Ain Shams Engineering Journal*, *12*(4), 4261–4274. https://doi.org/10.1016/j.asej.2021.04.015

Uehara, T., Cordier, M., & Hamaide, B. (2018). Fully Dynamic Input-Output/System Dynamics Modeling for Ecological-Economic System Analysis. *Sustainability*, *10*(6), Article 6. https://doi.org/10.3390/su10061765

UN DESA. (2023). *Towards the 2025 SNA*. https://unstats.un.org/unsd/nationalaccount/towards2025.asp

United Nations, European Commission, International Monetary Fund, Organisation for Economic Co-operation and Development, & World Bank (Eds.). (2009). *System of national accounts 2008*. United Nations.

van Beek, L., Hajer, M., Pelzer, P., van Vuuren, D., & Cassen, C. (2020). Anticipating futures through models: The rise of Integrated Assessment Modelling in the climate science-policy interface since 1970. *Global Environmental Change*, *65*, 102191. https://doi.org/10.1016/j.gloenvcha.2020.102191

Van Soest, H. L., Van Vuuren, D. P., Hilaire, J., Minx, J. C., Harmsen, M. J. H. M., Krey, V., Popp, A., Riahi, K., & Luderer, G. (2019). Analysing interactions among Sustainable Development Goals with Integrated Assessment Models. *Global Transitions*, *1*, 210–225. https://doi.org/10.1016/j.glt.2019.10.004

van Vuuren, D. P., Lowe, J., Stehfest, E., Gohar, L., Hof, A. F., Hope, C., Warren, R., Meinshausen, M., & Plattner, G.-K. (2011). How well do integrated assessment models simulate climate change? *Climatic Change*, *104*(2), 255–285. https://doi.org/10.1007/s10584-009-9764-2

Varga, J., Roeger, W., & Veld, J. in ’t. (2021). *E-QUEST, a multi-region sectoral dynamic general equilibrium model with energy: Model description and applications to reach the EU climate targets.* Publications Office. https://data.europa.eu/doi/10.2765/954483

Victor, P. A., & Rosenbluth, G. (2007). Managing without growth. *Ecological Economics*, *61*(2), 492–504. https://doi.org/10.1016/j.ecolecon.2006.03.022

Vita, G., Lundström, J. R., Hertwich, E. G., Quist, J., Ivanova, D., Stadler, K., & Wood, R. (2019). The Environmental Impact of Green Consumption and Sufficiency Lifestyles Scenarios in Europe: Connecting Local Sustainability Visions to Global Consequences. *Ecological Economics*, *164*, 106322. https://doi.org/10.1016/j.ecolecon.2019.05.002

Wang, P. P., Li, Y. P., Huang, G. H., Wang, S. G., Suo, C., & Ma, Y. (2021). A multi-scenario factorial analysis and multi-regional input-output model for analyzing CO2 emission reduction path in Jing-Jin-Ji region. *Journal of Cleaner Production*, *300*, 126782. https://doi.org/10.1016/j.jclepro.2021.126782

Wassily Leontief. (1986). Technological change, prices, wages, and rates of return on capital in the U.S. economy. In *Input–Output Economics* (pp. 392–417). Oxgord University Press.

https://scholar.google.com/scholar_lookup?hl=en&publication_year=1986&pages=392-417&author=W.+Leontief&title=+Input%E2%80%93Output+Economics+

Wassily Leontief, Anne P. Carter, & Peter A. Petri. (1977). *The Future of the World Economy*. Oxford University Press.

Wiebe, K. S., Andersen, T., Simas, M., & Harsdorff, M. (2021). *Zimbabwe Green Jobs Assessment Report*. ILO, UNDP.

Wiebe, K. S., Bjelle, E. L., Többen, J., & Wood, R. (2018). Implementing exogenous scenarios in a global MRIO model for the estimation of future environmental footprints. *Journal of Economic Structures*, *7*(1), 20. https://doi.org/10.1186/s40008-018-0118-y

Wiebe, K. S., Harsdorff, M., Montt, G., Simas, M. S., & Wood, R. (2019). Global Circular Economy Scenario in a Multiregional Input–Output Framework. *Environmental Science & Technology*, *53*(11), 6362–6373. https://doi.org/10.1021/acs.est.9b01208

Wiebe, K. S., Simas, M., & Harsdorff, M. (2021). *Nigeria Green Jobs Assessment Report*. ILO, UNDP.

World Bank. (2022, April 26). Macroeconomics. *Macroeconomics*. https://www.worldbank.org/en/topic/macroeconomics/overview

Zhou, W., McCollum, D. L., Fricko, O., Fujimori, S., Gidden, M., Guo, F., Hasegawa, T., Huang, H., Huppmann, D., Krey, V., Liu, C., Parkinson, S., Riahi, K., Rafaj, P., Schoepp, W., Yang, F., & Zhou, Y. (2020). Decarbonization pathways and energy investment needs for developing Asia in line with ‘well below’ 2°C. *Climate Policy*, *20*(2), 234–245. https://doi.org/10.1080/14693062.2020.1722606

APPENDIX A. WISE REPRESENTATION IN GEM AND MACRO-ECONOMETRIC IO MODELS BASED ON MIDAS AND KNOWSSDGS

The tables below summarize the coverage of social, environmental and fundamental right impacts of the models reviewed in MIDAS. The MIDAS impact areas also include economic impacts[16], but we do not list all of those here as we focus on the representation of well-being, inclusion and sustainability in economic models. Among the social effects are also " Public Health And Safety And Health Systems", however, none of the models included in the review of macro-economic models (GEM and macro-econometric IO) reflect this dimension. Only those impact models, that can be classified as integrated assessment models., such as GAINS or VM model or MELISA. Regarding "Efficient Use Of Resources (Renewable & Non-Renewable)", "Land use", "Soil quality or resources", " Waste Production / Generation / Recycling", "Water Quality And Resources" which are part of impact category Environment, is not represented in any of the detailed macro-economic models reviewed here in detail. Those are represented in partial models, or in the integrated assessment models that have an aggregate representation of the economy.

Table 3: WISE representation in General Equilibrium Models

Model	Model type	SDG coverage	WISE representation through SDGs	MIDAS impact area Social[17]	MIDAS impact area Environment[18]	MIDAS impact area Fundamental rights[19]
GTAP CGE	CGE	NA	NA	NA	NA	NA
MONASH	CGE	NA	NA	NA	NA	NA
GEM-E3[20]	CGE	1, 2, 3, 7, 8, 9, 10,	Representative Household income,	Households income and at risk of poverty rates,	Air Quality, Emission of greenhouse gases, Economic	

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[16] https://web.jrc.ec.europa.eu/policy-model-inventory/explore/impact-types/economy/

[17] https://web.jrc.ec.europa.eu/policy-model-inventory/explore/impact-types/social/

[18] https://web.jrc.ec.europa.eu/policy-model-inventory/explore/impact-types/environment/

[19] https://web.jrc.ec.europa.eu/policy-model-inventory/explore/impact-types/fundamental-rights/

[20] https://knowsdgs.jrc.ec.europa.eu/themes/sdgs/assets/pdf/models-mapping-factsheets/gem-e3.pdf

Model	Model type	SDG coverage	WISE representation through SDGs	MIDAS impact area Social[17]	MIDAS impact area Environment[18]	MIDAS impact area Fundamental rights[19]
		11, 12, 13, 17	Impact of climate and energy policies on food prices, Decarbonisation of all sectors in the supply chain, International trade is modelled, Air pollution, macroeconomic impact, Sectoral output and employment and emissions	Inequalities and the distribution of incomes and wealth, Access to and quality of social protection benefits, Economic growth and employment, Impact on jobs, Impact on jobs in specific sectors, professions, regions or countries, Indirect effects on employment levels, Employment, social protection and poverty impacts in non-Member States (including developing countries), Wages, labour costs or wage setting mechanisms	incentives set up by market based mechanisms, International Environmental Impacts, Sustainable production and consumption, Relative prices of environmental friendly and unfriendly products, Pollution by businesses, Energy intensity of the economy, Fuel mix used in energy production, Energy and fuel consumption, Vehicle emissions, Demand for transport	
RHOMOLO[21]	CGE	8, 9, 10	Analysis of economic growth, productivity growth, R&D, employment creation, Unemployment rate by skill (L, M, H), Net disposable income by skill (L, M, H), Analysis of fiscal policies and net disposable income by skill to look at	Impact on jobs, Impact on jobs in specific sectors, professions, regions or countries, Factors preventing or enhancing the potential to create jobs or prevent job losses		

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[21] https://knowsdgs.jrc.ec.europa.eu/themes/sdgs/assets/pdf/models-mapping-factsheets/rhomolo.pdf

Model	Model type	SDG coverage	WISE representation through SDGs	MIDAS impact area Social[17]	MIDAS impact area Environment[18]	MIDAS impact area Fundamental rights[19]
			inequality			
QUEST[22]	DSGE	4, 7, 8, 9, 10, 12, 17	Some versions of the model: differentiated skill in labor market, explicit role for climate policies and green R&D modelling by introducing nonenergy and energy composite, R&D and product innovation, and their associated productivity and employment linkages, some level of households disaggregation (differentiated skills, wages), global trade dynamics, e.g. the effect of tariff shocks.	Inequalities and the distribution of incomes and wealth, Economic growth and employment, Impact on jobs, Impact on jobs in specific sectors, professions, regions or countries, Indirect effects on employment levels, Wages, labour costs or wage setting mechanisms	Emission of greenhouse gases	
EU-EMS[23]	CGE	1, 4, 7, 8, 9, 10, 11, 12, 13, 17	Poverty indicators,	Level of education and training outcomes, Skills used by individuals, Education and mobility of workers, Access to education and training, Households income and at risk of poverty rates, Inequalities and the		

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[22] https://knowsdgs.jrc.ec.europa.eu/themes/sdgs/assets/pdf/models-mapping-factsheets/quest.pdf

[23] https://knowsdgs.jrc.ec.europa.eu/themes/sdgs/assets/pdf/models-mapping-factsheets/eu-ems.pdf

Model	Model type	SDG coverage	WISE representation through SDGs	MIDAS impact area Social[17]	MIDAS impact area Environment[18]	MIDAS impact area Fundamental rights[19]
				distribution of incomes and wealth, Financing and organisation of social protection systems, Access to and quality of social protection benefits & basic goods and services, Indirect effects on employment levels, Factors preventing or enhancing the potential to create jobs or prevent job losses, Employment, social protection and poverty impacts in non-Member States (including developing countries), Wages, labour costs or wage setting mechanisms		
EUROMOD[24]	CGE	1, 8, 10	tax and social benefit policies poverty for different categories of individuals (children, old age, women, lone parents, etc.), households disposable income, labour supply responses	Households income and at risk of poverty rates, Inequalities and the distribution of incomes and wealth, Financing and organisation of social protection systems, Impact on jobs, Impact on jobs in specific sectors, professions, regions or countries, Employment protection		Different impact on women and men
IO-DSGM	DSGE			Economic growth and employment, Impact on		Fundamental rights

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[24] https://knowsdgs.jrc.ec.europa.eu/themes/sdgs/assets/pdf/models-mapping-factsheets/euromod.pdf

Model	Model type	SDG coverage	WISE representation through SDGs	MIDAS impact area Social[17]	MIDAS impact area Environment[18]	MIDAS impact area Fundamental rights[19]
				jobs, Impact on jobs in specific sectors, professions, regions or countries, Indirect effects on employment levels, Wages, labour costs or wage setting mechanisms		
MAGNET[25]	CGE	1, 2, 7, 8, 9, 10, 12, 13, 15, 17	Per capita income distributed by income class, Food access & availability indicators, Share of household spending on energy, Relative competitiveness of fossil fuel to renewables, material footprints	Households income and at risk of poverty rates, Inequalities and the distribution of incomes and wealth, Impact on jobs, Impact on jobs in specific sectors, professions, regions or countries, Indirect effects on employment levels, Factors preventing or enhancing the potential to create jobs or prevent job losses, Wages, labour costs or wage setting mechanisms	Emission of greenhouse gases, International Environmental Impacts, Change in land use, Waste production, treatment, disposal or recycling, Sustainable production and consumption	
ENV-LINKAGE, ENV-Growth, METRO trade model	CGE	NA	NA	NA	NA	NA

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[25] https://knowsdgs.jrc.ec.europa.eu/themes/sdgs/assets/pdf/models-mapping-factsheets/magnet.pdf

Table 4: WISE representation in macro-econometric (and) input-output models

Model	**Model type**	**SDG coverage**	**WISE representation through SDGs**	**MIDAS impact area Social**[26]	**MIDAS impact area Environment**[27]	**MIDAS impact area Fundamental rights**[28]
E3ME	ME IO	NA	NA	Economic growth and employment, Impact on jobs, Impact on jobs in specific sectors, professions, regions or countries, Indirect effects on employment levels	Emission of greenhouse gases, International Environmental Impacts, Sustainable production and consumption, Relative prices of environmental friendly and unfriendly products, Pollution by businesses, Energy intensity of the economy, Fuel mix used in energy production, Energy and fuel consumption, Vehicle emissions, Demand for transport	
GINFORS(-E)	ME IO	NA	NA	Economic growth and employment, Impact on jobs, Impact on jobs in specific sectors, professions, regions or countries, Indirect effects on employment levels, Wages, labour costs or wage setting mechanisms	Air Quality, Emission of greenhouse gases, International Environmental Impacts, Sustainable production and consumption, Relative prices of environmental friendly and unfriendly products, Pollution by businesses, Energy intensity of the economy, Fuel mix used in energy	

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[26] https://web.jrc.ec.europa.eu/policy-model-inventory/explore/impact-types/social/

[27] https://web.jrc.ec.europa.eu/policy-model-inventory/explore/impact-types/environment/

[28] https://web.jrc.ec.europa.eu/policy-model-inventory/explore/impact-types/fundamental-rights/

Model	Model type	SDG coverage	WISE representation through SDGs	MIDAS impact area Social[26]	MIDAS impact area Environment[27]	MIDAS impact area Fundamental rights[28]
					production, Energy and fuel consumption, Vehicle emissions, Demand for transport	
FIDELIO[29]	ME IO	7, 8, 12, 13	macroeconomic impact of energy efficiency and sustainable consumption and production policy at country and sector level, limited heterogeneity across worker's characteristics, but detailed household conumption	NA	NA	NA
LINK	ME			NA	NA	NA
MFMOD [30]	ME			NA / Employment and wages		
NEMESIS				Economic growth and employment, Impact on jobs, Wages, labour costs or wage setting mechanisms	Emission of greenhouse gases, Energy intensity of the economy	
LUISA[31]	ME	8, 9, 11, 12, 15	GDP and employment at regional level, transport, built	NA	NA	NA

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[29] https://knowsdgs.jrc.ec.europa.eu/themes/sdgs/assets/pdf/models-mapping-factsheets/fidelio.pdf

[30] https://openknowledge.worldbank.org/server/api/core/bitstreams/3ef71fcd-2146-5c61-88af-a2e8453f5486/content

[31] https://knowsdgs.jrc.ec.europa.eu/themes/sdgs/assets/pdf/models-mapping-factsheets/luisa.pdf

Model	Model type	SDG coverage	WISE representation through SDGs	MIDAS impact area Social[26]	MIDAS impact area Environment[27]	MIDAS impact area Fundamental rights[28]
			environment, urbanisation and land use			
MaGE[32]	ME	5, 8	Gender employment gap, education and demography as determinants of economic growth	NA	NA	NA

APPENDIX B. MAIN CHARACTERISTICS OF SELECTED IAMs[33]

Model name	Description	Geographical coverage	Sector coverage	Time period	Indicators relevant for WISE approach
AIM/HUB	AIM is a one-year-step recursive-type dynamic general equilibrium model developed by the National Institute for Environmental Studies in Japan. Its focus is on impact mitigation of GHG emissions, the model has a detailed description of energy sources and energy demand according to exogenous drivers (population, policies, lifestyle). No evidence of feedback loops on the core model, inequality is not addressed, and lacks connection of other impacts related	17 regions of the world	42 industrial sectors	N/A not clearly specified	Well described emissions. Remuneration to households' soft link to wellbeing and SDG's . Economic losses caused by climate impacts.

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[32] https://knowsdgs.jrc.ec.europa.eu/themes/sdgs/assets/pdf/models-mapping-factsheets/mage.pdf

[33] For a deep review of models and manuals see https://www.iamconsortium.org/resources/models-documentation/

Model name	Description	Geographical coverage	Sector coverage	Time period	Indicators relevant for WISE approach
	with environmental variables different from GHG gasses.				
FARM	CGE model with high focus on agricultural and land use change. The use of GTAP allows to have some differentiation across income but it is not used in the model. Connects CGE with land use changes which allows to identify scarcities and land problems in future scenarios.	13 world regions	GTAP + detailed agriculture	5 years steps 2007-2052	Standard set of indicators (employment, income, emissions). The detailed land use may be useful for linking with deforestation and other related topics but no use of this is found.
MAGNET	CGE model designed in a modular way, this gives the flexibility of incorporating "extensions" related to climate and social aspects. Still a neoclassic macro-econ model, assumptions on market clearance, rationality, and no evidence of feedback loops.	GTAP[34]	GTAP	Yearly to 2050	Using the extensions (additional modules) it is possible to get indicators on: Nutrition, household food security, SDG indicators.
IMAGE	Set of modules that model the interactions between the earth system and the human system. Economics is represented in simplified form while the earth system is very well described. Some feedback loops are included (how climate change and changes in precipitation affect land productivity and agricultural production).	26 world regions	5 sectors in the energy model. 1 detailed agriculture econo	annual or five-year time steps 2050-2100	Wide range of indicators related to agriculture and land use which can be used to infer other indicators (hunger, food, prices, etc).

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[34] GTAP includes 65 sectors and 141 countries (or less depending on the version) and also includes regional aggregation (up to 19 global regions), see https://jgea.org/ojs/index.php/jgea/article/view/181/221.

Model name	Description	Geographical coverage	Sector coverage	Time period	Indicators relevant for WISE approach
			mics model		
COFFEE	Partial and multiregional, multisector CGE model. It assumes total market clearance (through commodity price equilibrium), zero profit condition for producers (with constant-returns-to-scale) and perfect competition to reach general equilibrium.	18 regions	GTAP	2100 in 14 steps	Traditional set of indicators, focus on land use and energy prices indicators.
ENV-LINKAGES	OECD CGE model built based on GTAP database. There is no evidence of feedback loops in the core model.	GTAP	GTAP	2050	Air pollution data used to get indicators on health and environment, climate change. Other results from the model are water stress and water quality and soft link with biodiversity (via deforestation).
ENVISAGE	Dynamic Multi-region and multisector CGE model. It incorporates a feedback loop that links changes in temperature to impacts on the economy (agricultural yield and sea level rise).	112 countries and regions	57 sectors	2050?	Basic set of indicators.
EPPA	Dynamic Multi-region and multisector CGE model. It incorporates physical accounts in terms of energy.	GTAP	GTAP	2050?	Estimates of physical depletion of natural resources, land availability, health effects due to air pollution. When coupled with the ocean, atmosphere, and land modules it can get indicators of changes on the atmosphere composition, ocean dynamic cycles, sea level rise, biochemical processes and water/energy budgets.
EU-CALC	Bottom-up model based on changes in aggregated sectors (energy-intensive and material intensive ones). The model does not optimize but based on workshop with	EU + Switzerland and Britain. Modified	Aggregate5 sectors	2050	Emissions, Health, Job creation and competitiveness, European lifestyles.

Model name	Description	Geographical coverage	Sector coverage	Time period	Indicators relevant for WISE approach
	experts and literature review stablishes the different scenarios for the possible pathways given levers/changes in demand.	version of GTAP			Land change and resource use (Water, minerals, fuels)
EXIOMOD	Input Output and CGE model. It uses extended accounts to measure impacts on materials, land use, energy. There is no evidence of feedback loops, although it is promised to be working and included in EXIOMOD plus.	Exiobase[35]	Exiobase	2050	Calculation of consumption-based indicators, decomposing price and volume effects, policy scenarios to reach 2050 resource efficiency targets.
FeLiX	The model consists of over 1300 elements including 91 stocks. Its outcomes are determined by many interacting feedback loops encompassing 8 model sectors: Economy, Energy, Carbon Cycle, Climate, Biodiversity, Water, Population and Land Use. Wherever possible, elements and stocks are calibrated to historical data available from the FAO, IEA, and UNIHP.	World	N/A	1900-2100	HDI, Education, income, health. Biodiversity.
FUND	The Climate Framework for Uncertainty, Negotiation and Distribution (FUND) is a so-called integrated assessment model of climate change. FUND was originally set-up to study the role of international capital transfers in climate policy, but it soon evolved into a test-bed for studying impacts of climate change in a dynamic context, and it is now often used to perform cost-benefit and cost-effectiveness analyses of greenhouse gas emission reduction policies, to study equity of climate change and climate policy, and to support game-theoretic investigations	16 regions	N/A	1950-3000 yearly	

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[35] Exiobase is a global IO database, covering 44 countries, 5 rest of the world regions, 200 products, and 163 industries in their latest version. See https://www.exiobase.eu/index.php/about-exiobase

Model name	Description	Geographical coverage	Sector coverage	Time period	Indicators relevant for WISE approach
	into international environmental agreements. FUND links scenarios and simple models of population, technology, economics, emissions, atmospheric chemistry, climate, sea level, and impacts. Together, these elements describe not-implausible futures.				
GCAM	Dynamic recursive model, it is based on market equilibrium but as such it is not CGE. It does not optimize through time but it does clear markets each period. Agent rationality is assumed (cost-minimizing and profit-maximizing)	32 regions		5 years steps (1990-2100)	Focus on Land, energy, emissions, and trade changes as consequence of climate change and climate policies.
GRACE	Global CGE model	GTAP	GTAP	2050	Standard set of indicators
ICES	Dynamic CGE model, it includes a sustainability module that uses the ASDI framework to project the SDGs based on 28 indicators.	GTAP	GTAP	2050	SDG, emissions, growth, income, education.
IMACLIM-R	Hybrid dynamic CGE model.			2001-2100 yearly	
MEDEAS	IAM model that combines Input-Output analysis with system dynamics in a post-Keynesian approach.	Global/Regional	35 industrial sectors + household (WIOD)	1995-2050	

APPENDIX C. EXAMPLES OF SFC MODELS

Jackson, T., & Victor, P. A. (2015b). Does credit create a 'growth imperative'? A quasi-stationary economy with interest-bearing debt. Ecological Economics, 120, 32–48. https://doi.org/10.1016/j.ecolecon.2015.09.009

Nikiforos, M., & Zezza, G. (2018). Stock-Flow Consistent macroeconomic models: a survey. Analytical Political Economy, 63-102.

Xing, X., Pan, H., & Deng, J. (2022). Carbon tax in a stock-flow consistent model: The role of commercial banks in financing low-carbon transition. Finance Research Letters, 50, 103186. https://doi.org/10.1016/j.frl.2022.103186

Yannis Dafermos, Maria Nikolaidi, Giorgos Galanis: A stock-flow-fund ecological macroeconomic model. In: Ecological Economics 131, 2017, pp.191–207, doi:10.1016/j.ecolecon.2016.08.013

Berg, M. J., Hartley, B., & Richters, O. (2015). A stock-flow consistent input–output model with applications to energy price shocks, interest rates, and heat emissions. New Journal of Physics, 17(1), 015011. https://doi.org/10.1088/1367-2630/17/1/015011

Deissenberg, C., Van Der Hoog, S., & Dawid, H. (2008). EURACE: A massively parallel agent-based model of the European economy. Applied Mathematics and Computation, 204(2), 541–552. https://doi.org/10.1016/j.amc.2008.05.116

Naqvi, A. (2015). Modeling Growth, Distribution, and the Environment in a Stock-Flow Consistent Framework. Policy Paper no 18. European Commission, bmwfw. WWWforEurope

Godin, A. (2013). Green Jobs for Full Employment, a Stock Flow Consistent Analysis. Palgrave Macmillan US eBooks. https://doi.org/10.1057/9781137313997_2

Jonathan Barth, Oliver Richters: Demand driven ecological collapse: A stock-flow fund-service model of money, energy and ecological scale. In: Samuel Decker, Wolfram Elsner, Svenja Flechtner (ed.): Principles and Pluralist Approaches in Teaching Economics: Towards a Transformative Science. Routledge, 2019, pp. 169–190, ISBN 978-1-1380-3768-7. doi:10.4324/9781315177731-12

Detzer, D. (2018). Inequality, emulation and debt: The occurrence of different growth regimes in the age of financialization in a stock-flow consistent model. Journal of Post Keynesian Economics. https://doi.org/10.1080/01603477.2017.1387499

Carvalho, Laura and Di Guilmi, Corrado, Income Inequality and Macroeconomic Instability: A Stock-Flow Consistent Approach with Heterogeneous Agents (September 1, 2014). CAMA Working Paper No. 60/2014, Available at SSRN: https://ssrn.com/abstract=2499977 or http://dx.doi.org/10.2139/ssrn.2499977

Eugenio Caverzasi, Antoine Godin: *Post-Keynesian stock-flow-consistent modelling: a survey* In: *Cambridge Journal of Economics* 39(1), 2015, pp. 157–187, doi:10.1093/cje/beu021

Matthew Berg, Brian Hartley, Oliver Richters: *A Stock-Flow Consistent Input-Output Model with Applications to Energy Price Shocks, Interest Rates, and Heat Emissions*. In: *New Journal of Physics* 17(1), 2015, 015011, doi:10.1088/1367-2630/17/1/015011

Yannis Dafermos, Maria Nikolaidi, Giorgos Galanis: *A stock-flow-fund ecological macroeconomic model*. In: *Ecological Economics* 131, 2017, pp.191–207, doi:10.1016/j.ecolecon.2016.08.013

Yannis Dafermos, Maria Nikolaidi, Giorgos Galanis: *Climate change, financial stability and monetary policy*. In: *Ecological Economics* 152, 2018, pp. 219–234, doi:10.1016/j.ecolecon.2018.05.011

Jacques, P., Delannoy, L., Andrieu, B., Yilmaz, D., Jeanmart, H., & Godin, A. (2023). Assessing the economic consequences of an energy transition through a biophysical stock-flow consistent model. Ecological Economics, 209, 107832. https://doi.org/10.1016/j.ecolecon.2023.107832

Alessandro Caiani, Antoine Godin, Eugenio Caverzasi, Mauro Gallegati, Stephen Kinsella, Joseph E. Stiglitz: *Agent Based-Stock Flow Consistent Macroeconomics: Towards a Benchmark Model*. In: *Journal of Economic Dynamics and Control* 69, 2016, pp. 375–408, doi:10.1016/j.jedc.2016.06.001

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