To Be

Towards sustainable wellbeing: Integrated policies and transformative indicators.

Deliverable 4.1

Report on the capacity of existing models to incorporate wellbeing and sustainability indicators

WP4 – Modelling wellbeing and sustainability outcomes

Version 1.0 | *November 2023*

HORIZON-CL2-2022-TRANSFORMATIONS-01 -
Towards sustainable wellbeing: Integrated policies
and transformative indicators.

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Funded by the European Union in the framework of the Horizon Europe Research and Innovation Programme under grant agreement N° 101094211.

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Document History

Deliverable Title	Report on the capacity of existing models to incorporate wellbeing and sustainability indicators
Brief Description	A targeted review of existing Environment–Society–Economy models conducted as part of Task 4.1
WP Number	WP4
Lead Beneficiary	UNIVLEEDS
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Deliverable Due Date	30 Nov 2023
Dissemination Level	Public

Date	Ver	Contributors	Comment
04.10.2023	0.1	Rob Van Eynde, Daniel Horen Greenford, Daniel W. O’Neill, Federico Demaria	Outline
01.11.2023	0.2	Rob Van Eynde, Daniel Horen Greenford, Daniel W. O’Neill, Federico Demaria	First draft of the report
13.11.2023	0.3	Jordi Solé, Tuuli Hirvilammi, Brent Bleys	Internal review
24.11.2023	1.0	Rob Van Eynde, Daniel Horen Greenford, Daniel W. O’Neill, Federico Demaria	Final version of the report

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Research and Innovation Programme under grant agreement N° 101094211.

Executive Summary

One of the most pressing questions of this century is how countries can meet the basic needs of their citizens without overburdening the planet's ecosystems. The mainstream economic paradigm is unfit to address this challenge, as it lacks a satisfactory description of how the economy is embedded within broader societal and environmental systems. To understand how societies can become sustainable and fair, economic models need to be expanded to include a more holistic depiction of the economy within its broader context. Several initiatives such as the Doughnut of social and planetary boundaries and the Sustainable Development Goals have paved the way by proposing a broader set of indicators that capture the social and environmental performance of society.

This report analyses how capable current macroeconomic models are of simulating the transition to a more just and sustainable society. First, we assess how well-represented social and environmental indicators are in a sample of 50 models. Second, we investigate the methods that are used to model these indicators in a smaller targeted sample of 15 models. Last, we analyse which variables are commonly used to determine social and environmental outcomes.

We find that most existing models lack a broad coverage of social and environmental indicators. The indicators with the best representation are those that can be easily linked to economic variables such as GDP, government spending, and household income. The best represented environmental indicators include climate change, energy use, land conversion, and water use. The best represented social indicators include jobs, income, economic development, and income equality. A key challenge is to include indicators that go beyond traditional macroeconomic thinking. These include less tangible social goals like life satisfaction and social support, and broad measures of environmental pressure like the ecological footprint. It is essential to represent a diversity of social and environmental indicators, as not including them runs the risk that they are not taken into account by policymakers.

Models also need to better include environmental limits, such as those associated with the planetary boundaries framework, and social thresholds, such as those associated with meeting basic human needs. Of some concern, we find that most models lack a representation of feedback mechanisms from the environment and society back to the economy. Information in existing models tends to flow in one direction: from the economy to society and the environment, but not back the other way. We argue that modelers should rely less on monetary variables to model social outcomes and environmental pressures. Furthermore, modelers and policymakers should acknowledge the intrinsic value of different social goals, instead of treating them as means in the service of economic growth.

Macroeconomic models are an essential decision-making tool for policymakers, but we find that existing models are inadequate to help societies navigate their way towards a sustainable future. To address this shortcoming, models should represent a wider variety of social and environmental indicators, and incorporate important thresholds and limits linked to these. Moreover, they should include a more holistic depiction of the interactions between environmental, societal, and economic systems. By adopting this broader perspective, policymakers will be better able to prioritize human and planetary wellbeing instead of economic growth.

About ToBe

ToBe is a 3-year project funded by the European Union through the Horizon Europe framework programme. Tampere University (Finland) acts as a coordinator for the project.

The ToBe project aims at studying the way in which mindsets, indicators, innovations, and policies could better work together towards a sustainability paradigm. The need for moving toward a sustainability paradigm has been widely called for, yet the path to achieving that is not clear. ToBe aims to contribute to filling this gap and create an understanding of a sustainable wellbeing economy through integrated policies and transformative indicators.

The ToBe consortium brings together acknowledged scholars with previous high-quality research on the topic and with diverse backgrounds from social sciences, ecological and political economy, environmental and innovation studies, science and technology, data science, AI and machine learning. All partners represent well-known and established universities, other research institutions and non-governmental organisations (NGOs). Table 1 lists the members of the consortium, which consists of 13 beneficiaries and one associated partner.

Table 1. ToBe Consortium Members

No	Role	Short Name	Legal Name	Country
1	COO	TAU	TAMPEREEN KORKEAKOULUSAATIO SR	FI
2	BEN	SU	STOCKHOLMS UNIVERSITET	SE
3	BEN	VTT	TEKNOLOGIAN TUTKIMUSKESKUS VTT OY	FI
4	BEN	EURADA	ASSOCIATION EUROPEENNE DES AGENCESDE DEVELOPPEMENT	BE
5	BEN	Sciences Po	FONDATION NATIONALE DES SCIENCES POLITIQUES	FR
6	BEN	ICHEC	HAUTE ECOLE ICHEC - ECAM - ISFSC	BE
7	BEN	IPE	INSTITUT ZA POLITICKU EKOLOGIJU	HR
8	BEN	UB	UNIVERSITAT DE BARCELONA	ES
9	BEN	Ugent	UNIVERSITEIT GENT	BE
10	BEN	EPC	EUROPEAN POLICY CENTRE	BE
11	BEN	UAB	UNIVERSIDAD AUTONOMA DE BARCELONA	ES
12	BEN	EPN Ecuador	ESCUELA POLITECNICA NACIONAL	EC
13	BEN	CHAL	CHALMERS TEKNISKA HOGSKOLA AB	SE
14	Associated partner	UnivLeeds	UNIVERSITY OF LEEDS	UK

The main objective of ToBe is to contribute to a clearer understanding of how to move to a sustainability paradigm. More specifically, ToBe aims at achieving the following objectives:

- Construct a theoretical framework for a sustainable wellbeing economy by providing a systemic and dynamic understanding of how changing policy goals, mindsets, indicators, innovations and policies work together towards a sustainability paradigm.
- Identify different processes of economic growth by analysing their social and environmental implications.
- Evaluate and compare alternative growth initiatives as systemic innovations with a focus on drivers and barriers to implementation and impacts.
- Develop an ecological macroeconomic model combining conventional macroeconomic variables with indicators of wellbeing and sustainability to assess policies from a multidimensional perspective, and to reveal the synergies and trade-offs inherent in the transition to sustainability.
- Co-create policy solutions together with stakeholders to help institutionalise the new policies and indicators in Europe and beyond (potentially including South American and African countries).

1. Introduction

No country in the world meets basic needs for its citizens at a globally sustainable level of resource use (O'Neill et al., 2018). As such, one of the most pressing challenges for the 21st century is how to reconcile human wellbeing and equity with the carrying capacity of our planet. To address this challenge, we need a better understanding of the interactions between environmental, societal, and economic systems (Hafner et al., 2020; Hardt & O'Neill, 2017; Wiebe et al., 2023). Economic discourses that treat these systems in isolation or that rely on a one-dimensional indicator to evaluate their performance cannot provide the required detail (Brand-Correa et al., 2022). Instead, we need models that integrate multiple environmental, social, and economic systems and use a variety of indicators. In this report, we analyse the inclusion of environmental and social indicators in existing Environment–Society–Economy models.

Mainstream economics has been criticized for treating the economy as operating in isolation from the broader societal and biophysical systems in which it is embedded (Daly & Farley, 2011; Martinez-Alier & Schlüpmann, 1990). The Doughnut of social and planetary boundaries has emerged as a useful framework for addressing the environmental and socioeconomic challenges of our times (Raworth, 2017a). It defines a clear goal, namely reaching a safe and just space for humanity, where basic needs are met for all without overburdening our planet's ecosystems. The Doughnut contains a set of non-substitutable indicators that assess the health of critical Earth systems and the achievement of important social thresholds for the global population.

The Doughnut provides measurable targets, but it does not explicitly address how to get there. To explore possible pathways towards a sustainable future, several academic fields have developed models that link the economy with environmental and societal systems. We refer to this class of models as Environment–Society–Economy (ESE) models. These models approach policy and transition simulation more holistically, as economic outcomes can be assessed together with social and environmental outcomes. The most well-known examples are the integrated assessment models (IAMs) used by the IPCC for exploring climate scenarios.

Planetary boundaries and human needs have received increased attention from policy makers, for instance through the adoption of the Sustainable Development Goals (SDGs) by the United Nations. Although many ESE models include some of the dimensions from these frameworks for sustainable development, only a few models cover a broad set of indicators. Due to the interconnectedness of the various biophysical and social systems, a too narrow scope of target indicators risks oversimplifying the problems and rendering invisible important dimensions.

In this report, we address this gap by assessing the level of adoption of important social and environmental indicators in ESE models, drawing on the Doughnut framework. We examine (1) the prevalence of different environmental and social indicators, (2) the methods used to model these indicators, and (3) the driving variables that affect these indicators. By providing an overview of common modelling formulations for a broad set of environmental and social indicators, we aim to facilitate their inclusion in existing models. Additionally, our analysis highlights which indicators are currently lacking, providing directions for improvement. To make our results more accessible to nonmodelers, we represent our results in visual terms. After synthesizing this analysis, we suggest ways that the next generation of ESE models can better incorporate indicators and linkages to make them more capable of exploring synergies and trade-offs between diverse environmental and social goals.

The remainder of this report is as follows. Section 2 discusses the literature on Doughnut economics, types of ESE models, the distinction between neoclassical and heterodox economics, and the advent of ecological macroeconomics. Section 3 discusses the methods we used to analyse the coverage of indicators. In Section 4 we present the main results from our analysis, while in Section 5 we discuss key insights originating from this analysis. Section 6 concludes arguing that although some environmental and social indicators are well covered, more work is required to ensure a broad inclusion of Doughnut indicators in ESE models.

2. Literature review

2.1 The Doughnut of social and planetary boundaries

The concept of planetary boundaries has emerged as a focal point in environmental research, emphasizing the critical Earth-system processes that have sustained the Earth's climate in the stable Holocene epoch, a period conducive to human societies' flourishing (Rockström et al., 2009). This framework delineates a "safe operating space" by defining nine planetary boundaries, which are the maximum allowable levels of anthropogenic pressure on Earth systems. The Sustainable Development Goals include multiple targets that relate to these boundaries (Randers et al., 2019). While it was already known that important boundaries like climate change and biosphere integrity have been crossed, recent research highlights the severity of the situation, as six of the nine planetary boundaries have now been transgressed (Richardson et al., 2023).

The economist Kate Raworth has contributed to this framework through her work on the Doughnut of social and planetary boundaries (Raworth, 2017b), in which she has complemented the concept of planetary boundaries with a set of social foundations. These social indicators establish minimum thresholds for human wellbeing. Together, these two sets of boundaries determine a "safe and just space," where human prosperity is not at odds with the preservation of a good life for future generations. However, previous research has shown that currently, no country operates within this safe and just space (O'Neill et al., 2018). Furthermore, historical analysis shows that countries are transgressing planetary boundaries faster than they are achieving social thresholds (Fanning et al., 2022).

The looming threats of ecological and societal breakdown make the question of how to achieve a good life for all more urgent. In the twilight of the Holocene, the challenge has become: How can nations and the global community provide the basis for dignified human life while respecting planetary boundaries? This question remains a subject of vigorous debate within the academic community. Some argue that economic growth can continue in an environmentally sustainable manner, effectively decoupling economic growth from its impact on Earth-systems (Bowen & Hepburn, 2012; Drummond et al., 2021). Proponents of post-growth theories have challenged this narrative with empirical evidence to the contrary (Haberl et al., 2020; Hickel & Kallis, 2020; Parrique et al., 2019; Vogel & Hickel, 2023), emphasizing the need to separate wellbeing from material throughput (Jackson & Victor, 2019b) and to transform the provisioning systems that satisfy human needs (Fanning et al., 2020; Hickel et al., 2022; O'Neill et al., 2018; Vogel et al., 2021). To address this question, scholars have used a wide variety of model types, to which we now turn.

2.2 Types of Environment–Society–Economy models

Environment–Society–Economy (ESE) models have proven to be an essential tool to simulate possible transition scenarios and to evaluate policy proposals. To create structure in the diverse modelling landscape, several taxonomies have been proposed. We employ existing model categorizations, building mainly on previous reviews of macroeconomic approaches to modelling environmental and social outcomes by Wiebe et al. (2023) and Hardt & O'Neill (2017). This categorization includes equilibrium models, integrated assessment models, macroeconometric and input–output models, stock–flow consistent models, system dynamics models, and "other" models (to capture those not completely fitting in the previous categories).

Equilibrium models include all optimization-based models that maximize or minimize a single variable, usually welfare or cost, respectively. These models are typically based on neoclassical assumptions. The main classes are computable general equilibrium and dynamic stochastic general equilibrium models.

Integrated assessment models (IAMs) are a broader category consisting of "legacy" and heterodox IAMs. The former have been included in the IAM consortium (IAMC, 2020) and their analyses have been used in assessment reports of the Intergovernmental Panel on Climate Change (IPCC). Most of these models contain a neoclassical macroeconomic core that is coupled to biophysical components. More recently, heterodox IAMs have been gaining relevance in the climate policy and sustainable development community, even though they are not included in the IAM consortium. Their distinguishing feature is their use of non-optimizing techniques such as system dynamics or macro-econometrics.

Macro-econometric and input–output models are calibrated to actual data and are often combined. The former describe the economy by a set of equations that can be estimated econometrically. Input–output models express the economy as a set of flows between distinct sectors and are used to assess the effects of macroeconomic changes on a sectoral level. When extended with data on biophysical flows, they provide insights into the impact of economic activities on the environment.

Stock–flow consistent (SFC) models focus on the financial side of the economy. They track monetary stocks and flows between economic actors and money creation by banks. Financial stocks are simultaneously assets for one party and liabilities for another. By accounting for the origin and destination of all transactions, stock–flow consistent models have the advantage of describing an economy without "black holes". As stock–flow consistency is an accounting framework that tracks monetary flows, it can be applied to various types of models. Furthermore, the method can also be extended to stocks and flows of matter and energy.

System dynamics provides a methodology that approaches model building from a different perspective. It originates from systems theory (Forrester, 1971) and focuses on understanding the behaviour of complex systems by including dynamic interactions and nonlinear feedback mechanisms between different elements. This technique is used in a wide range of disciplines and has gained popularity in heterodox macroeconomics.

Last, we include "other" models with a focus on specific indicators that do not fall into above categories, such as LUISA for land use (Lavalle et al., 2020), and feminist macroeconomic models for unpaid care work. Due to their specific focus, the techniques used do not necessarily match the typical macroeconomic categories.

It is essential to recognize that these categories are not mutually exclusive and that their boundaries are fuzzy; models may fit into multiple categories when they combine different techniques. For example, input–output and stock–flow consistent approaches can be added onto many other approaches, and are not standalone models, in and of themselves, since they require a production function to simulate economic dynamics. These dynamics can be simulated either through optimization techniques (e.g. general equilibrium) or non-optimization approaches (system dynamics). Furthermore, within each category, there exists substantial diversity in theoretical and ideological foundations.

2.3 Neoclassical vs. heterodox economics

Another way of distinguishing between models is to look at their theoretical background. Here we distinguish between neoclassical and heterodox economics. Colander (2000) characterizes the neoclassical school by the tenets of utilitarianism, focus on marginal trade-offs, farsighted rationality, methodological individualism, and the focus on the general equilibrium of the whole economy. As we found these assumptions in most IAMs and equilibrium models, we will describe these categories as neoclassical. Heterodox economics is a group of economic theories that have intellectual roots in Post-Keynesian, feminist, ecological, and other disciplines (Brand-Correa et al., 2022). These schools focus on concepts such as accumulation, intersectional understandings of socioeconomic relationships, economic and social reproduction, the environment, and provisioning systems (Lee, 2012). Heterodox schools of thought typically reject the neoclassical assumptions and as a result use different methodologies.

A clear dividing line between heterodox and neoclassical economics is whether economic inputs like labour, capital, material, or energy are substitutable. Substitutability implies that a certain input can be replaced by another input to produce the same outcomes. The strong versus weak sustainability debate is directed towards the substitutability of different forms of natural capital by built capital (Traeger, 2011). Weak sustainability argues that these forms of capital can be substituted for each other. Strong sustainability argues that substitution possibilities are limited because natural capital provides different types of functions, and that not all these functions can be substituted by produced capital (Dietz & Neumayer, 2007). The planetary boundaries framework follows the strong sustainability approach, as the violation of one boundary cannot be compensated by reducing pressure on another one.

Regarding human welfare, substitutability is also debated. Human needs theory underpins the social goals of the Doughnut (O'Neill et al., 2018), and posits that humans have a set of non-substitutable basic needs (Doyal & Gough, 1991; Max-Neef et al., 1991). In this regard, human needs theory is different from neoclassical utility theory, which conceptualizes human welfare by the one-dimensional concept of utility, and implicitly treats human needs as substitutable by focusing on preference satisfaction (Gough, 2023).

2.4 Ecological macroeconomics

Mainstream ESE models have been criticized for (1) reducing climate mitigation to monetary cost–benefit analysis and too strongly discounting future damages (Ackerman et al., 2009; Drouet et al., 2021; Ludwig et al., 2005), (2) addressing climate change while ignoring overshoots of other planetary boundaries (Gambhir et al., 2019; Hickel et al., 2021), and (3) relying on overly optimistic assumptions about technological solutions to reduce environmental pressures (Hickel & Kallis, 2020; Larkin et al., 2018).

To address these shortcomings, many scholars have started developing alternatives, giving rise to the field of ecological macroeconomics. The seminal *Limits to Growth* report proposed a foundational global system dynamics model (World3) that embedded human socioeconomic systems within a finite biophysical environment (Meadows et al., 1972). Subsequently, scholars such as Herman Daly described the macroeconomy as an open subsystem within the finite biophysical ecosystem, urging economists to consider the question of the optimum scale of human activity (Daly, 1991). Victor and Rosenbluth (Victor & Rosenbluth, 2007) introduced the first ecological macroeconomic model, which explored policy options to fulfil social and environmental goals without relying on perpetual economic growth.

Since then, the field of ecological macroeconomics has witnessed the development of multiple models, including LowGrow SFC (Jackson & Victor, 2019a), Eurogreen (D'Alessandro et al., 2020), MEDEAS (Capellán-Pérez et al., 2020; Solé et al., 2020), DEFINE (Dafermos & Nikolaidi, 2022), Earth4All (Randers & Collste, 2023), and WILIAM (Pastor et al., 2020), with several reviews documenting their contributions (Hafner et al., 2020; Hardt & O'Neill, 2017; Wiebe et al., 2023). Although not the only field that links macroeconomics to the biophysical and social spheres, ecological macroeconomics distinguishes itself by adhering to three key principles. First, the economy is conceptualized as a subsystem of society, which is in turn a subsystem of the biosphere (Daly, 1991). There is an inextricable connection between these different systems, and they can profoundly affect each other (Fontana & Sawyer, 2016). Second, the discipline allows for the exploration of multiple, non-substitutable goals (O'Neill, 2020), in contrast to traditional aggregate measures like Gross Domestic Product (GDP), which have faced substantial critique (Costanza et al., 2014; Fioramonti, 2013; Hoekstra, 2019; Stiglitz et al., 2009). Third, heterodox scholars in general call for transparency in vision and ethical judgments when building models, emphasizing their impact on the narrative of transition pathways (Becker, 2023; Power, 2004; Sgouridis et al., 2022; Spash, 2012).

Recently, the "provisioning systems" framework has gained attention in ecological economics as a way to understand the link between biophysical resource use and social outcomes. Fanning et al. (2020) define a provisioning system as "a set of related elements that work together in the transformation of resources to satisfy a foreseen human need". Vogel et al. (2021) make a global analysis of how energy use and need satisfaction depend on a set of provisioning factors. Their analysis shows that improving provisioning systems can be an important strategy to improve basic needs satisfaction while reducing environmental pressures. Furthermore, studying provisioning systems is required to understand their growth-dependencies and how welfare can be decoupled from economic growth (Corlet Walker et al., 2021). Scholars have started addressing this challenge by analysing specific provisioning systems in more detail (Dillman et al., 2023; Renton, 2023; Virág et al., 2022; zu Ermgassen et al., 2022).

3. Methods

Our method consists of four phases. First, we compiled a list of environmental and social indicators. Second, we constructed a longlist of 90 ESE models. Third, we reduced this list to a medium list of 50 model for which we analysed the indicator coverage. Fourth, we created a shortlist of 15 models, which we analysed in detail to understand how they include the environmental and social indicators and what their driving variables are. Hereafter we explain each phase in detail.

Table 1 shows the list of environmental and social indicators we compiled in the first phase, with their corresponding definitions. The starting point for this list was the Doughnut framework (Raworth, 2017b), supplemented with inputs from other relevant literature on social and environmental indicators (Hafner et al., 2020; Hardt & O'Neill, 2017; Wiebe et al., 2023), as well as the Sustainable Development Goals (United Nations).

Table 1. List of environmental and social indicators considered in our analysis of ESE models

Environmental indicators	
Climate change	Metrics of climate change, e.g. CO2, all GHG emissions, and/or simulated climate response to anthropogenic GHG emissions.
Phosphorus loading	Inefficient or excessive use of phosphorus as fertilizer.
Nitrogen loading	Inefficient or excessive use of nitrogen as fertilizer.
Water use	The use of water, either blue (freshwater from lakes, rivers, and reservoirs), green (water in the soil, usually used by plants and soil microorganisms), or tracking of other water sources or uses (e.g. grey).
Land conversion	The conversion of natural lands into land useful for human activity.
Biodiversity loss	The loss of biodiversity, reduction in the number and variety of species.
Ozone layer	Emissions that damage the ozone layer.
Air pollution	The emissions of air pollution, including anthropogenic aerosols, particulate matter (e.g. fine particulate matter PM10 or PM2.5), or other pollution
Chemical pollution	The release of hazardous chemicals or plastic waste into the environment.
Marine harvesting	Depletion of fish stocks due to fishing activity.
Human Appropriation of Net Primary Production (HANPP)	The human appropriation of net primary production or biomass.
Ecological footprint	Societies' pressure on ecosystems, measured in the amount of land necessary to meet its needs.
Material use	The extraction, conversion, and disposal of biomass, minerals, and fossil fuels.
Energy use	The total energy use by society.

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Soil quality	Depletion of soil nutrients or erosion of soil, ability for soil to sustain agriculture (carbon content and nutrient content). Can also include sediment quality or runoff for water basins.
Social outcomes	
Energy access	Access to energy or electricity.
Water access	Access to safe drinking water.
Sanitation access	Access to safe sanitation infrastructure.
Housing access	Access to safe and affordable housing.
Education	Access to quality education, or metrics of education (e.g. literacy rates, rate of secondary school completion).
Health	The life expectancy or healthy life expectancy of the population.
Political voice	Governance that responds to democratic will.
Income	Measure of income per capita, possibly relative to a poverty line.
Jobs	Unemployment rates, and other measures of quality of work (e.g. whether jobs are “decent” or “dignified”).
Food access	Access to food and decent nutrition, and other metrics of food security.
Internet access	Access to internet or telecommunications.
Mobility access	Access to affordable transportation, emphasis on public transport.
Income equality	Income equality within countries (could also include income equality globally or between countries)
Social support	Access to a support network of family, friends, community members.
Gender equality	Equality and empowerment for women and girls (e.g. pay, labour time, health outcome equity).
Peace	Measure of whether there is peace in a society (e.g. violent crime rates, absence of inter- and intranational conflict).
Justice	The effectiveness of the rule of law, equal access to justice, absence of corruption.
Life satisfaction	An individual's overall feelings about their life. Can also include eudaimonic and hedonic conceptions of happiness.
Work-life Balance	The time spent on paid and unpaid work versus the time spent on personal or leisure time.
Economic development	Technological improvements, increases in productivity, or other measures of structural change or economic progress.
Resilience	The ability of our societal system to withstand shocks or disturbances (e.g. economic downturns, environmental catastrophes).

In the second phase, we created a longlist of 90 ESE models. We first identified models featured in key databases like MIDAS (https://web.jrc.ec.europa.eu/policy-model-inventory/) and reviews such as (Wiebe et al., 2023), (Hafner et al., 2020), and Hardt & O’Neill (Hardt & O’Neill, 2017). We also searched online databases (e.g. Google Scholar) for new literature that cited these reviews using search terms such as “ecological”, “environmental”, “climate”, “wellbeing” (or “well being”, “well-being”), “health”, “macroeconomic”, and “model”. Our underlying selection criterion was the capacity of the models to model the Doughnut, specifically by linking at least two of the spheres of environment, economy, and society. Furthermore, we applied more specific criteria: (1) suitability for mid- to long-term policy evaluation, (2) aggregation of societies at the national or global scale, (3) inclusion of multiple agents, such as households, firms, and governments, and (4) the ability to disaggregate the economy into different sectors. For our selection we allowed both theoretical and empirical models.

In phase three, we reduced the longlist to a medium list of 50 models. First, we selected a more balanced sample of model types and coverage, removing ones that were redundant or ill-equipped to model relevant indicators. This step required some subjective judgment as to which models (1) were better developed and up-to-date, (2) included enough relevant indicators, or (3) could be excluded because they were quite similar to already-included models. The abridged medium list allowed us to strengthen our analysis by looking more carefully at our sample and verifying model details. For each of these models, the documentation and relevant literature were searched with key words and relevant sections were perused to evaluate the inclusion of the indicators from Table 1. To confirm the validity of our results we contacted the authors of the models and asked them to verify our assessment. We got a response rate of 72%. This evaluation enabled the creation of a high-level overview, detailing the extent of coverage for each indicator.

In the last phase, we created a shortlist of 15 models. From the medium list, we selected five models with the broadest indicator coverage from three categories that we felt presented a balanced sample of existing models (1. Neoclassical, 2. Heterodox, 3. Macroeconometric, and 4. Other). Most models in the shortlist were comprehensive models that included at least ten indicators. We then revised this selection, considering diversity in modelling approaches and theoretical foundations, selecting several models from each category that together covered the widest array of indicators. Models with unique features were prioritized to ensure a wider spectrum of perspectives in the shortlist.

Each model on the final shortlist (Table 2) was subjected to an in-depth analysis, focusing on the modelling of our list of environmental and social indicators (Table 1). Within this analysis, we documented the variables employed as drivers for the environmental and social indicators and the functional relationships used within each model. To provide visual insights into the similarities and differences among models, we created graphical network representations showing the causal relationships between variables.

The data generated through this process were synthesized to create modelling “archetypes” for each indicator. These archetypes capture common elements between models delineate distinct modelling approaches. Finally, the archetypes were used to quantify which variables are most often used as determinants. This quantification offers valuable insights into the variables commonly used by modelers, shedding light on their perceived importance and convenience.

Table 2. Shortlist of models and their classification

Model name	Equilibrium model	IAM	Macroeconometric, input-output	Stock-flow consistent	System dynamics	Other
MEDEAS	0	1	1	0	1	0
Eurogreen	0	1	1	1	1	0
LowGrow SFC	0	0	0	1	1	0
Earth4All	0	0	0	0	1	0
GEM-E3	1	1	0	0	0	0
MAGNET	1	1	0	0	0	0
E3ME (9.0)	0	0	1	0	0	0
EXIOMOD (2.0)	1	1	1	0	0	0
REMIND (v 3.2.0)	1	1	0	0	0	1
International Futures scenarios (IFs)	1	1	0	0	0	0
iSDG	0	1	0	0	1	0
Onaran et al. (2022)	0	0	0	0	0	1
Vasudevan & Raghavendra (2022)	0	0	0	0	0	1
Ilkkaracan et al. (2021)	0	0	1	0	0	1
Dasgupta (2021)	1	0	0	0	0	1

In the next section we present the results of analysing the sample of ESE models intended to represent the diversity in modelling approaches and indicator coverage. We analyse how social and environmental indicators are represented and linked to macroeconomic determinants. Moreover, we also investigate what interlinkages or feedbacks exist in these models.

4. Results

In this section we discuss the outcomes of our analyses regarding the coverage of environmental and social indicators in ESE models. The first two analyses (Figs. 1-2) are based on the medium list of 50 models, while the subsequent analyses (Figs. 3-5) are based on the shortlist of 15 models. We first review the differences in the number of included indicators between model categories (Fig. 1). Second, we assess the frequency with which the environmental and social indicators are covered (Fig. 2). Third, we report common modelling approaches for some of the environmental and social indicators (Figs. 3 and 4). Last, we discuss which driving variables are often used to model the indicators in our set (Fig. 5).

4.1 Models and their coverage of environmental and social indicators

We find that system dynamics models and IAMs generally cover the most environmental and social indicators, while stock–flow consistent models cover the least (Fig. 1). System dynamics models on average include the most indicators. This is particularly true for the models Earth4All (Randers & Collste, 2023), International Futures (IFs) (Hughes, 2019), and iSDG (Millennium Institute, 2021), which are explicitly designed to simulate the interaction of economic, social, and environmental systems. Stock–flow consistent approaches have not been as widely used in ESE models thus far, which explains their lack of indicator coverage.

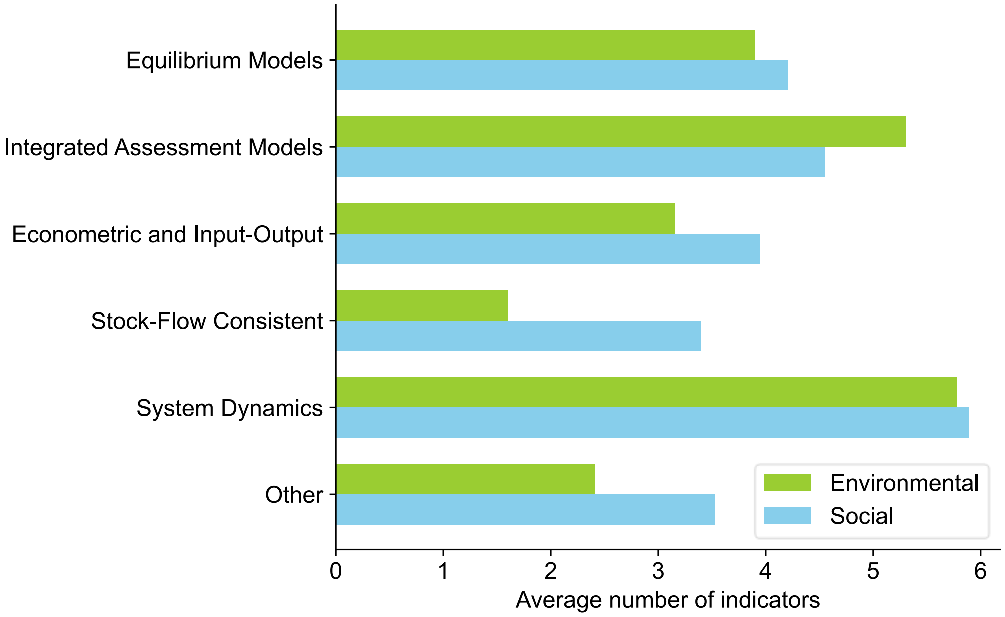

Figure 1. Environmental and social indicator coverage by model category. Bars show the average number of total indicators for each category.

On the environmental side, there is a clear emphasis on climate change, energy use, and land conversion (Fig. 2). The prevalence of climate change and energy use aligns with the observation that ESE models are often used by scholars and policy makers to analyse climate mitigation and the related energy transition (Drouet et al., 2021; Gambhir et al., 2019). The prominence of environmental indicators like water, land, and material use is explained by their presence in environmental extensions of input–output tables, which facilitates their inclusion in input–output models (Kitzes, 2013).

The indicators soil quality, ecological footprint, and human appropriation of net primary production (HANPP) are the least included. HANPP is now included in the planetary boundaries framework (Richardson et al., 2023), but was only modelled in detail in our sample by iSDG. Soil quality is covered poorly but could be included in a model that covers nutrient balances (Roy et al., 2003). Ecological footprint is not included explicitly in many models, but some models have been used to calculate ecological footprints, such as EXIOMOD 2 (Bulavskaya et al., 2016).

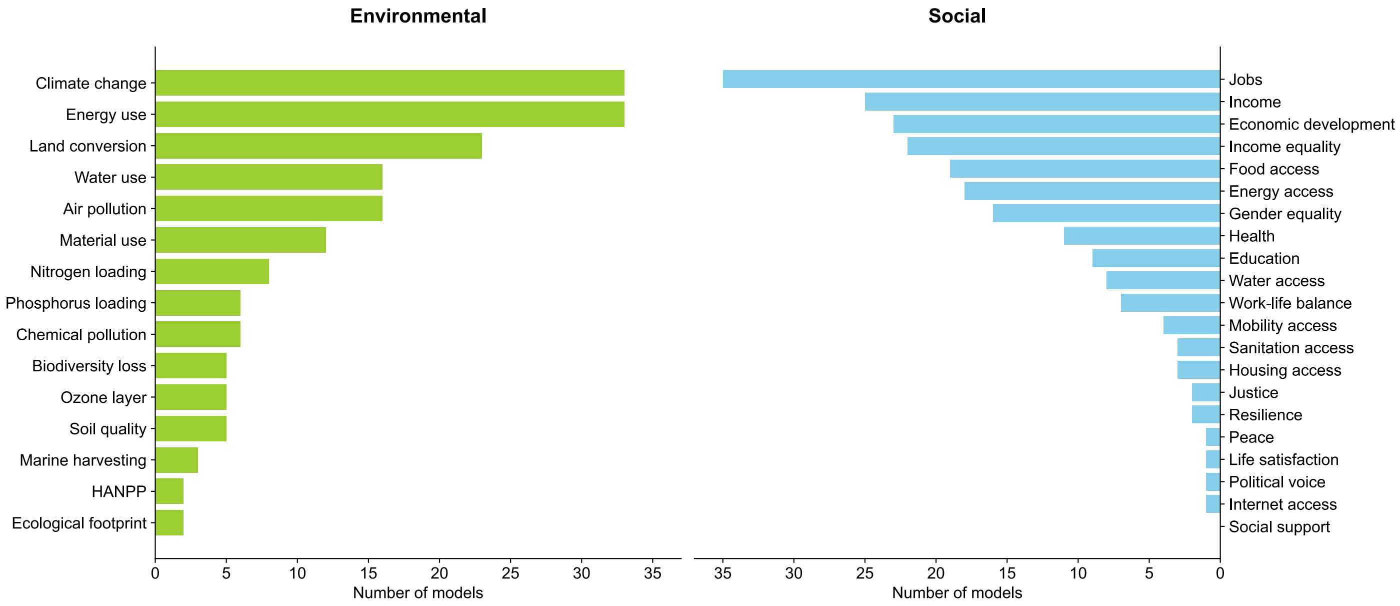

Figure 2. Coverage of environmental and social indicators across the "medium list" of models.

On the social side, the most covered indicators are those that are easily derived from a conventional macroeconomic framework, such as jobs, income, and economic development (Fig. 2). Gender equality is often represented as gendered income inequality because of data availability on wages and employment at this level. Other sources of inequality are still absent (e.g. race, gender and sexual identities, and disability). While many models focus on modelling energy use, fewer contain adequate measures of energy access that, for example, could account for energy poverty. Some models also focus on modelling agriculture and food production, and a subset of these contains measures of food access. The least covered social indicators (except for internet access) are those that are intangible and thus difficult to quantify, such as peace, justice, political voice, social support, and resilience.

4.2 Archetypes for modelling environmental indicators

Figure 3 shows a selection of the conceptual archetypes for modelling environmental indicators. These archetypes outline common modelling approaches that we identified in our analysis of the 15 shortlisted models.

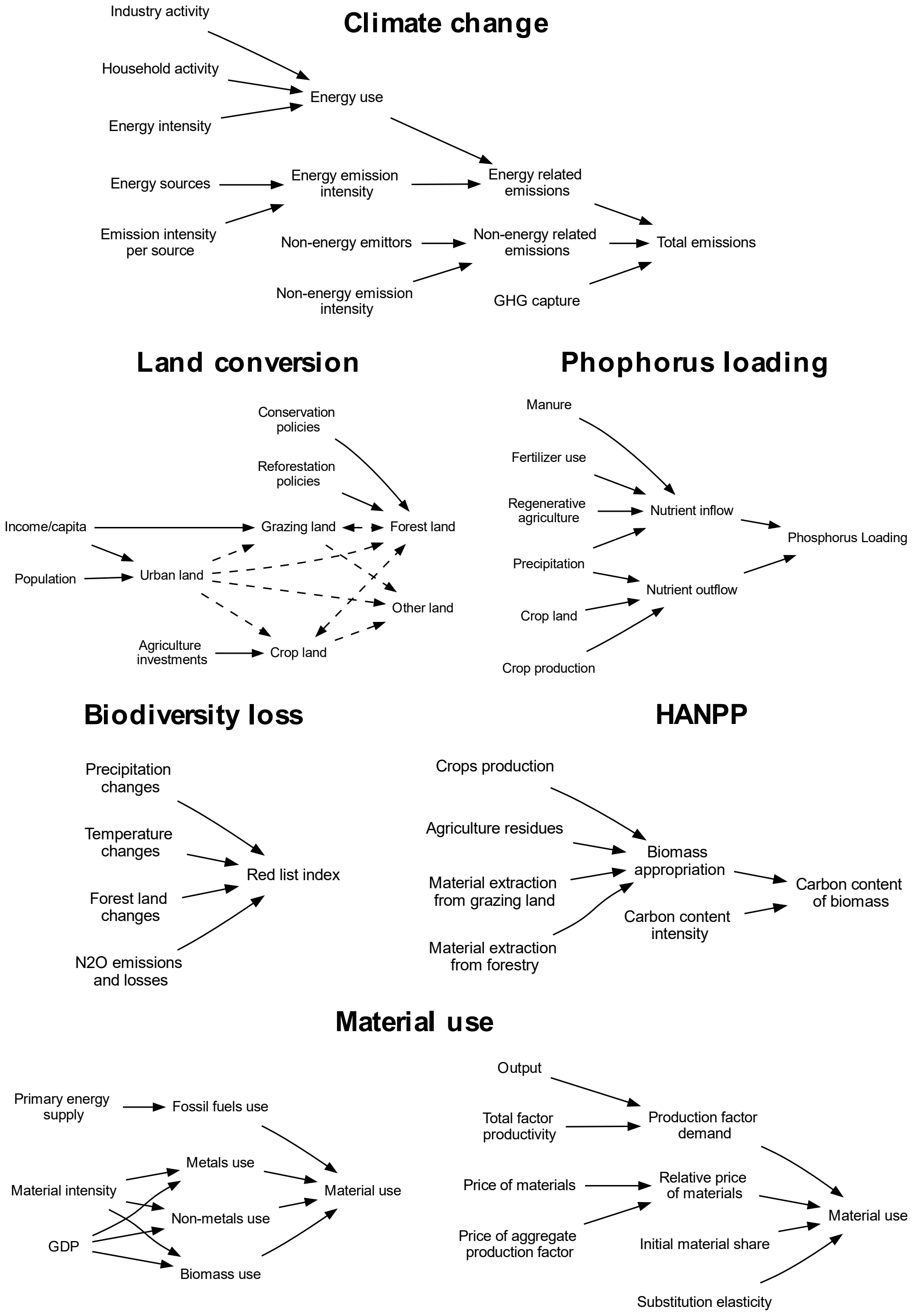

Figure 3. Dependency graphs for selected environmental indicators. The graphs show which variables influence indicators or their proxies. Causal directions (i.e. order of operation) are indicated by arrow direction. Dashed lines in land conversion indicate a flow between stocks in the opposite direction of the arrow (e.g. urban land determines grazing land, but urban land is taken from grazing land, which is taken from forest land to replenish itself). Material use shows both heterodox (left) and neoclassical (right) approaches, where only the latter allows for substitution between inputs.

Climate change

Climate change is the most modelled environmental dimension, and energy use is its strongest driver (Fig. 3). Energy-related emissions are commonly calculated as the product of energy use and emissions intensities per energy unit. Energy use can be determined from the demand or the supply side. The demand-driven approach converts the monetary flows from demand from households, industries, and government into energy demand with energy intensity variables. In the supply-driven approach, energy is calculated as an input to total production, and varies with production levels. Most IAMs use a supply-driven approach to decide on energy use. These include REMIND (Aboumahboub et al., 2020), GEM-E3 (Van Regemorter et al., 2013), and MAGNET (Shutes et al., 2018). However, heterodox models tend to use a more demand-driven approach. These include Eurogreen (D'Alessandro et al., 2020) and LowGrow SFC (Jackson & Victor, 2019a).

The emission intensity of the total energy use depends on the mix of energy sources such as coal, gas, and renewables. In some models, the energy mix is specified as an exogenous trend (e.g. Eurogreen, LowGrow SFC). In other models, the energy sector is modelled explicitly, and the energy mix is driven endogenously through prices (neoclassical models), resource availability or policy priorities (e.g. MEDEAS; Capellán-Pérez et al., 2020).

Land conversion

The demand for land is driven predominantly by population and income per capita (Fig. 3). Typically, models distinguish between the categories of forest, urban, agricultural, and other land. The stock of forest land is converted into agricultural or urban land when the demand for these types increases. The demands for agricultural and urban land are sometimes in competition (e.g. Earth4All; Randers & Collste, 2023). Some models include demand for land for renewable energy generation (e.g. MAGNET, MEDEAS).

Agricultural land may be split between cropland and grazing land, to distinguish between the impacts of plant-based and meat-based diets, where meat demand grows with increasing income per capita. Investments in agriculture can promote conversion of land for agricultural purposes. In some models the government can intervene through conservation and reforestation policies to limit forest conversion. In Earth4All, farming practices can also impact the rate of land conversion.

Phosphorus loading

Phosphorus and nitrogen loading typically follow the same modelling structure (Fig. 3). We highlight the approach from iSDG (Millennium Institute, 2021), which calculates the balance between nutrient inflows and outflows. Next to agricultural production, there are biophysical determinants such as precipitation and the evaporation from cropland. Farming practices can moderate the flow of fertilizers. For instance, Earth4All and iSDG model sustainable farming practices as requiring less or no external fertilizer application.

Biosphere integrity

The planetary boundary for "biosphere integrity" consists of two measures: genetic diversity and functional integrity. Genetic diversity is quantified as biodiversity loss through a species extinction rate (Fig. 3), while functional integrity is quantified as the energy available to ecosystems through HANPP (Fig. 3). Biodiversity loss is not often modelled on a macro scale, as biodiversity loss occurs on local and regional scales (Rockström et al., 2009). iSDG aims to capture genetic diversity through an index of threats to biodiversity but does not model extinction rates explicitly. Functional integrity is also included in iSDG. It expresses HANPP as the carbon content of biomass that is extracted through agriculture and forestry. Dasgupta (2021) models a natural capital stock that generates biomass which can be appropriated by human activity. This approach could be seen as a high-level approximation of HANPP inclusion.

Material use

For capturing material use, there is a clear difference between heterodox and neoclassical models (Fig. 3). In heterodox models (left-hand side) the material intensities are fixed or follow an exogenous trend. In neoclassical models (right-hand side), the material intensity of economic activity is affected by the price of materials as they can be substituted for other production factors. The material flows can be modelled on the aggregate scale of the whole economy, or they can be disaggregated by sector and material type by having material intensity variables for each sector and material type. Environmentally extended input–output databases typically have this information available.

4.3 Archetypes for modelling social indicators

Figure 4 shows a selection of the conceptual archetypes for modelling social indicators. Similar to the environmental indicators, these archetypes outline common modelling approaches that we identified in our analysis of the 15 shortlisted models.

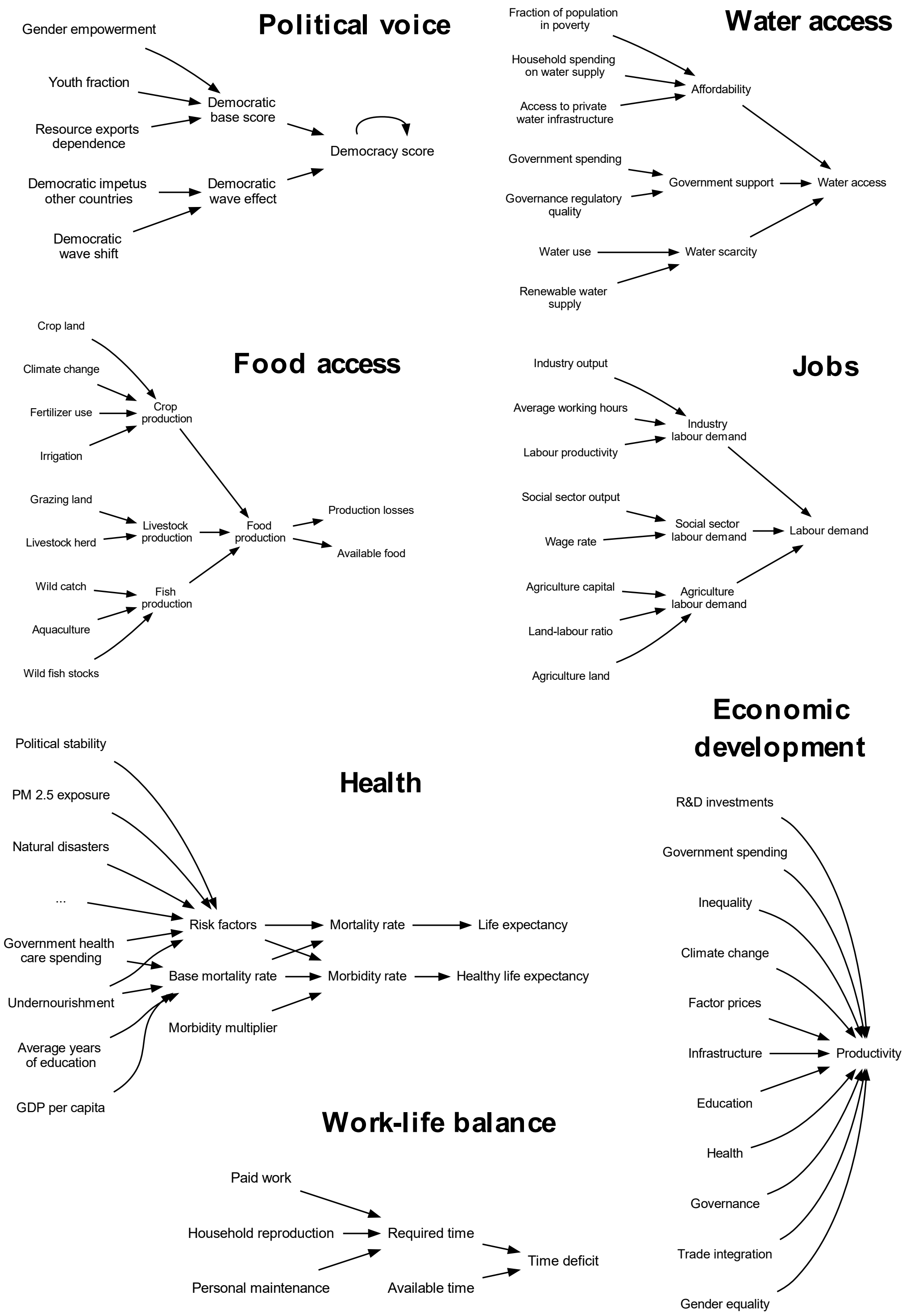

Figure 4. Dependency graphs for selected social indicators. The graphs show which variables influence indicators or their proxies. Causal directions (i.e. order of operation) are indicated by arrow direction.

Funded by the European Union in the framework of the Horizon Europe Research and Innovation Programme under grant agreement N° 101094211.

Political voice

Political voice is only included in two models of our sample. iSDG includes it exogenously, while IFs (Hughes, 2019) endogenizes political voice (Fig. 4) as the democratic score from the Polity IV index for democracy (Center for Systemic Peace, 2021). The formulation includes theoretical contributions from political science, namely the democratic wave effect and the age-structural maturity thesis. Furthermore, it includes path dependency of the democracy score as it depends on its previous values using a moving average.

Water access

Within our sample, only iSDG and IFs include access to water explicitly. There are three aggregate drivers for water access, namely government support, affordability of water, and water scarcity. The archetype shows a link between environmental pressure of water use and the basic need of access to water. The affordability component uses variables such as poverty and household spending on water, which are also available in Eurogreen, MEDEAS, and EXIOMOD 2. The strength of this modelling approach is that it combines environmental indicators with socioeconomic ones, which could be a good example for modelling other provisioning systems.

Food access

The main models from our sample that cover food are Earth4All, IFs, iSDG, MAGNET, and REMIND. In general, three types of food are considered: crops, livestock, and fish. iSDG and MAGNET focus on the supply side, while IFs and Earth4All include both food supply and demand. Here we describe the supply.

Food production in heterodox models is determined mainly by the availability of physical production factors such as crop and grazing land, and biophysical inputs like fertilizer use and irrigation (Fig. 4). Neoclassical models tend to have a stronger focus on economic factors such as agricultural labour and capital. In iSDG and IFs, climate change can inhibit crop production through changes in precipitation and average temperatures, but this feedback has not been widely implemented across other models.

Jobs

Employment is one of the most modelled indicators, but only a few models include both labour supply and demand (E3ME, Earth4All, Eurogreen, LowGrow SFC, and GEM-E3). The labour supply is mainly modelled as the working age population multiplied by a labour force participation rate, which itself can be driven by factors such as wages or preference for leisure time.

For labour demand, there is a distinction between neoclassical and heterodox models. The neoclassical approach treats labour as a production factor, partially substitutable by energy and capital (EXIOMOD 2, GEM-E3, MAGNET, REMIND). The heterodox approach (Fig. 4) starts from total production or total capital and derives the corresponding labour demand (E3ME; Earth4All; Eurogreen; iSDG; Onaran et al., 2022; Ilkkaracan et al., 2021; Vasudevan & Raghavendra, 2022; LowGrow SFC). Some models include variation between sectors in how labour demand is determined, which is illustrated in the figure. For instance, Onaran et al. (2022) keep labour productivity out of the social sector to stress that productivity gains there are undesirable. In the agriculture sector, iSDG uses agricultural land as a driver for labour demand. In the long term, labour demand can be affected by changes in the labour productivity or capital-to-labour variables.

Health

Only iSDG and IFs cover health explicitly. Both models distinguish between a base mortality rate and category-specific mortality rates (Fig. 4). The former is driven by aggregate variables such as government spending and provides a base mortality rate for the whole population. Then, for each specific mortality category there are specific risk factors that can increase the base rate, such as exposure to particulate matter or political stability. IFs also calculates healthy life expectancy using morbidity multipliers.

Economic development

Many models include economic development as some measure of productivity growth in the economy. This measure can capture productivity for specific input factors such as labour or energy, or generalized productivity of the aggregate economy. Over all models there is a wide variety of drivers linked to productivity growth (Fig. 4). The variables that we show represent those included in at least two of our surveyed models.

We suggest that the choice of drivers included in any particular model may be due more to the modeler's pre-analytical vision and ideological considerations than empirical observation of what influences labour productivity. Within a growth paradigm it makes sense to argue that certain social outcomes (such as gender equality or health) are important policy targets if they positively influence productivity growth. This approach treats social outcomes as instrumental variables to achieve GDP growth. By contrast, the value of a strong sustainability approach like the Doughnut is to position a set of non-substitutable social outcomes as ends in themselves.

Work–life balance

Although no model explicitly includes a metric for work-life balance, some include variables on time use that could be used to measure work-life balance (Eurogreen; Onaran et al., 2022; Ilkkaracan et al, 2021; Vasudevan & Raghavendra, 2022). The typical time use categories are paid work, unpaid work, personal maintenance, and leisure time. Each model includes time use in a slightly different way. For instance, Ilkkaracan et al. (2021) apply a time poverty formulation (Fig. 4). Here, household members require a certain amount of time for reproductive household work, for personal maintenance (e.g. sleep) and for paid work to meet the household's basic needs. If the total time spent on these three categories exceeds the weekly available time, a household is considered time-poor. The strength of this model is that it can show time poverty, and that it represents unequal burdens among household members over different household types.

4.4 Driving variables

We used the archetypes from the previous sections to analyse which variables are most often used as drivers for the environmental and social indicators (Fig 5). Overall, income per capita is most widely used as a driving variable because many social outcomes in ESE models are often expressed as a function of income.

On the environmental side, the most important drivers are the agriculture sector (i.e. agricultural output and fertilizer use) and economic output (GDP). GDP is a prevalent driver of environmental impacts because it measures aggregate economic activity and can be linked to biophysical flows with intensity variables.

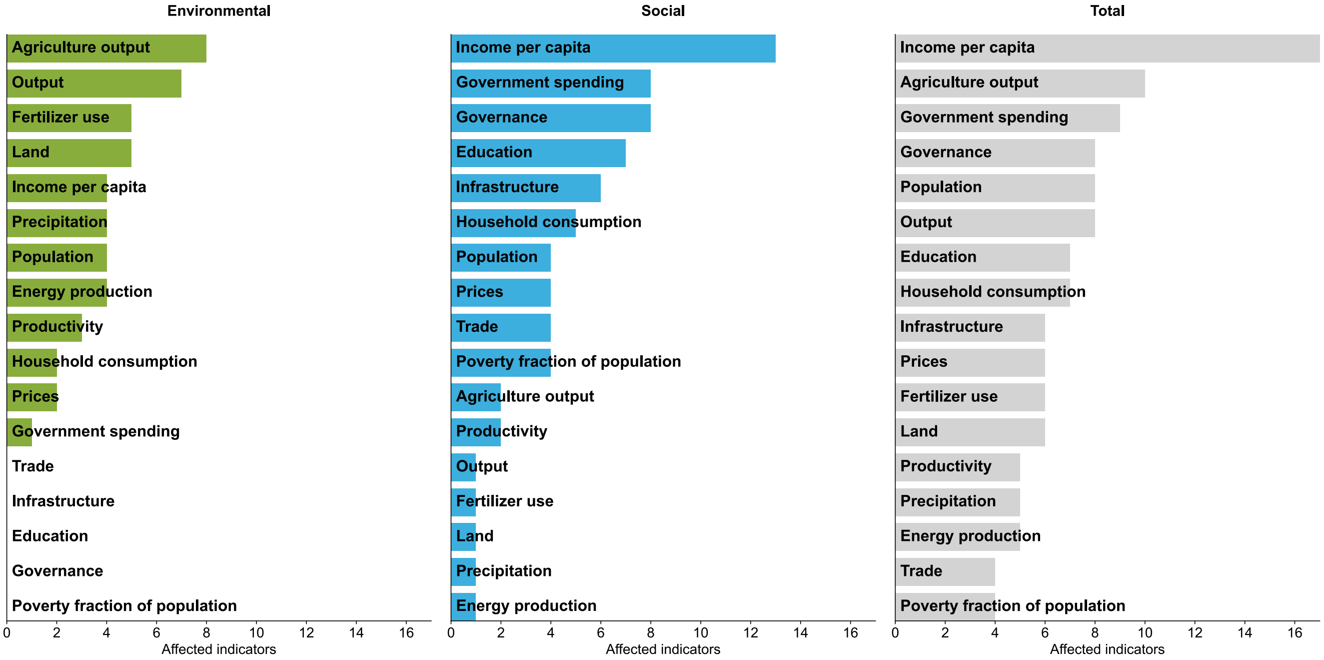

Figure 5. The most important variables in terms of how many environmental and social indicators they affect

On the social side, in addition to income per capita, a strong emphasis is given to the role of governments, through variables for governance, government spending, infrastructure, and education (Fig 5). Although governance affects many social indicators in models such as IFs and iSDG, only IFs includes it as an endogenous variable. Government spending, while playing a critical role in social provisioning, is a narrow description of the role that the state can play in a post-growth transition (Corlet Walker et al., 2021). Exceptionally, IFs and iSDG make noteworthy attempts at modelling health and education provisioning systems.

5. Discussion

Our results show that although some environmental and social indicators are well covered, further research is required to ensure a broad inclusion of environmental and social indicators in ESE models. The least covered environmental indicators are those that are difficult to link to GDP in an aggregate way. On the social side, the most intangible indicators are covered the least, as they are more difficult to define and cannot easily be linked to a macroeconomic framework. In general, modelers should rely less on economic variables as catchall determinants for various social and environmental outcomes. Specific provisioning systems should be modelled in more detail, with a stronger focus on complementing socioeconomic variables with political and environmental aspects.

5.1 Linking the economy to society and the environment

Most models link the economy to the societal and environmental spheres through monetary flows, as they are important determinants of environmental and social outcomes in a monetary economy. However, a strong reliance on monetary variables risks entrenching their use as policy levers. To envision transformative pathways towards radically different futures, models need to step beyond the conceptual structures that created the current socioeconomic systems.

Environmental pressures are mainly calculated as the product of sectoral economic output with intensity variables. Even though this approach gives a good high-level overview, it obscures which types of production and consumption are the most intensive. For the most covered indicators, namely climate change and energy use, we generally found a more detailed structure of their determinants. These formulations can be used as examples for modelling other environmental indicators. Modelers should include enough detail on drivers of environmental pressures so that policies can be evaluated in a meaningful way.

On the social side, we find that most models link social outcomes to income per capita, GDP per capita, or public spending. While these variables have their role to play, models should not default to using income to predict social variables just because this information is readily available. We should aim to understand what the real drivers of social outcomes are and try to better model these. Income should be complemented with biophysical, sociopolitical, and infrastructural elements. Models like iSDG and Ifs provide examples of how to incorporate a more diverse set of drivers.

The least covered social indicators were intangible constructs such as political voice and social support. Decisions on which measurable concepts constitute democracy or social relations are invariably influenced by the modeler’s positionality. Ideally, a plurality of definitions should be adopted among models, where the formulations are decided upon by a broader group of people with different backgrounds and worldviews. Although several databases and indicators exist that capture some of these dimensions, such as the Worldwide Governance Indicators (Kaufmann & Kraay, 2023) or Polity dataset (Center for Systemic Peace, 2021), they have been criticized on their conceptualization, measurement and aggregation (Munck & Verkuilen, 2002; Slinko et al., 2017; Thomas, 2010). Furthermore, there is mixed empirical evidence on determinants for these intangible constructs (Rød et al., 2020). Although these limitations explain the lack of inclusion of these indicators, they are still important policy goals that should be included in ESE models. Not including variables because they are hard to quantify leads to faulty models (Meadows, 2008).

A comprehensive and intersectional representation of inequality presents a special challenge in macroeconomic modelling. We suggest conceptualizing inequality in macroeconomic models using two dimensions: (1) the axes of discrimination (e.g. gender, race, ability) and (2) the forms of inequality (e.g. equality in income, time use). We found that gender and skill level are the most prevalent axes of discrimination that are currently modelled, while the forms of inequality that are included in current models include income, employment, time use, and education level. Future research could extend both axes of inequality, by including more data on different social groups and by including inequalities in a wider variety of social systems such as access to care and access to food.

5.2 Substitutability

The Doughnut framework starts from a vision of strong sustainability, as planetary boundaries and social goals cannot be substituted for one another. Within this context, neoclassical single-target optimization is problematic due to its aggregation of multiple goals into a single metric, implying that these goals are substitutable. Conversely, approaches such as system dynamics and macroeconometric input–output models allow for the complexity of multiple, potentially conflicting objectives. In theory, optimization-based models could align with the Doughnut framework if they imposed minimum thresholds on social indicators and maximum thresholds on environmental pressures. In practice, imposing such constraints could complicate the solution methods for these models significantly. Nevertheless, optimization models could provide valuable benchmarks for transition pathways.

On the production side, neoclassical models allow for substitution between production factors such as built capital, labour, energy, and materials. The degree of substitutability — and which factors can be substituted — depend on the model, and even on the sectors that are modelled. If there is substitutability, then the ecological impacts of economic activity can change due to relative price changes between different production factors. In contrast, most heterodox models envision production as having non-substitutable inputs. Therefore, ecological impacts can only be reduced through gains in efficiency and productivity. Models based on input–output data by default do not allow for substitution, unless additional functionality is added (e.g. EXIOMOD 2).

On the consumption side, neoclassical models allow for substitution between different goods, but some impose minimum consumption thresholds for each category of goods (e.g. GEM-E3). Above these thresholds, households can substitute between consumption goods. Such an approach aligns with the ideas of a human needs framework but lacks a theoretical foundation that explains how certain forms of consumption fulfil different needs. Some heterodox models (e.g. Eurogreen, IFs) allow for substitution between consumption categories depending on the prices of the goods. Instead of using utility functions, they base the consumption of each category of goods on historical data. In general, there is a gap in how consumption can be linked to needs satisfaction, and which other factors (e.g. social norms, government policy) affect consumption patterns.

5.3 Two approaches to biophysical limits

Most models do not have “hard” biophysical limits. Instead, they allow environmental impacts to increase well beyond safe limits without the economy being damaged or collapsing. Two notable exceptions are the Dasgupta and MEDEAS models. In the Dasgupta model, the exhaustion of the stock of natural capital beyond a safe limit hampers its regeneration, leading to a collapse of the economy. In MEDEAS, increasing climate change reduces the available energy supply in the energy system. As the economy in MEDEAS is constrained by the energy supply, this feedback mechanism imposes a strong biophysical limit. Although there are other models that include climate feedback mechanisms, they do not appear to explicitly impose a hard limit on economic activity.

In contrast to focusing on limits, some models direct their attention towards how positive social outcomes can be achieved without growth in environmental pressures. Instead of exploring what happens to society and economy when we exceed limits, these models explore what happens to society and the economy when resource use is stabilized or reduced. LowGrow SFC uses a suite of policies (e.g. redistributive measures, carbon taxes) to lower emissions and material use while improving social outcomes like working hours and equality (Jackson & Victor, 2019a). Eurogreen performs similar policy experiments and shows that redistributive measures paired with a decrease in consumption and exports can improve inequality and meet emissions goals, at the cost of increasing government deficits (D’Alessandro et al., 2020).

5.4 Drivers of productivity growth

Technological progress and labour productivity growth are an important part of many ESE models, and economic models in general, as they are seen as a core driver of economic growth. Our results suggest that the drivers for productivity growth included in different models may be attributable to the different ideologies and worldviews of the modelers. We see the use of social variables as drivers of productivity as an inverted approach that instrumentalizes social outcomes, making them serve economic output instead of treating economic output as a means to achieve social goals. This dynamic occurs widely across models since productivity is generally expressed as the ratio of output to input factors. Framing technological progress or productivity increases in this way further entrenches the problematic depiction of GDP as an end in itself, and reinforces the hegemony of a growth agenda in the modelling community.

5.5 Documentation and software

In our analysis, we encountered a wide diversity in the quality and format of model documentation, which hampers the transparency required for the scientific process and the critical assessment of these models. The most accessible documentation consisted of visual representations of the most important relationships, followed by concise, precise, and clear mathematical formulations of these relationships. This approach requires that all variables are clearly defined, either immediately below the equation or in a supplementary overview table. IFs is a good example of this best practice.

We also note that many of the surveyed models are not publicly available or use proprietary software, posing a barrier to understanding model mechanics and reproducing model results. We suggest that future generations of models should aim to use open-source software and programming languages (e.g. Python). We understand that for specific model techniques, there are few freely available software packages. As part of a long-term research agenda, open-source software for Computable General Equilibrium (CGE) and Dynamic Stochastic General Equilibrium (DSGE) modelling could be developed.

5.6 Limitations, caveats, and future research

It is important to note that our sample of models is not intended to be a fully representative sample of ESE models but was designed to capture the broadest coverage of indicators and approaches within the modelling community. There are two main limitations to our research.

First, our analysis is based on a sample of 50 models, from which we investigated 15 in-depth, so our results and conclusions are necessarily biased towards this sample. However, by including the models with the broadest coverage of indicators, our conclusions about the coverage of indicators should be quite representative. Furthermore, we included a diversity of model categories and theoretical underpinnings to avoid underrepresenting certain approaches.

Second, we focused on how ESE models represent our list of environmental and social indicators. This implies that we may have overlooked some indirect relationships. Furthermore, as we were limited by the available documentation, we may have misinterpreted some relationships. However, we reduced this risk by contacting the authors of the medium list models to verify our high-level analysis.

6. Conclusion

Our study highlights the urgent need to model what matters in Environment–Society–Economy models. Our analysis reveals significant gaps, particularly in the coverage of essential Doughnut indicators. While some environmental aspects such as climate, energy, land, and water are well-represented, others, notably biosphere integrity (i.e. biodiversity loss and HANPP) and soil quality remain inadequately addressed. Similarly, including less tangible social indicators presents the greatest challenge, since it is difficult to relate outcomes such as wellbeing, peace, justice, and political voice to macroeconomic variables. However, not including them in models risks invisibilizing critical societal goals.

Moreover, the prevalent focus on monetary flows and overreliance on existing macroeconomic structures limit our understanding of the interconnections between environmental, social, and economic systems. Relying on economic variables like income per capita as the primary determinant of social outcomes also stands in the way of understanding how to decouple wellbeing from consumption and biophysical resource use. Modelling provisioning systems in more detail would require the inclusion of biophysical, socioeconomic, political, and infrastructural variables, thus reducing the dependency on income as a driver of social outcomes in ESE models. It would also contribute to a new generation of models tailored to exploring post-growth futures that are able to move beyond historical trajectories and incumbent policy approaches.

Finally, our findings show a lack of integration and feedback mechanisms from the social and environmental realms back to the economy. To create meaningful change, future ESE models must embrace a holistic approach that encompasses diverse dimensions, acknowledging the intrinsic, rather than instrumental, value of positive social outcomes, and incorporating feedback loops from environmental and social systems. We must move beyond the confines of monetary measurements and transition towards models that directly link social provisioning to biophysical and socioeconomic inputs. By embracing this comprehensive perspective, modelers can help pave the way for sustainable futures, and empower policymakers to make informed decisions that prioritize the wellbeing of both our societies and our planet.

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