iSD Model Documentation

June, 2025

Edited By

Matteo Pedercini

and

Emil Zaharia-Kézdi

Washington D.C., June 2025

Millennium Institute

Acknowledgments

The iSD Model is the direct descendant of the early modeling effort made at the Millennium Institute in the early 1990s, initially guided by Gerald O. Barney and Bob Eberlein, and subsequently led for over two decades by Weishuang Qu and Jed Shilling. During these 40-plus years of continuous model development, several other people have contributed to its development in different capacities. The Millennium Institute is especially grateful to all the researchers, students, modelers, development professionals, and government officials that have enriched the model from very many different perspectives.

Editors

Matteo Pedercini, Emil Zaharia-Kézdi

Contributing Lead Authors (CLAs) in alphabetical order

Steve Arquitt; Moulaye Bamba; Cynthia Kreidy; Estee Miltz; Igor Oliveira; Vadim Nuñez Pawlowsky; Fernando Redivo; and Nathalie Spittler.

Table of Contents

Introduction

The iSD model is a System Dynamics based tool that has been designed to support national development planning. At its core, the iSD model stems from the well-vetted, time tested and validated Threshold21 (T21) model, and has since evolved to integrate multidimensional sustainable development frameworks (e.g. UN SDGs, national accounts, NDCs, LT-LEDs, Planetary boundaries, Human development metrics etc.). It thereby enables policymakers and planning officials at all levels of governance to understand the interconnectedness of policies designed to achieve development goals and test their likely impacts before adopting them.

More specifically, the iSD is structured to analyze medium-long term development issues at the nationwide level. In a single, modular framework, the model integrates the economic, social and environmental dynamics of development planning. The level of aggregation used makes it ideally suited to assess resource allocation issues across different investment options. Further, the iSD model is designed and developed to support decision makers in addressing questions such as: What level of resources is needed to achieve specific development goals? How to distribute investment across different sectors of the economy? How to finance such investment? Thus, iSD is conceived to complement budgetary models, sectoral models, and other short-medium term planning tools by providing a comprehensive and long-term perspective on development.

At its core, the iSD maintains a focus on integrated planning and is useful at four levels in the planning process. First, it allows analyzing how – under business as usual conditions – the country would progress towards the stated development goals. Such analysis provides an initial overview of the areas that require more attention from policymakers. Second, the high level of interconnectedness among the sectors in the model allows for building a shared understanding among stakeholders of how development in each area affects (and might be necessary for) developments in other areas. Such understanding provides important insights on the fundamental leverage points in the system – i.e. points of intervention that can lead to rapid and positive change. Third, the model supports the simulation of a broad variety of policies relevant to sustainable development, in isolation and in combination with others, to appreciate their impact and possible synergies. Finally, based on such analysis a coherent development strategy can be built, and the financial needs for its implementation can be assessed. The model thereby provides fundamental trends for hundreds of relevant development indicators by 2050 under a business-as-usual scenario, and supports the analysis of relevant alternative scenarios.

The iSD has evolved over two decades as applications to individual countries were developed, tested, modified, and refined. The model has been extensively used by ministries of finance, planning and other line ministries; UN agencies, the World Bank, and other international institutions; private sector and academic institutions. To date, the model has been customized for over forty developing and industrialized economies, and adapted through a participatory customization process to address the very different planning needs of countries across the world.

New applications have required new sectors to be added, for example health, nutrition, education, energy, water, etc. Based on such experience, iSD has been continuously improved and all the most valuable extensions retained in the subsequent versions of the iSD model. In case the country's need for long-term integrated planning extends beyond the core structure of iSD, the model can be customized to address additional issues, or to capture countries' specificities. Additional sectors can be introduced to capture the reality of a country (e.g. tourism). Similarly, some sectors can be eliminated during the customization process if not relevant to a specific country's situation. This document represents the official documentation of the core iSD model, and is meant for the general public. This documentation does not include highly technical modeling aspects, nor all the references on which the iSD model has been built. For simplicity and readability, we indicate only the most relevant sources of information.

1.1 Policy Support

The iSD model is a broad and integrated tool to support the design and assessment of effective development strategies. It has low resolution compared to sector-specific models, which can include a higher level of detail on selected issues and policy options. The model's results inherently embed a high degree of uncertainty, being long-term in nature (thus, a large variety of unforeseeable changes can take place); and broad in scope (thus including many parameters with uncertain future value). Because of such characteristics, the iSD model is not to be intended as a substitute to short-term or sector-specific models that are used in support of various phases of the policy process, but as a tool to support policy-makers in establishing policy coherence and building an integrated view on development strategies.

The policy process can be very different across countries and sectors. In most cases, however, the process can be organized around five main steps:

1 Agenda setting / identification of issues
2 Policy design / formulation / assessment
3 Policy adoption
4 Policy implementation

5 Policy assessment / monitoring / evaluation

The iSD model can be used for different purposes in the different stages of the process, although it has been designed especially to support Step 2. For instance, when developing a SDGs strategy or program, such steps can become very complex as alternative options of resource allocation across different sectors are assessed, discussed, and negotiated. In this case, the iSD model can be used (also for live simulation as part of multi-stakeholders events) to provide quantitative background to explorative discussions on the key areas of intervention. The base run of the model provides a first assessment of the progress on each goal by 2030, highlighting the areas in the direst need of intervention. In addition, the set of policy interventions included in the core version of the model can be rapidly simulated to assess their relevance with respect to the strategic objectives. The model also provides an initial assessment of the financial resources requirements.

As another example, the model can be used in a more advanced phase of policy formulation and assessment, when details of policies and implementation mechanisms are defined. As interventions in each area are elaborated by sector experts (by way of detailed, sector-specific models) the iSD model can be used to simulate such interventions in isolation and in combination in order to assess cross-sector synergies (positive and negative) and fine-tune interventions to increase their effectiveness - though this may require model modification to represent policies as defined by sector experts. Such exercise also provides an estimation of the development impact of the combined interventions and enhances strategy coherence.

The iSD model can also be used to assess the alignment of existing national strategies and budgets with the SDGs. Such exercise involves the simulation of iSD with the fundamental interventions included in existing national strategies, subject to model modifications, in order to assess the extent to which such interventions facilitate the country’s progress towards the SDGs. Major gaps between goals and simulation results indicate the necessity of adjusting resources allocation over time and/or envision additional interventions. A similar exercise can be carried out on the national yearly budget.

1.2 General Characteristics of the Model

MI’s iSD model is a System Dynamics based model for comprehensive and participatory development planning. By this, we mean that the model:

- Integrates economic, social, and environmental factors;
- Represents the important elements of complexity – feedback relationships, non-linearity and time delays – that are fundamental for proper understanding of development issues;

- Is transparent in its structure, assumptions, equations, and data requirements, to serve as a participatory tool in consensus building and policy discussions;
- Is flexible enough to be customized to specific countries by trained users based on country-specific conditions;
- Simulates the medium- and long-term consequences of alternative policies; and
- Allows for easy comparison to reference scenarios and supports advanced analytical techniques, such as sensitivity analysis and optimization.

The model provides policymakers and other users with an estimate of the consequences to be expected from current and alternative decisions. Such estimates are not to be taken as exact forecasts (no model can accurately forecast long-term development trends) but as reasonable and coherent projections, based on a set of clear assumptions.

The iSD model is especially well suited to analyze the interactions among policies directed to achieve the SDGs and underlying frameworks. All sectors of the model are dynamically interacting; hence, any policy introduced in any given sector has cross-sector impacts that spread throughout the model. Any number of policies can be simultaneously simulated, and through the *synergy assessment tool* the model supports the analysis of the contribution of each policy to the final result for any indicator; and of synergies among policies.

1.2.1 Model boundaries and time-horizon

iSD's structure represents development mechanisms that can be found in most developing and industrialized countries, and covers relevant indicators for all 17 Sustainable Development Goals, in addition to a range of indicators to support more recent international and national reporting frameworks (e.g. Paris Agreement, NDCs, LT-LEDs, Planetary Boundaries, Human Development Index). As such, it covers a broad range of issues: from poverty to environmental degradation, from education to health, from economic growth to demographic expansion. The following paragraphs describe the fundamental boundaries of the model in various dimensions.

Endogenous, exogenous and excluded variables

A first level of boundaries defines what variables are considered endogenous, exogenous or excluded from the model. iSD's fundamental approach is to endogenously represent variables that are considered an essential part of the development mechanisms under analysis. For example, the Gross Domestic Product (GDP), population, or the demand and supply of natural resources (and their main determinants) are endogenously calculated.

Variables that have an important influence on the issues analyzed, but which are only weakly influenced by the issues analyzed, or which fall beyond the iSD model boundary are exogenously represented. For example, rain cycles, the level of grants received, or the exchange rate are exogenously determined. In addition, since the focus of iSD is on long-term development issues, inflation and interest rates are also exogenously represented. For specific country applications, where supported by evidence, these variables can be made endogenous in the model.

Finally, variables that are outside the scope of the analysis, that have no quantifiable effect on the issues being analyzed, or that are not likely to change over the time horizon considered, are not explicitly represented in the model. Examples include earthquakes, ethnic issues, cultural diversity, etc. Note that the fact that such variables are not explicitly represented in the model does not necessarily mean that their effect on the system is neglected, but in most cases, that their effect is implicitly embedded in other functions of the model, and not separately analyzed. For instance, cultural aspects that are not explicitly represented might affect the response curve of access to healthcare services to income: such assumption is acceptable as long as we do not envision a substantial change in the way cultural aspects will affect that relationship in the future.

Level of aggregation

Another aspect of the model boundary defines the level of aggregation. iSD is conceived as a national model and, from a geographic perspective, data are aggregated at the national level. All variables therefore represent the national total (or average) of their real-world counterparts. For example, agriculture production represents the total agriculture production in the country, and it is not disaggregated into provinces of origin. The literacy rate represents the average for the whole country, and it is not disaggregated by province or municipality.

Although geographical disaggregation is not used in iSD, the main social, economic and environmental variables are broken down in sub-components as required in order to analyze the focus issues. For example, population is divided into 101 age-cohorts and 2 genders, and the age-gender distinction is used in most social indicators; production is divided into industry, services and agriculture (following the ISIC 4 classification); agriculture activities are further divided by type of crop, fish, animal, and wood; and, land is divided into forest, agriculture land, settlement and other land. Full details on the level of aggregation for each variable are provided in the following chapters of this documentation and in Appendix II.

Geographic boundaries

The focus of iSD is on the specific country being analyzed. Although the model also addresses the impacts of developments in the rest of the world (e.g., through changes in oil prices, global GDP, etc.) on the country, the model is centered on the internal issues of the country. The model can therefore address questions of what a country can do to help further its own progress and sustainability.

The model also determines outputs from the country to the rest of the world, e.g. CO2 emissions. However, the *small country* assumption is made, that is, the performance of the country is assumed to have no relevant effect on the rest of the world. For example, oil prices are generally considered exogenous, as well as other commodities' prices. This assumption is generally relaxed when the country being analyzed has a particularly relevant role in affecting a global issue. For example, when analyzing energy problems in the U.S.A., oil prices are considered endogenous.

Time horizon

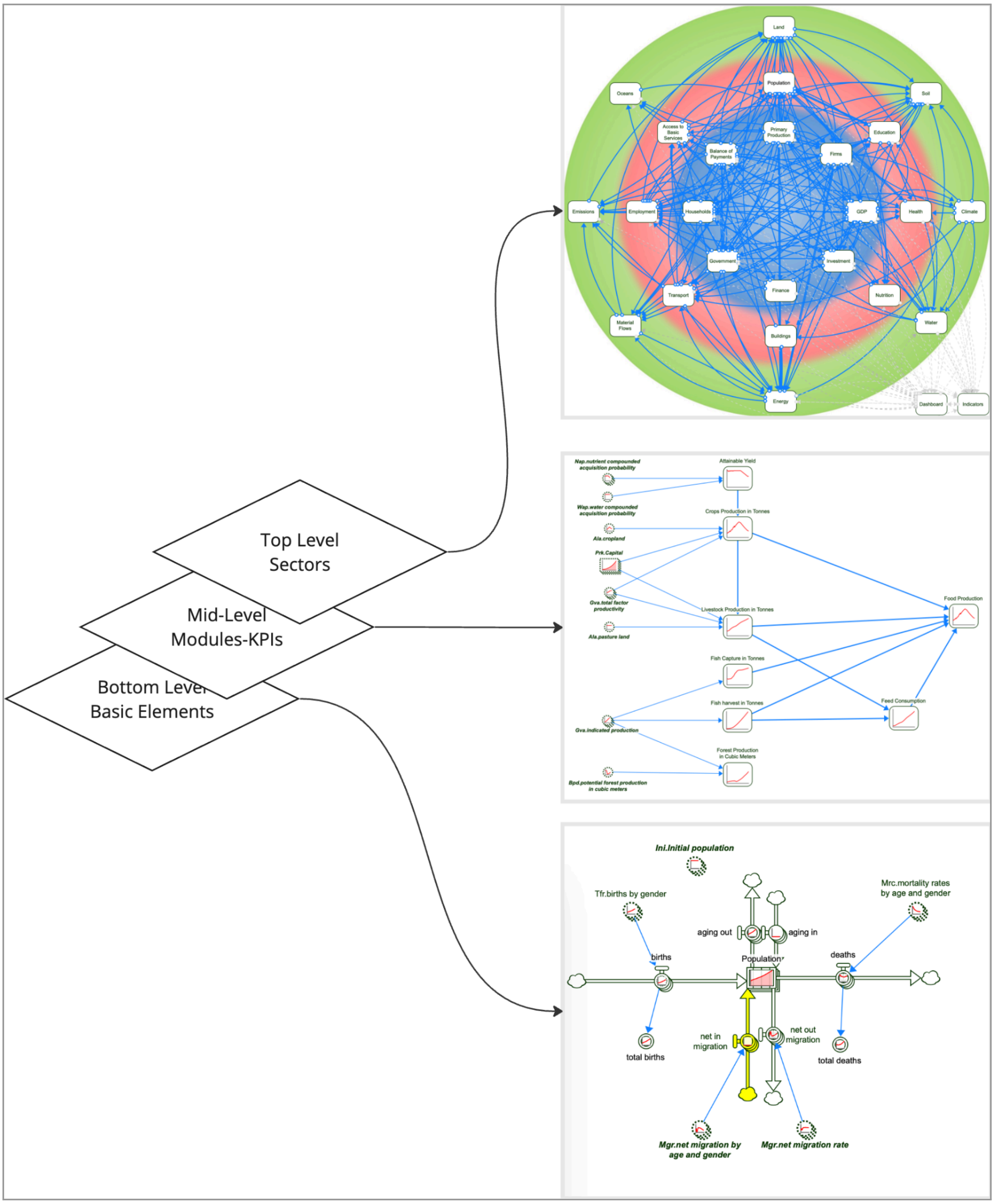
iSD is built to analyze long-term development issues. The typical time horizon for simulation starts in 2000 and extends to 2050. At the time of writing, this means simulating 25 years of historical behavior and projecting 25 years into the future.

Beginning the simulation in 2000 ensures that, in most cases, the long-term trends characterizing the issues being investigated can be fully observed and replicated. The starting date of the simulation is however highly dependent on data availability, and often has to be adjusted to more recent periods, for which country data are reliable.

iSD projections extend to the year 2050 to ensure that the long-term effects of policies implemented today on the development of the country can be well appreciated. For specific analytical purposes, e.g. long-term sustainability assessment, the simulation can be extended further into the future, which requires a careful assessment of the exogenous inputs to be used (e.g. projections of global GDP growth).

1.2.2 iSD Modular Structure

As a result of the broad scope of the model, iSD is considered in its category to be a large-sized model: it includes over 4500 variables (which ascend to almost 100,000 when accounting for array disaggregation) and several thousand feedback loops. Given the size and the level of complexity of the model, its structure is organized into three hierarchical layers, as illustrated in the Figure below. The top layer consists of logical units called "sectors". A sector represents a broad domain area that is relevant to development policy analysis, such as "Education", "Energy" or "Transport". Each sector contains various "modules", smaller pieces of structure with self-contained internal logic that are functional to calculating a key indicator, and that can be understood in isolation from the rest of the model. Within a sector, modules are interconnected to reflect the main dynamics in that domain and are also interconnected with modules from other sectors. Inside each module, variables are represented using stock and flow diagrams, each defined by one or more equations, or exogenously set through input data. iSD is composed of 24 main sectors (plus two sectors dedicated to managing input and output variables), and 231 modules (full list provided in Appendix I).



Logical layers of model architecture

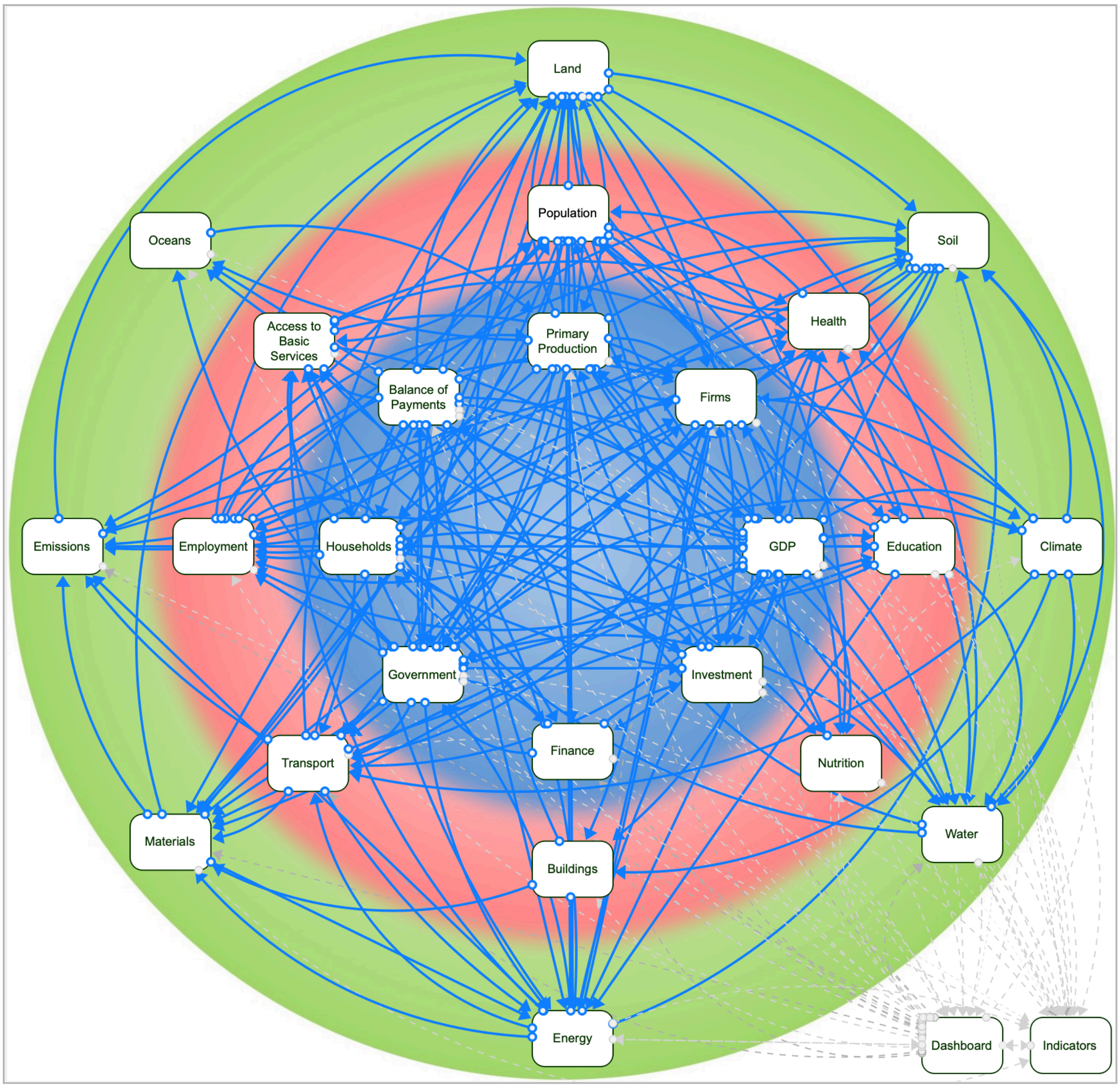
The 24 sectors composing iSD include: 8 social sectors, 8 economic sectors, and 8 environmental sectors (Table 3), each characterized by a name and a reference alphabetic letter (in square brackets in the table). The sectors interact with one another dynamically through a complex network of feedback loops.

Table 3: Sectors of iSD

Society	Economy	Environment
[P] Population	[Q] Primary Production	[L] Land
[R] Health	[K] Firms	[S] Soil
[E] Education	[Y] GDP	[C] Climate
[N] Nutrition	[I] Investment	[W] Water
[B] Buildings	[F] Finance	[V] Energy
[T] Transport	[G] Government	[M] Materials
[J] Employment	[H] Households	[X] Emissions
[A] Access to basic services	[B] Balance of Payments	[O] Oceans

The scope of each sector is reflected in the name used to identify it. Although the names of some sectors can be easily associated with the definitions of some of the SDGs, there is no one-to-one association between sectors and goals: normally, the indicators used to monitor a goal are calculated across various sectors. The overview below provides a graphic representation of the 24 sectors and their affiliation to the environmental sphere (outer green circle); the social sphere (middle red circle); and the economic sphere (inner blue circle) [1]. The overview includes the connections among sectors, which form a complex network of feedback loops that determines the system's behavior over time. From the model's perspective, economic activities take place within the society (from which social resources are drawn to generate economic value); and the broader natural environment (source and sink of natural resources, emissions, and waste). The accumulation of socioeconomic resources, and the use of environmental resources, drives development, which in turn generates additional socioeconomic resources, further driving the development process. On the other hand, the diminishing returns in the use of resources, or their limited availability, constrains development.

[1] The actual structures represented in each sector can extend beyond an individual sphere: for instance, the Soil sector can also contain minor economic components; or the Agriculture sector can contain biophysical relationships.

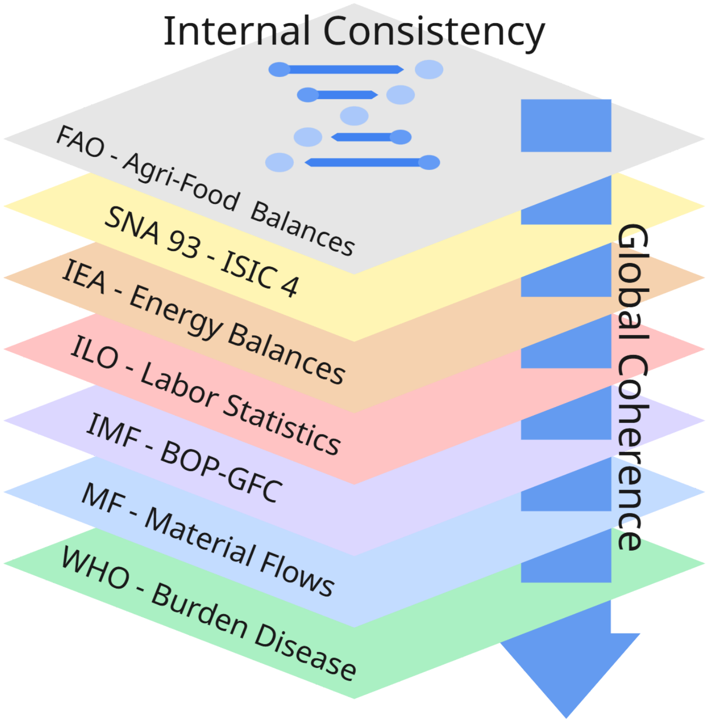


Overview of iSD sectors

In the following chapters of this documentation, a description of the specific assumptions and formulations used in each sector is provided. The structure of the individual sectors are based on well-established analytical frameworks and research, also including applied research performed by the Millennium Institute's modeling team. The major distinctive characteristic of iSD lies in the way the various sectors are linked together, forming a complex network of feedback loops that is the determinant of the model's behavior, as further described in the following paragraphs.

1.2.3 Indicators in iSD

The iSD model produces results for a broad range of social, economic, and environmental indicators. The model includes fundamental dynamics important for national-level decision-making and disaggregates related indicators according to international and national reporting standards. Economic activities for instance are defined and disaggregated according to the International Standard Industrial Classification (ISIC Rev. 4). Similarly, data and dynamics in the Agricultural sub-sectors are structured according to the convention of the FAO- Agri-Food Balances. The figure below highlights the main analytical frameworks that are used consistently within each sector, and in a coherent way across the whole model. A detailed description for the different sectors is further provided in the documentation for each respective sector. Lastly, Appendix II provides a complete overview of the disaggregation for all model variables, also known as array elements.



In terms of the model outputs, the iSD model measures a range of output indicators aligned with international and national metric frameworks, with a main focus on the UN SDGs, but also including indicators around the Human Development Index, Planetary Boundaries, as well as key performance indicators (KPIs) related to Poverty, Employment, Government Accounts, Energy, Emissions, Land Use and Material Consumption.

In the case of the SDG indicators - the model includes indicators and relevant policies for all the 17 Goals, with the data structured according to the UN Statistics Division categorization. The table below provides an overview of the indicators relevant to each Goal that are included (directly or through relevant proxies) in the core version of the model, for a total of 65 indicators. Additional information about the calculation of the performance of each indicator and respective goal is documented in supplementary material, and can be provided upon request. Further indicators can be included in the process of customization to a particular country's characteristics and analytical needs.

Table 1: SDG indicators in the iSD Core model

Goal	Indicators
G1	1.1.1 Proportion of population below the international poverty line, by sex, age, employment status and geographical location (urban/rural) 1.2.1 Proportion of population living below the national poverty line, by sex and age 1.4.1 Proportion of population living in households with access to basic services 1.5.1 Number of deaths, missing and persons affected by disaster per 100,000 people 1.5.2 Direct disaster economic loss in relation to global GDP
G2	2.1.1 Prevalence of undernourishment 2.2.1 Prevalence of stunting among children under 5 years of age 2.2.2 Prevalence of malnutrition among children under 5 years of age, by type (wasting and overweight) 2.3.1 Value per labour unit by classes of farming/pastoral/forestry enterprise size 2.4.1 Proportion of agricultural area under productive and sustainable agriculture
G3	3.1.1 Maternal mortality ratio 3.1.2 Proportion of births attended by skilled health personnel 3.2.1 Under-five mortality rate 3.2.2 Neonatal mortality rate 3.4.1 Mortality rate attributed to cardiovascular disease, cancer, diabetes or chronic respiratory disease 3.6.1 Death rate due to road traffic injuries 3.7.1 Proportion of women of reproductive age who have their need for family planning satisfied with modern methods 3.7.2 Adolescent birth rate per 1,000 women in that age group 3.8.1 Coverage of essential health services
G4	4.1.2 Proportion of children and young people: (a) in grades 2/3; (b) at the end of primary; and (c) at the end of lower secondary achieving at least a minimum proficiency level in reading and mathematics, by sex 4.3.1 Participation rate of youth and adults in formal and non-formal education and training in the previous 12 months, by sex 4.5.1 Parity indices (female/male, rural/urban, bottom/top wealth quintile and others such as disability status, indigenous peoples and conflict affected as data become available) 4.6.1 Percentage of population in a given age group achieving at least a fixed level of proficiency in functional (a) literacy and (b) numeracy skills, by sex
G5	5.5.2 Proportion of women in managerial positions 5.6.1 Proportion of women aged 15-49 years who make their own informed decisions regarding sexual relations, contraceptive use and reproductive health care
G6	6.1.1 Proportion of population using safely managed drinking water services 6.2.1 Proportion of population using safely managed sanitation services, including a handwashing facility with soap and water 6.4.1 Change in water use efficiency over time 6.4.2 Level of water stress: freshwater withdrawal as a proportion of available freshwater resources
G7	7.1.1 Proportion of population with access to electricity 7.2.1 Renewable energy share in the total final energy consumption 7.3.1 Energy intensity measured in terms of primary energy and gross domestic product
G8	8.1.1 Annual growth rate of real GDP per capita 8.2.1 Annual growth rate of real GDP per employed person 8.4.1 Material footprint (MF) and MF per capita, per GDP 8.4.2 Domestic material consumption (DMC) and DMC per capita, per GDP 8.5.2 Unemployment rate, by sex, age and persons with disabilities 8.6.1 Proportion of youth (aged 15-24) not in education, employment or training
G9	9.1.1 Proportion of the rural population who live within 2 km of an all-season road 9.2.1 Manufacturing value added as a proportion of GDP and per capita 9.2.2 Manufacturing employment as a proportion of total employment

	9.4.1 CO2 emission per unit of value added
G10	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 10.2.1 Proportion of people living below 50 per cent of median income, by age, sex and persons with disabilities 10.4.1 Labour share of GDP, comprising wages and social protection transfers 10.4.2 Redistributive impact of fiscal policy
G11	11.3.1 Ratio of land consumption rate to population growth rate 11.5.1 Number of deaths, missing and persons affected by disaster per 100,000 peopled 11.5.2 Direct disaster economic loss in relation to global GDP, including disaster damage to critical infrastructure and disruption of basic services 11.6.1 Percentage of urban solid waste regularly collected and with adequate final discharge with regard to the total waste generated by the city 11.6.2 Annual mean levels of fine particulate matter (e.g. PM2.5 and PM10) in cities (population weighted)
G12	12.2.1 Material footprint (MF) and MF per capita, per GDP 12.2.2 Domestic material consumption (DMC) and DMC per capita, per GDP
G13	13.1.2 Number of deaths, missing and persons affected by disaster per 100,000 people 13.2.2 GHG emissions per capita
G14	14.4.1 Proportion of fish stocks within biologically sustainable levels 14.5.1 Coverage of protected areas in relation to marine areas
G15	15.1.1 Forest area as a proportion of total land area 15.1.2 Proportion of important sites for terrestrial and freshwater biodiversity that are covered by protected areas, by ecosystem type 15.5.1 Red List Index
G16	16.1.1 Number of victims of intentional homicide per 100,000 population, by sex and age 16.5.2 Proportion of businesses who had at least one contact with a public official and who paid a bribe to a public official, or were asked for a bribe by these public officials, during the previous 12 months 16.6.2 Proportion of the population satisfied with their last experience of public services
G17	17.1.1 Total government revenue as a proportion of GDP, by source 17.1.2 Proportion of domestic budget funded by domestic taxes 17.4.1 Debt service as a proportion of exports of goods and services

1.2.4 Areas of Intervention

The areas of intervention indicated in the table below include a core set of policies and assumptions that directly (or indirectly) impact on different economic sectors in terms of social, economic and environmental outcomes. For example, in a given country poverty eradication could be more effectively achieved through a comprehensive education and agriculture program, than through direct subsidies to the poorest households. The iSD model is often customized to simulate additional policies, other than those documented in Table 2.

Table 2: iSD-model areas of intervention

Social	Economic	Environmental
– Subsidies and transfers – Public healthcare	– Direct tax revenue	– Efficient irrigation systems

– Reproductive health – Public education – Education gender bias – Productivity gender bias – Employment gender bias – Improved water sources – Improved sanitation facilities – Road infrastructure – Rail infrastructure	– Indirect tax revenue – Tax revenue from international trade – Tax progression – Financing choices – Governance indexes – Foreign grants – Public vs. private resource mobilization – Public investment in private sector – Agriculture training – Fertilizer subsidies	– Small scale photovoltaic – Small scale hydropower – Industry energy efficiency – Households energy efficiency – Vehicles efficiency – Waste management – Large scale sustainable energy generation – Climate change adaptation – Marine areas protection – Terrestrial areas protection – Reforestation

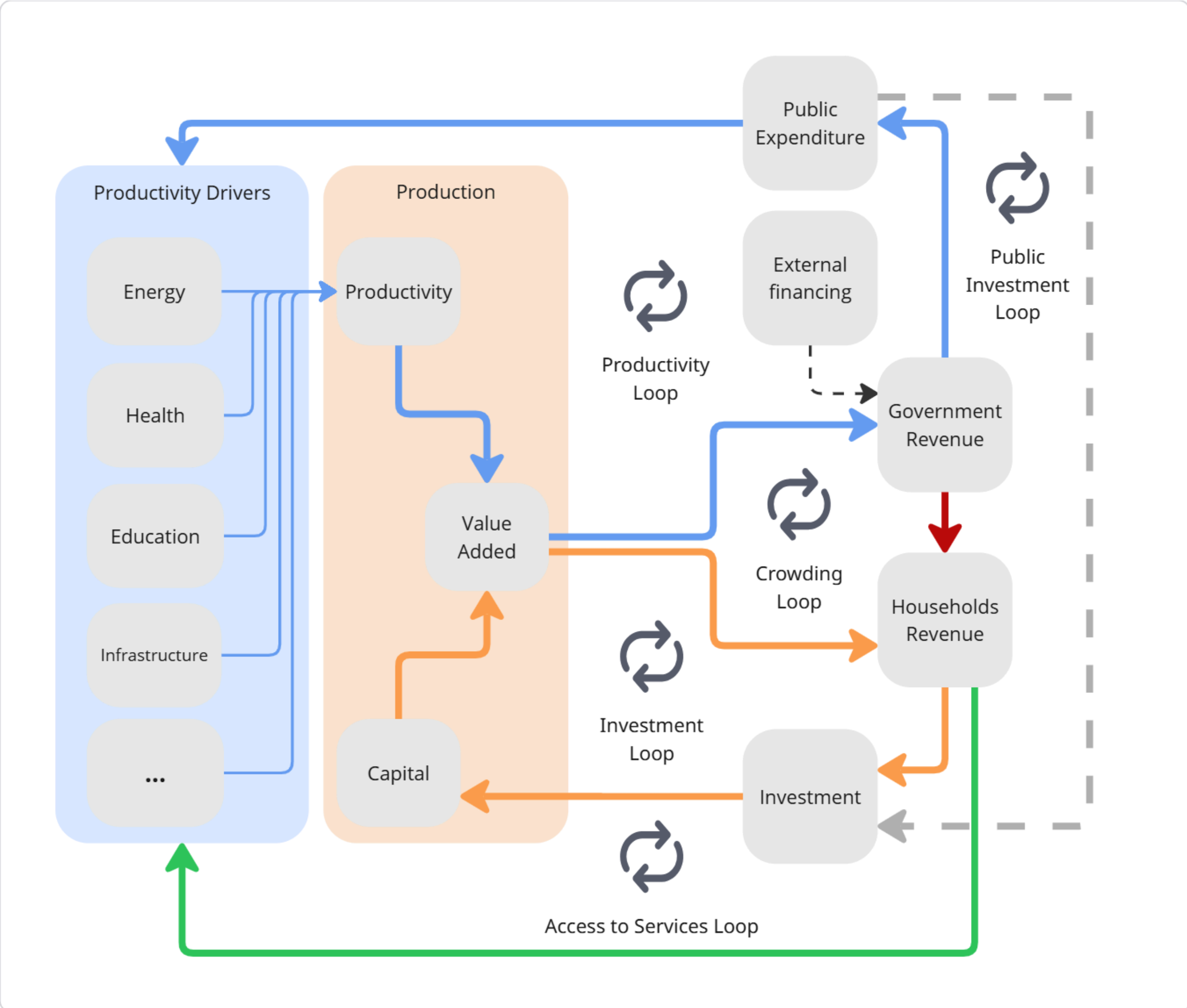
1.3 Fundamental Dynamics

Several feedback loops drive - or hinder - development in the iSD model. These mechanisms include relationships that connect variables across the economic-social and environmental sectors, creating powerful reinforcing or balancing mechanisms. While it would be impractical to describe all those feedback loops, here we show some of the loops that, under normal circumstances, are central to the model behavior.

1.3.1 Major Feedback Loops Driving Development

While economic growth is not a good proxy for a country's development, economic activity is central to a country's transformation, in that it provides the means and resources to successfully undertake such a process. The figure below shows how various interconnected feedback loops link productivity drivers, production, government finance and investment in the model. At the center, productivity is influenced by key drivers such as energy, health, education, infrastructure and other societal factors. These drivers enhance productivity, which creates economic value through production. The total value added then contributes both to government and household revenue. Government revenue supports public expenditure and investment (via the *Public investment loop*), while households' revenue contributes to private investment (the *Investment loop*). Both public and private investments boost capital, which further increases the amount of value added. Simultaneously, increased households revenue reinforces the *Access to Services loop*; while government expenditure (through the provision of social services and infrastructure) provides productivity gains that support the *Productivity loop*. Government investment can also lead to compressing the space for private investment (the *Crowding loop*) by absorbing private saving or exhausting viable opportunities for private investment. External financing further contributes to government revenue, providing an additional source of government revenue.

In summary, these feedback dynamics drive the growth in the productivity of society, which contributes to value creation through economic activities, and in turn reinforce government expenditure and investment (public and private) into the economy. These dynamics broadly reflect the macro-economic theory underlying neoclassical growth and endogenous economic growth, and the fundamental hypothesis on production are further described in section 1.3.3 below.

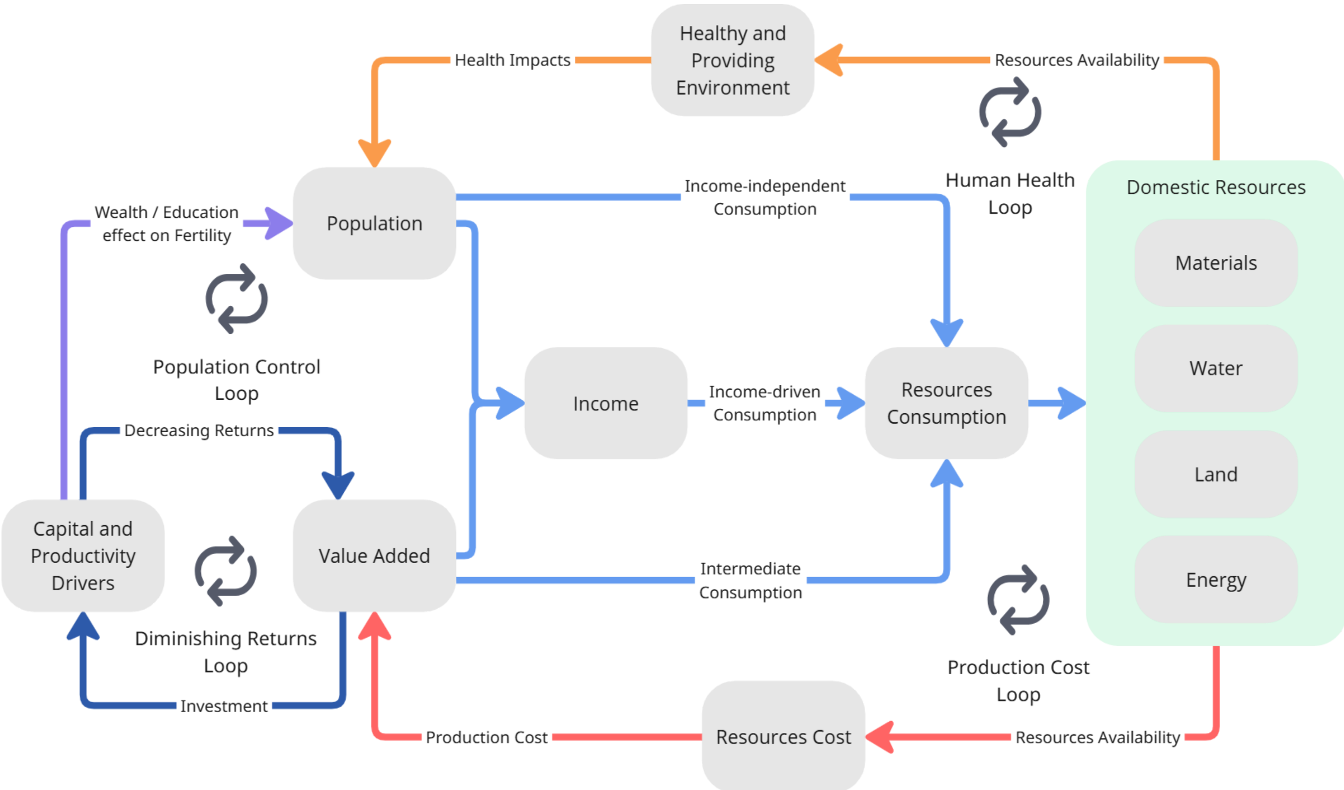


1.3.2 Major Feedback Loops Hindering Development

As the feedback loops discussed above drive development in the iSD model, other key feedback loops slow development, by weakening or counteracting the reinforcing feedback loops discussed above.

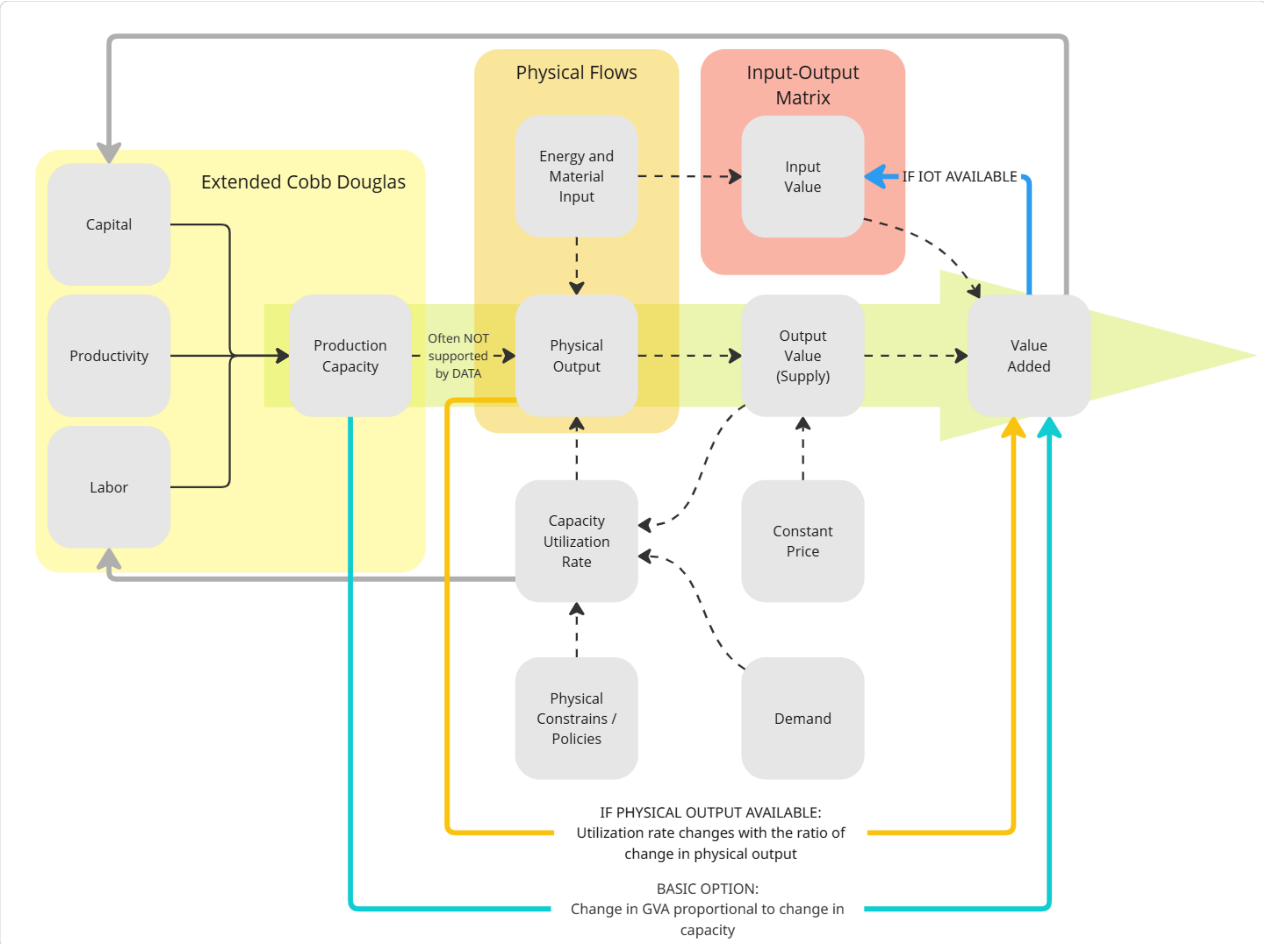
These main limiting (or balancing) feedback loops stabilize interactions between population growth, economic development and environmental sustainability. Firstly, the *Population Control loop* shows how increases in added economic value - driven by economic activity and production - can lead to improvements in wealth and education, and in turn reduce fertility rates and population growth. The *Diminishing returns* loop captures the effects of ongoing investment into capital and productivity which progressively result in smaller gains, moderating economic growth. The *Production Cost loop* highlights the effects of environmental constraints, as a result of increased resource consumption from population and income growth. This in turn results in a decline in domestic resource availability, driving up resource and production costs hence limiting value addition. Lastly, *Human health* captures the role of environmental quality in sustaining the population and economy. As resource consumption degrades the environment, population health deteriorates, which in turn decreases labor productivity, income generation and constrains population growth.

Together, these loops slow down development, emphasizing the interconnectedness of society and economy with the environment. While some of these dynamics are difficult to appreciate in the short term, they can become dominant in the longer-term, and thus it is important to recognize them when crafting long term development strategies.



1.3.3 Fundamental Hypotheses on Production

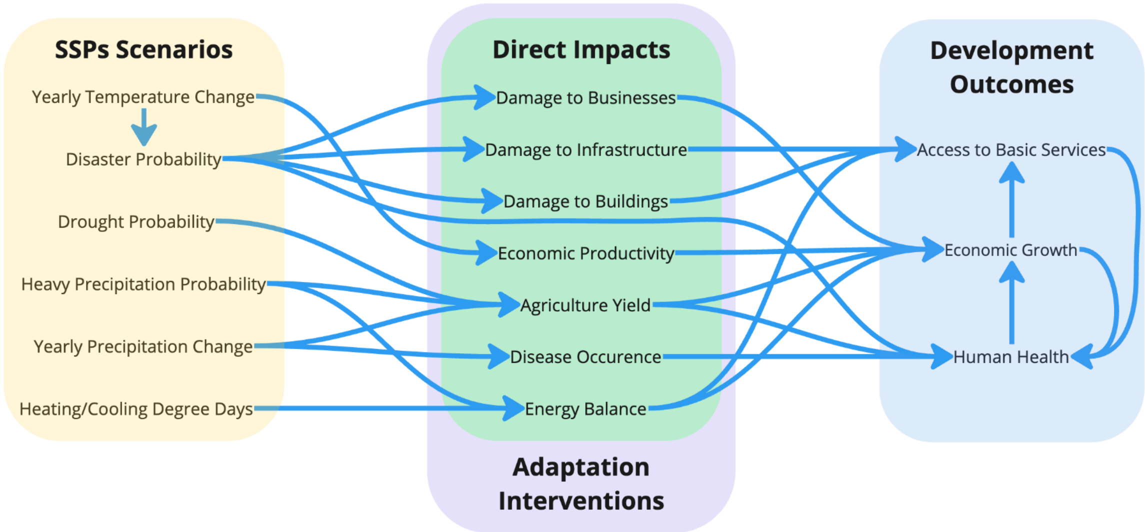
The major feedback loops driving and limiting development further play a key role in formulating the *production hypothesis* in the iSD model. The Cobb-Douglas function captures the combined effects through which capital, labor and total factor productivity affect production capacity and eventually value added. Productivity is further dependent on a range of economic, social and biophysical drivers. The representation of the relationship between production capacity and value added can take on different forms, depending on the specific economic activity and the available data. The simplest, basic option, involves assuming a constant, direct proportionality between production capacity and value added, as illustrated by the green arrow in the figure below. This is useful when data on physical output is not available, and thus capacity utilization cannot be computed. When such data is available, physical output is computed in the model, and a direct relationship is assumed between output and value added. Changes in consumption then affect the capacity utilization and hence the output and value added. In case Input-Output data is available, the relationship between output and value added can be further enriched, by considering the cost of input and determining value added by difference. This setup allows adapting swiftly to data availability and scope of the analysis.



1.3.4 Climate Impact Pathways

The figure below illustrates the key climate pathways in the iSD model, that map the effects of climate change on development outcomes. The main climate variables (temperature change, disaster probability, drought conditions, precipitation etc.) are exogenous to the iSD model, meaning that the underlying climate conditions are not simulated within the model but are derived from external data, specifically the Climate Change Knowledge Portal (CCKP) of the World Bank (World Bank, 2024). The iSD model is not a climate model, and therefore relies on external data from global climate model compilations derived from observations and climate ensembles. This ensures that the climate variables incorporated into the analysis are grounded in robust projections. Future climate conditions are further embedded in the scenarios from the Shared Socio-economic Pathways (SSP) framework to provide varying narratives for global development. The iSD model includes, by default, five SSPs that the user can rapidly select: SSP1 (1.9c increase in temperature by 2100); SSP1 (2.6c); SSP2 (4.5c); SSP3 (7.0c); and SSP5 (8.5c). This broad range of external scenarios allows for exploring how domestic strategies can respond to a variety of possible future conditions.

The key climate variables directly and indirectly affect various sectors in the model. Changes in temperature and precipitation directly affect agricultural yields, disease occurrence and disrupt the energy balance. Extreme climatic events cause direct damage to buildings, businesses, and infrastructure. All of these have longer-term effects on economic growth and human health, thus fundamentally affecting a nation's development trajectory. These climate pathways further present strategic opportunities for policy intervention. Targeted adaptation and mitigation measures, such as reforestation, investments in renewable energy, advanced irrigation technologies, and water-use efficiency improvements, amongst others, can mitigate the cascading climate impacts in the model.



1.4 Calibration and Validation

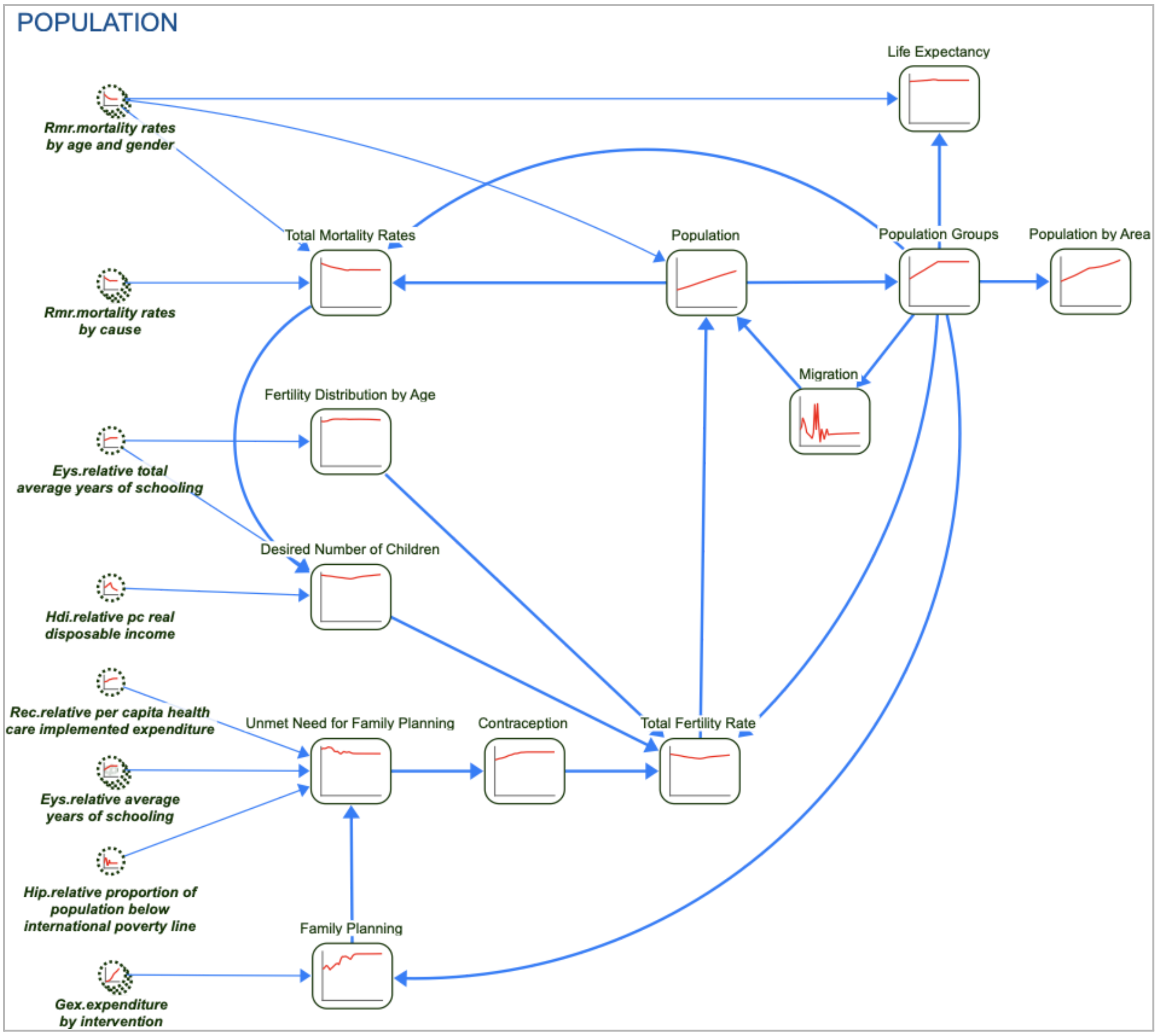
The iSD model is structured to analyze medium to long-term development trends at the national level to provide policy insights. As such, the model does not provide forecasts, but rather provides projections of future trends based on a set of structural as well as exogenous assumptions. Future projections thereby embed a degree of uncertainty over the time horizon of the simulation. To address the uncertainty, the iSD calibration and validation process focuses on strengthening the underlying assumptions based on available data and research.

Validation is an extensive process in system dynamics models, which involves examining the model's structure and the behavior that it generates under different conditions; comparing it with the available data and qualitative information; and assessing its adequacy based on the purpose of the analysis to be performed. The structural validation of the iSD model has been an ongoing process over the last 30+ years, involving the application of the model to several countries, the study of relevant research for the topical areas; and discussions with hundreds of experts in the different fields. The result of this process is the core iSD model structure, as described in the documentation of the individual sectors, in the following section.

The calibration process (sometimes including some structural customization) is instead a country-specific process. The model parameters are normally estimated based on relevant literature and historical calibration for the period 2000-2024. Primarily, calibrating the iSDG model implies adjusting the model's parameters (constants) to reflect a country's reality. Calibration is performed by way of partial model calibration cycles, including rounds of multi-parametric optimization. In practice, optimization algorithms search the parameter space across pre-defined thresholds to estimate each model parameter such as to minimize the residual error between the simulated variables and the historical data. To measure the model's ability to replicate the behavior of historical data, a range of summary statistics including the coefficient of determination (R2), the Root Mean Square Percent Error (RMSPE) and the Theil Statistics for error decomposition are calculated and assessed. The present documentation refers to the generic structure of the iSD model, and as such we do not describe and discuss estimates for parameter values that are country specific. The user can refer to the iSD calibration process guidelines for further information.

Social Sectors

[P] Population



Representation of the key variables and relationships within the Population sector.

Purpose, Perspective and Level of Aggregation

Demographic dynamics have a major influence on development, and it is therefore important for integrated, long-term models such as iSD to endogenously determine population levels over time. That allows to capture population growth in different scenarios, and most importantly, the impact that alternative policies might have on a country's demographic development, which often lead to policy resistance, or amplification effects.

The population sector simulates total population and population age distribution based on endogenous fertility and mortality. ***Total mortality rates*** are computed based on age and cause-specific mortality, which are determined in the Health sector (described later in the document). ***Total fertility rate*** is calculated by averaging the ***desired number of children*** and natural fertility, relative to family planning and contraceptive use. Finally, ***migration*** is determined based on an exogenous migration rate, which is applied to the population, and distributed by age and gender. ***Population*** is then used to compute various sub-indicators, including population aggregated by age group (***population groups***), ***population by area***, and ***life expectancy***.

The Population sector is disaggregated into 101 age cohorts (age 0 to 100 and over) for each gender. The flexibility of using one-year age cohorts in iSD makes for easy application of the model in any country and does not significantly complicate the programming or data input.

Main Assumptions

- Fertility rate is affected by income (Birsdall 1988)
- Fertility rate is affected by education level (Cypher *et al.* 2004)
- Unit cost of family planning interventions are based on (Weissman 2007)
- Migrants have the same fertility and mortality behavior as the rest of the population (Nahmias 2004)

Main Limitations

The model does not explicitly include cultural and biological factors that can significantly affect fertility rate. While some of those factors might be well correlated with changes in education and income, that might not necessarily be true in the long-term. Being highly country-specific, their inclusion in the model should be considered as part of the customization process.

The model treats net migration exogenously: a proper endogenous treatment of migration would imply considering changing conditions and regulations in both the country of origin and the target host country, which is beyond the scope of this model. Treating net migration exogenously implies that it is not affected by any policy that is implemented during the simulation. While that solution provides the flexibility to make different assumptions about migration in the future, it is not suitable to analyze policies directed to favor, or counter, migration.

Data Sources

The demographic statistics are sourced from three periodically updated datasets maintained by UNDESA's Population Division: the World Population Prospects (WPP), the World Urbanization Prospects (WUP) and the Family Planning Indicators (FPI) datasets.

The following indicators are sourced from WPP:

- Population on 1st of January, by single age
- Births
- Total Fertility Rate
- Age-Specific Fertility Rate
- Sex Ratio at Birth
- Male and Female Deaths
- Male and Female Life Expectancy at Birth
- Infant Mortality Rate
- Under-five Mortality Rate
- Net Migration Rate

The following indicators are sourced from FPI:

- Contraceptive prevalence, by method
- Demand for family planning satisfied, by method
- Total demand for family planning
- Unmet need for family planning

Finally, urbanization rate figures are sourced from WUP.

References

Birdsall, N., 1988. Economic approaches to population growth. In: H. Chenery and T.N. Srinivasan, eds. *Handbook of Development Economics*, Vol. 1. Amsterdam: Elsevier Science Publishers B.V., pp.478–542.

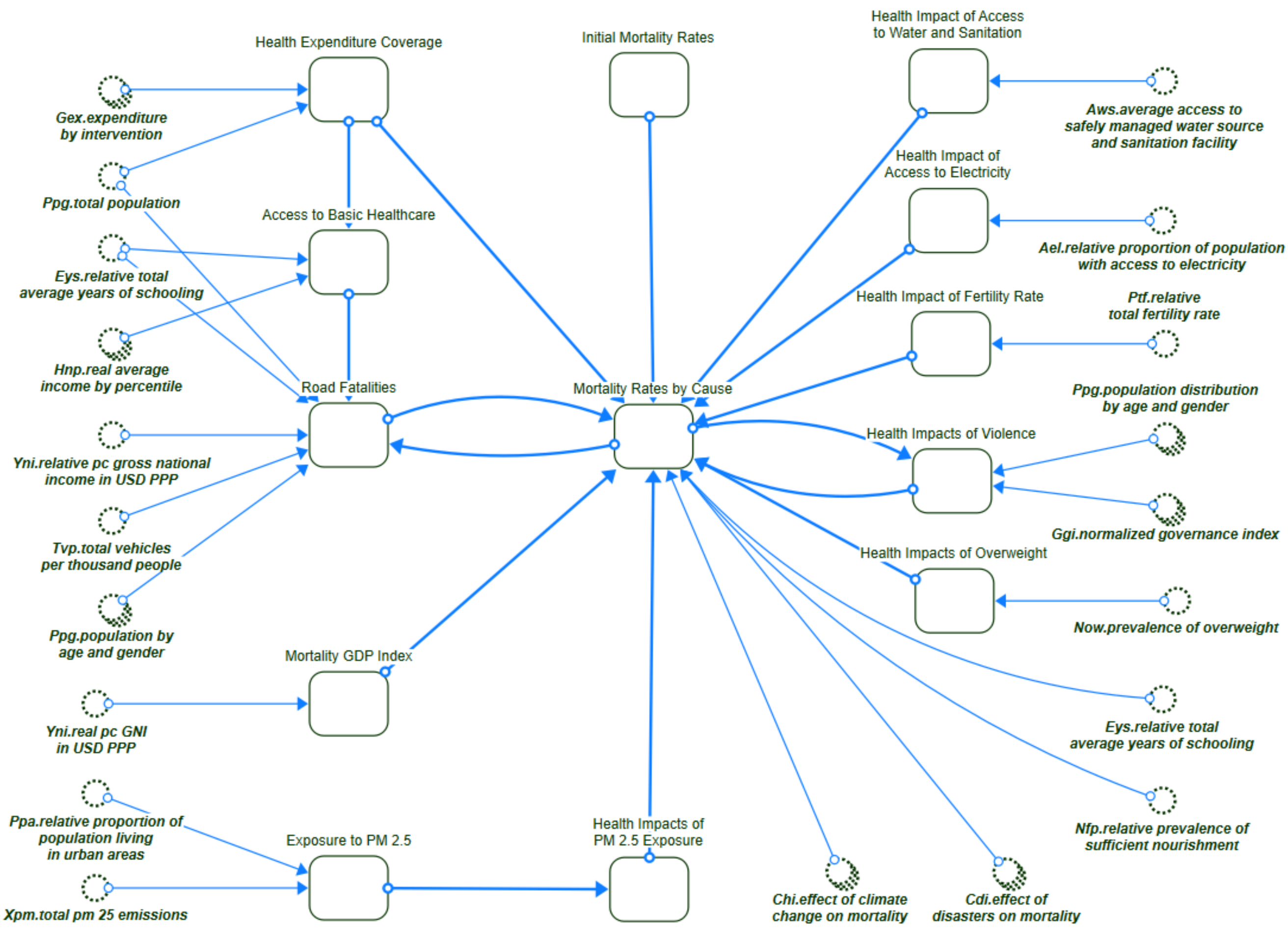
Cypher, J.M. and Dietz, J.L., 2004. *The process of economic development*. London: Routledge.

Nahmias, P., 2004. *Fertility behavior of recent immigrants to Israel: A comparative analysis of immigrants from Ethiopia and the former Soviet Union*. *Demographic*

Research, 10(4), pp.83–120. Max Planck Institute for Demographic Research, Rostock, Germany.

Weissman, E., 2007. *Cost of family planning literature review*. Washington, DC: Futures Group, USAID | Health Policy Initiative, Task Order 1. [online] Available at: https://www.avenirhealth.org [Accessed 3 June. 2025].

[R] Health



Representation of the key variables and relationships within the Health sector.

Purpose, Perspective and Level of Aggregation

Health is fundamental to human well-being, and also a key enabling factor for development: good health is essential for productivity, and for broader prosperity. In iSD, we represent the fundamental socio-economic and environmental drivers of mortality, which can be generalized across countries. This way, policies addressing health issues can be tested, and the spillover effects of other policies on health are also captured.

The Health sector computes mortality rates according to WHO's Burden of Disease framework. **Mortality rates by cause** are individually computed based on their available initial values, and the impact of a broad variety of factors over time. The main drivers considered to affect mortality from all causes are income**,** public health expenditure coverage, education and nutrition. Other drivers influencing mortality rates for specific causes include health impacts from **road fatalities**, **climate change and natural disasters**, **exposure to PM 2.5 emissions**, **impacts from nutrition, access to water and sanitation, access to electricity, fertility rates and health impacts from violence**.

The iSD distinguishes among 13 different causes of death: aids, diarrhoeal, parasitic and vector, respiratory, maternal, neonatal, nutritional, neoplasm, diabetes, cardiovascular, road, violence and other. Causes of death are also differentiated by age and gender.

Main Assumptions

- Per capita income affects overall mortality (Baker et al. 2011, Carrin et al. 2008, Preston 1975)
- Access to basic health care affects overall mortality (Kunitz 2007)
- Education level affects overall mortality (Kunitz 2007)
- Nutritional sufficiency affects overall mortality (Fogel 1984)
- Access to electricity influences mortality due to respiratory illnesses (WB 2008, Ezzati et al 2002)
- Access to improved drinking water sources and sanitation influence mortality due to diarrhoeal diseases (WHO 2012)
- Exposure to air pollution (PM 2.5) affects mortality from respiratory diseases (WHO 2013)
- Political stability and absence of violence affects mortality from violence (Ro-Ting et al 2014)
- Number of motor vehicles affects mortality from road injuries (Kopits et al. 2008)
- Climate change affects mortality from diarrhea and vector borne diseases (WB, 2010)
- Overweight affects mortality from cardiovascular diseases (Khan et al. 2018)
- Per capita public health expenditure affects access to basic healthcare (Peters et al. 1999)
- Disposable income affects access to basic healthcare (Carrin 2008)
- Education level affects access to basic healthcare (Feinstein 2006)
- Infrastructure density income affects access to basic healthcare (Calderon 2004)

Main Limitations

While mortality indicators provide a fundamental perspective on health, disability is another important dimension related to health, which is not accounted for in the model. In addition, while the model represents the causes of mortality that are most often relevant across countries, additional explanatory variables might need to be considered when applying the model to a specific population.

Distribution of income and poverty levels have profound influence on health, including access to basic health care and undernourishment. The effect of income distribution on access to health care is modeled using a functional form that causes access to basic health care to increase at a decreasing rate, asymptotically approaching 1 as real average income by percentile approaches a saturation income. The effects of the other factors further accelerate such progress towards 100% access to basic health care.

Data Sources

The primary data source is the World Health Organization's (WHO) Global Health Estimates: Cause-Specific Mortality dataset, which provides estimates on mortality by cause, age group and sex.

Additionally, the following indicators are also sourced from WHO's Global Health Estimates:

- PM2.5 mean annual exposure
- Proportion of population exposed to PM2.5 levels exceeding WHO guidelines
- Maternal mortality ratio
- Neonatal mortality rate

References

Baker, D., Leon, J., Smith Greenaway, E.G., Collins, J. and Movit, M., 2011. The education effect on population health: a reassessment. *Population and Development Review*, 37(2), pp.307–332.

Carrin, G., Mathauer, I., Xu, K. and Evans, D.B., 2008. *Bulletin of the World Health Organization*, 86(11), pp.817–908.

Ezzati, M. and Kammen, D.M., 2002. Evaluating the health benefits of transitions in household energy technologies in Kenya. *Energy Policy*, 30, pp.815–826.

Fogel, R.W., 1984. Nutrition and the decline in mortality since 1700: some preliminary findings. *NBER Working Paper* No. 1402, July 1984.

Khan, S.S., Ning, H., Wilkins, J.T., Allen, N., Carnethon, M., Berry, J.D., Sweis, R.N. and Lloyd-Jones, D.M., 2018. Association of body mass index with lifetime risk of cardiovascular disease and compression of morbidity. *JAMA Cardiology*, 3(4), pp.280–287. doi:10.1001/jamacardio.2018.0022.

Kopits, E. and Cropper, M., 2008. Why have traffic fatalities declined in industrialized countries? *Journal of Transport Economics and Policy*, 42(1), pp.129–154.

Kunitz, S.J., 2007. *The health of populations: general theories and particular realities*. Oxford: Oxford University Press.

Preston, S.A., 1975. The changing relation between mortality and level of economic development. *Population Studies*, 29(2), pp.223–2248.

Ro-Ting, L., Chien, L.C., Chen, Y.M. and Chan, C.C., 2014. Governance matters: an ecological association between governance and child mortality. *International Health*, [online] Available at: https://academic.oup.com/inthealth/article/6/1/6/793949 [Accessed 3 Jun. 2025].

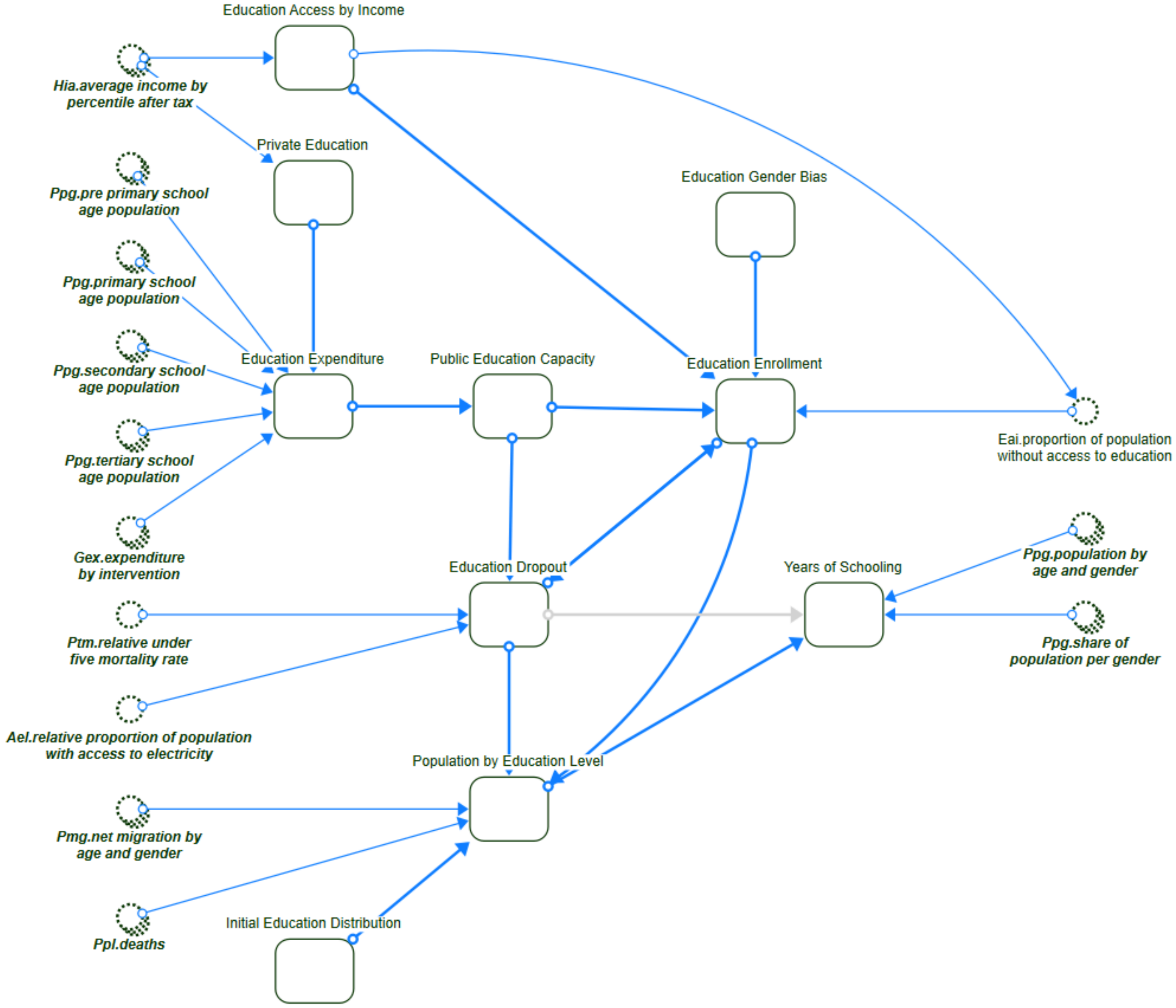
WB (World Bank), 2008. *The welfare impact of rural electrification: a reassessment of the costs and benefits*. An IEG Impact Evaluation. Washington, D.C.: World Bank.

WB (World Bank), 2010. *The costs to developing countries of adapting to climate change: new methods and estimates*. The Global Report of the Economics of Adaptation to Climate Change Study. Washington, D.C.: World Bank.

WHO (World Health Organization), 2012. *Global costs and benefits of drinking-water supply and sanitation interventions to reach the MDG target and universal coverage*. Geneva: WHO.

WHO (World Health Organization), 2013. *Health effects of particulate matter*. Copenhagen: WHO Regional Office for Europe.

[E] Education



Purpose, Perspective and Level of Aggregation

Education is a main driver of development. It is important for integrated, long-term models such as iSD to endogenously determine the education levels of populations over time, as education has a major role in worker's productivity, technological development and different aspects of health.

The Education sector uses average **Years of schooling** as a proxy of the education level in a given country. Its behavior over time, depends on the **Public Education Capacity**, a direct consequence of public investment (**Education Expenditure**)- and **Education Enrollment**, that depends on gross enrollment by education level, infrastructure density, **Education Gender Bias**, **Education Dropout** levels and access to electricity and income, with the last factor especially important in determining the proportion of students in the **Private**

Education system. Relative average years of schooling is then widely used across the model, for instance in the firms, employment or health sectors.

This sector uses the Barro-Lee educational attainment dataset and therefore, classifies education levels into 6 categories: no formal education (E0), incomplete primary (E1), complete primary (E2), lower secondary (E3), upper secondary (E4), incomplete tertiary (E5), and complete tertiary (E6).

Main Assumptions

- Education attainment is defined over seven levels, according to the Barro-Lee database methodology (Barro et al. 2013)
- Public education expenditure per school age person affects years of schooling (UNESCO 1984)
- Per capita income affects years of schooling (Pritchett et al 1998)
- Childrens' health status (we use under 5 mortality as a proxy) affects years of schooling (Behrman 1996)
- Quality of governance affects years of schooling (World Bank 2012, Samer 2013, Swaroop, Vinaya and Rajkumar 2002)
- Access to electricity affects years of schooling (Leipziger et al 2003)
- Transportation infrastructure density affects years of schooling (Calderon et al 2004)

Main Limitations

Although this sector provides a useful description of education progress over seven levels, it does not address the issue of education quality or the suitability of the education provided to job opportunities, and more broadly, development needs. Therefore, in a country investing heavily in education quality, substantial improvement in productivity can be observed even though education levels are unchanged. Similarly, a shift between different types of secondary or tertiary education to better match job opportunities can lead to faster development - a process that the model does capture.

Data Sources

The primary data sources are the World Bank's World Development Indicators (WDI) dataset, and the Barro-Lee Educational Attainment dataset. The following indicators are sourced from WDI:

- Adult literacy rate, male and female
- Primary gross enrollment rate, male and female
- Primary net enrollment rate, male and female
- Secondary gross enrollment rate, male and female
- Secondary net enrollment rate, male and female
- Tertiary gross enrollment rate

The following indicators are sourced from the Barro-Lee Educational Attainment dataset:

- Average years of schooling, male and female
- Adult population distribution by education level, sex and age group

References

Al-Samarrai, S., 2013. *Local governance and education performance: a survey of the quality of local education governance in 50 Indonesian districts*. Human Development. Jakarta, Indonesia: World Bank.

Barro, R.J. and Lee, J.W., 2013. A new data set of educational attainment in the world, 1950–2010. *Journal of Development Economics*, 104, pp.184–198.

Behrman, J.R., 1996. The impact of health and nutrition on education. *The World Bank Research Observer*, 11(1), pp.23–37.

Calderón, C. and Servén, L., 2004. *The effects of infrastructure development on growth and income distribution*. WPS3400. Washington, D.C.: World Bank.

Carrin, G., Mathauer, I., Xu, K. and Evans, D.B., 2008. Universal coverage of health services: tailoring its implementation. *Bulletin of the World Health Organization*, 86(11), pp.817–908.

Feinstein, L., Sabates, R., Anderson, T.M., Sorhaindo, A. and Hammond, C., 2006. What are the effects of education on health? In: *Measuring the Effects of Education on Health and Civic Engagement: Proceedings of the Copenhagen Symposium*. Paris: OECD.

Leipziger, D., Fay, M., Wodon, Q. and Yepes, T., 2003. Achieving the Millennium Development Goals: the role of infrastructure. *World Bank Policy Research Working Paper* No. 3163. Washington, D.C.: World Bank.

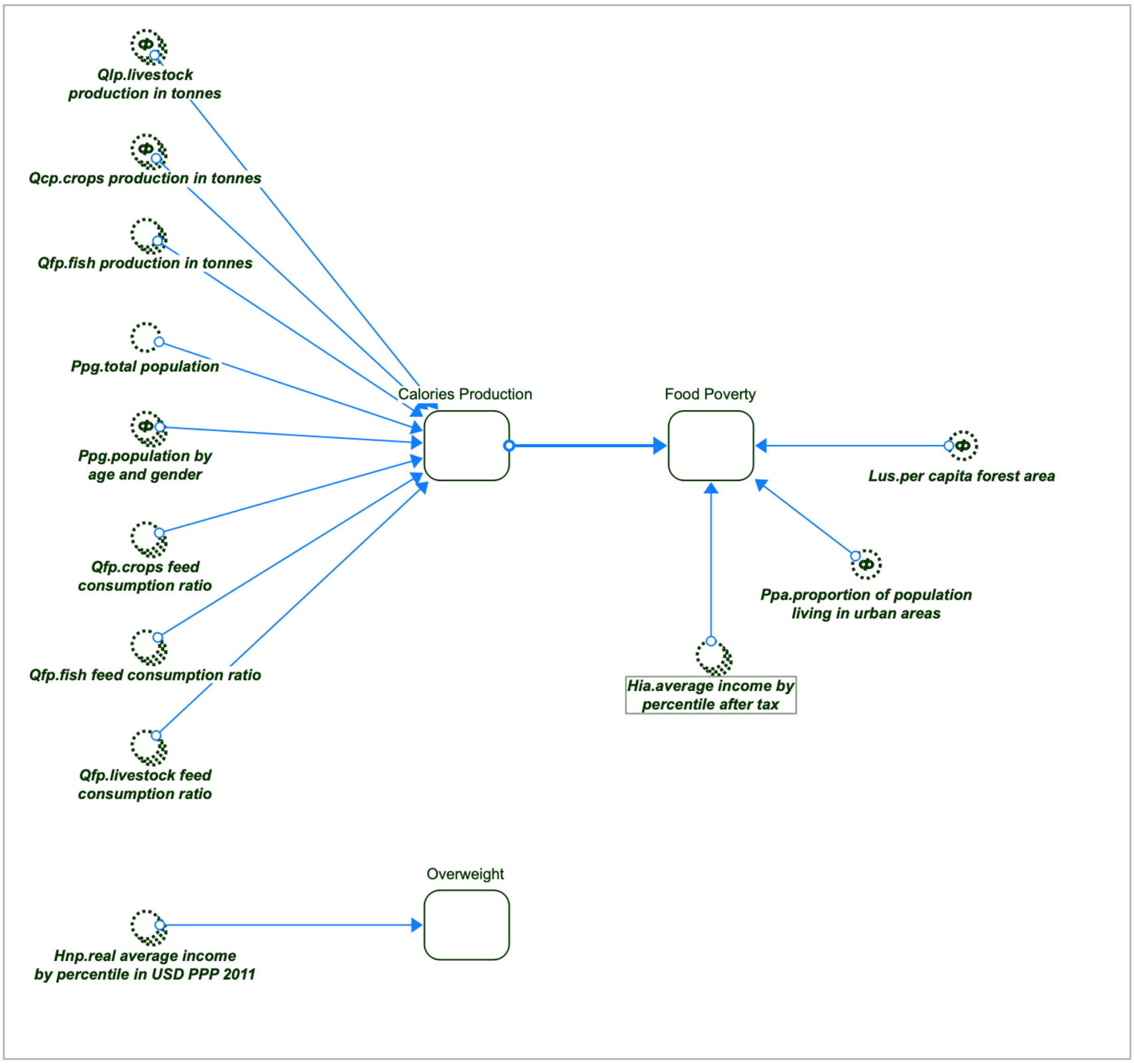
Pritchett, L. and Filmer, D., 1998. The effect of household wealth on educational attainment: demographic and health survey evidence. *Policy Research Working Paper*. Washington, D.C.: World Bank Development Research Group, Poverty and Human Resources.

Swaroop, V. and Rajkumar, A.S., 2002. Public spending and outcomes: does governance matter? *World Bank Policy Research Working Paper* No. 2840. Washington, D.C.: World Bank.

UNESCO, 1984. *The dropout problem in primary education*. Bangkok, Thailand: UNESCO Regional Office for Education in Asia and the Pacific.

World Bank, 2012. *Governance and management in the education sector (Cameroon)*. Report No. 67201-CM. Washington, D.C.: World Bank.

[N] Nutrition



Purpose, Perspective and Level of Aggregation

The purpose of the Nutrition sector is to detect issues linked to food poverty, such as undernourishment, stunting, wasting and **Overweight**. These are used in several indicators mainly linked to SDG 2 and 3 and the Health sector.

To represent **Food Poverty** dynamics, per capita daily **Calories Production** is computed and compared with the per capita calories needed. Then, the international food poverty line is multiplied by the calories production balance (i.e. how much of the calories needed are produced within the country), as well as the average feed consumption ratio, to account for the share of the calories provided by crops, livestock and fish that are not for human consumption, but rather feedstock for livestock and fisheries. Taking into account income distribution, the sector can determine the proportion of population under the real food poverty line and thus the prevalence of the health-related issues listed above.

The model computes calories coming from 2 different crop groups; cash crops and non-cash crops, one group of livestock and one group of fish (i.e. all livestock generated calories and all fish generated calories are captured as independent variables). Though, in the primary production sector, these can be further disaggregated if needed.

Main Assumptions

- Disposable income affects undernourishment (Ravallion 1990).
- Per capita food production affects undernourishment (Girard et al. 2012)

Main Limitations

The effect of lack of access to food on undernourishment, wasting, and stunting, is not assessed by age, but for the population as a whole. Therefore, the model is not capturing the effect of potential changes in access to food by age, which could occur endogenously (for instance, when the age profile of the poorest families changes); or exogenously, e.g. through specific food distribution programs.

Data Sources

The primary data sources are the World Health Organization's (WHO) Global Health Observatory, and the Food and Agriculture Organization's Statistical Database (FAOSTAT). The following indicators are sourced from WHO:

- Stunting prevalence among children five years of age
- Overweight prevalence among children five years of age
- Wasting prevalence among children five years of age

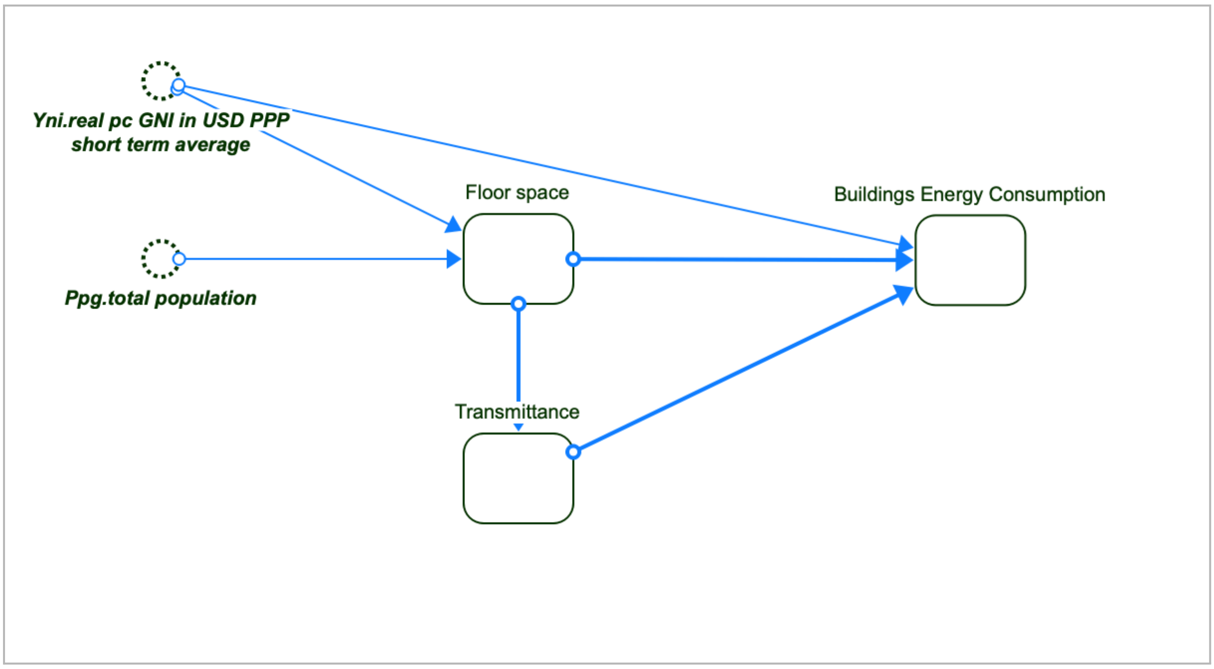
Figures on prevalence of undernourishment are sourced from FAOSTAT.

References

Girard, A.W., Self, J.L., McAuliffe, C. and Olude, O., 2012. The effects of household food production strategies on the health and nutrition outcomes of women and young children: a systematic review. *Paediatric and Perinatal Epidemiology*, [supplement] s1, pp.205–222.

Ravallion, M., 1990. Income effects on undernutrition. *Economic Development and Cultural Change*, 38(3), pp.489–515.

[U] Buildings



Purpose, Perspective and Level of Aggregation

The purpose of the Buildings sector is to compute their energy consumption, as it is a major driver of total energy consumption and therefore, an important source of emissions' saving if the right technologies are used to isolate the buildings and supply the energy required.

Factors like income and population are considered the main drivers for building new **Floor Space**. Thermal **Transmittance** is the factor representing building insulation. The model accounts for the initial average level of thermal transmittance, which is then used to compute an overall transmittance value over time via consideration of new buildings and renovation programs. Taking data from the climate sector related to the degree hours needed for heating and cooling, the overall thermal transmittance value and the overall external surface of the building stock, the **Buildings Energy Consumption** can be computed.

The model accounts for two types of buildings, residential and non-residential -which includes typically commercial and office buildings, but also any other use not accounted for in the first group.

Main Assumptions

- Buildings in terms of floor space coverage increases relative to economic growth, captured through GNI per capita and population growth.
- Improving U-values through new construction or renovation, through the uptake of more energy efficient construction materials, can positively impact the overall thermal performance of the building stock.

Main Limitations

While floor space is determined in units of surface, the calculation of thermal transmittance requires a set of assumptions regarding the average type of building in the country (whether these are primarily large buildings, or single-family houses). Therefore, the model does not endogenously represent changes in the mix of constructions, which can lead to changes in energy use, independently of the quality of insulation or the number of buildings.

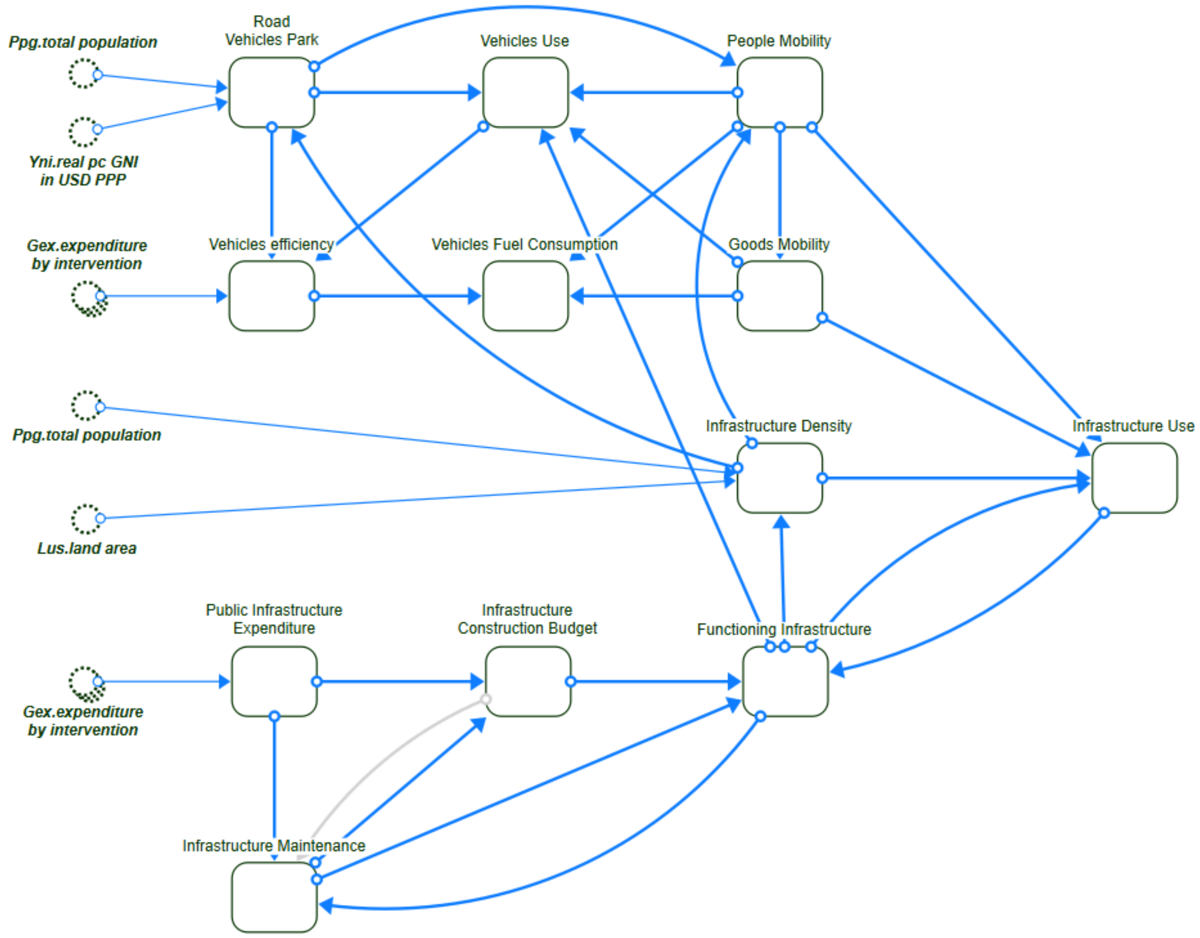
Data Sources

- International Energy Agency

References

Cabeza, L. F., Q. Bai, P. Bertoldi, J.M. Kihila, A.F.P. Lucena, É. Mata, S. Mirasgedis, A. Novikova, Y. Saheb, 2022: Buildings. In IPCC, 2022: Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change[P.R. Shukla, J. Skea, R. Slade, A. Al Khourdajie, R. van Diemen, D. McCollum, M. Pathak, S. Some, P. Vyas, R. Fradera, M. Belkacemi, A. Hasija, G. Lisboa, S. Luz, J. Malley, (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA. doi: 10.1017/9781009157926.011

[T] Transport



Purpose, Perspective and Level of Aggregation

The purpose of the transport sector is mainly to calculate vehicles' fuel consumption endogenously to analyze the impact of introducing sustainable mobility transportation modes on GHG and PM 2.5 emissions. In addition, the sector also computes transport infrastructure. As a networked infrastructure, transport systems impact many of the SDG targets, be it directly or indirectly, from access to health centers and education facilities to production or government venues, enabling the economy to function.

The Transport sector computes **Vehicle Use** (EV and ICE) as well as **People Mobility** and **Goods Mobility** by transportation mode. Adding to the model structure the **Vehicle Efficiency** dynamics, we are able to compute Vehicle Fuel Consumption as a result of different factors such as income, mobility cost, people's values or technological progress. **Functioning Infrastructure** for transportation is driven by **Public Infrastructure Expenditure** and the elements of construction and maintenance cost. **Infrastructure Density** measures the rural access index and assesses the impact of infrastructure in access to healthcare, education centers or its effect on productivity. Finally, **Infrastructure Use** calculates the intensity of infrastructure use relative to transportation of goods and people specifically for road and rail transport modes.

Transportation modes are further disaggregated between air, rail, public, private and shared rubber (i.e. vehicles on rubber wheels), active and water. Active transportation refers to walking and cycling or any other means where the energy is provided by the traveler. The model distinguishes between two types of road categories and rail infrastructure. The two road categories normally distinguish between paved and unpaved roads, but widening the range of iSD applications allow for more abstract categorization and leave the definition of the two groups to the choice of the end user.

Main Assumptions

- Transportation infrastructure funding is first allocated to maintenance. Funds remaining after maintenance are allocated to construction start-ups, a capital cost per kilometer of infrastructure (Lambert and Huh 2004, Rioja 2003)
- Governance, regulating the construction quality and use of transport infrastructure (not shown in diagram), potentially extends infrastructure life and reduces maintenance cost (Kenny 2007).
- Infrastructure construction and maintenance cost are estimated based on Archondo et al. (2000) and Collier et al. (2013)
- Roads density affects the rural access index (WB 2006)
- The purchase of vehicles is affected by income (Greenspan et al 1999)
- The purchase of vehicles is affected by road density (Litman 2015)
- Vehicles contribute to particulate emissions through fuel combustion and through tire, break, and road dust (Klimont et al 2002)
- Per unit emissions are greater for commercial than passenger vehicles (Klimont et al 2002)

Main Limitations

The model does not include geo-referencing of transportation infrastructure or mobility, but assess country needs at the aggregate, national level. This implies that the model cannot assess the suitability of investment in transportation infrastructure in specific locations, and therefore would not capture the increased efficacy coming from a better designed infrastructure investment plan.

The use of subscripts allows us to model the dynamics of paved roads, unpaved roads, and rail with the same basic structure. Therefore, the model does not include further classification of roads types: should it be necessary such subscripts can be expanded to include other elements.

Through the use of subscripts, we represent with the same structure the processes of purchase and scrapping of both private passenger cars and commercial vehicles. Should the analysis require a further breakdown of vehicles into subclasses, this can be implemented through the expansion of the vehicles subscript.

Data Sources

The three major data sets that are used in the Transport sector are vehicle stocks, road and rail network length, and mobility indicators. Figures for all three datasets are sourced from EUROSTAT, the United Nations Economic Commission for Europe (UNECE) and the United Nations Economic and Social Commission for Western Asia (UNESCWA). Additional figures for the three data sets, excluding railway data are sourced from the International Road Federation (IRF). Additional figures on vehicle stocks are sourced from the International Organization of Car Manufacturers (OICA). Additional figures on electric vehicle stock are sourced from the International Energy Agency (IEA).

References

Archondo-Callao, R., 2000. *Road works costs per km*. Washington, D.C.: World Bank.

Charles, K., 2007. Infrastructure governance and corruption: where next? *Policy Research Working Paper* No. 4331. Washington, D.C.: World Bank.

Collier, P., Kirchberger, M. and Soderbom, M., 2013. *The cost of road infrastructure in developing countries*. Centre for the Study of African Economies, mimeo.

Greenspan, A. and Cohen, D., 1999. Motor vehicle stocks, scrappage, and sales. *Review of Economics and Statistics*, 81(3), pp.369–383.

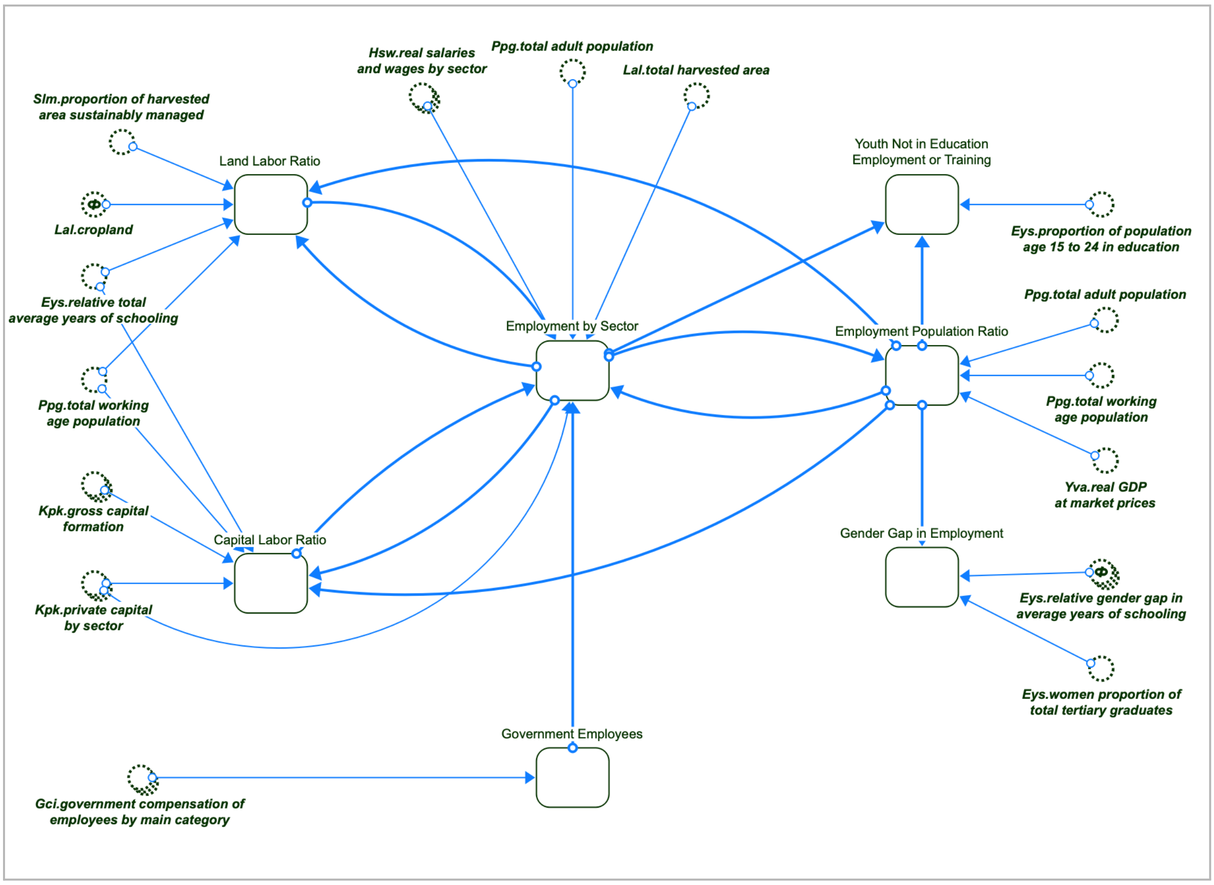
Klimont, Z., Cofala, J., Bertok, I., Amann, M., Heyes, C. and Gyarfas, F., 2002. Modelling particulate emissions in Europe: a framework to estimate reduction potential and control costs. *IIASA Interim Report*, IR-02-076.

Lambert, M. and Huh, K., 2004. *Fixing it first: targeting infrastructure investments to improve state economies and invigorate existing communities*. Washington, D.C.: NGA Center for Best Practices.

Rioja, F., 2003. Filling potholes: macroeconomic effects of maintenance versus new investment in public infrastructure. *Journal of Public Economics*, 87(9–10), pp.2281–2304.

World Bank, 2006. *Rural Access Index: a key development indicator*. Washington, D.C.: The International Bank for Reconstruction and Development / The World Bank.

[J] Employment



Purpose, Perspective and Level of Aggregation

Employment dynamics has broad implications in the socio-economic system as a key driver of production and households' income, and therefore influences economic growth, access to health, education, as well as income distribution and productivity.

In this section of the model structure we compute **Employment by Sector** as an adjustment process from the current employment levels to the indicated levels of employment given by the **Land to Labor Ratio** for land intensive sectors in agriculture, or given by the **Capital to Labor Ratio** for capital intensive sectors like industries and services. Changes in the stock of capital (and in land use for agriculture) then determine employment in the private sector. **Government Employees** involved in Public services are considered separately as their behavior over time is driven by different dynamics. From the **Employment by Sector** module, we can compute other variables relevant to the SDG indicators such as **Gender Gap in Employment** or **Employment Population Ratio.** 'Relative employment by sector' is in turn used as a driver of change in production, labor share and 'average employment to adult population', which further affects salaries and wages.

By default, the economic sectors considered in Employment correspond to the first-level groupings of economic activities (also referred to as sections) defined in Fourth Revision of the International Standard Industrial Classification of All Economic Activities (ISIC 4). The sections of economic activities are marked with letters A to U. The only exception is Agriculture, Forestry and Fishing (A), which by default is further subdivided at the level of divisions, marked by double digits

- Crop and animal production, hunting and related service activities (A01)
- Forestry and logging (A02)
- Fishing and aquaculture (A03)

The model can accommodate more aggregate or more disaggregate groupings if necessary. Furthermore, other classifications of economic activities, such as ISIC 3.1 or ISIC 5, may be used.

Main Assumptions

- Agriculture employment depends on the amount of agriculture land, productive capital per hectare, and technology (Agwu, Nwankwo, and Anyanwu 2014)
- Industry and services employment levels depend on the amount of productive capital and current levels of technology (Driver and Temple 1999 p. 102)

Main Limitations

Since the main driver of growth in employment is capital formation (and land use in agriculture) the model cannot capture rapid short-term changes in employment that can emerge from drops in demand in a sector: employment is only adjusted slowly over time to a new level, as investment in that sector. Also, the model represents average employment levels for the year, and does not represent seasonality.

Data Sources

Figures for the following indicators are sourced from ILOSTAT:

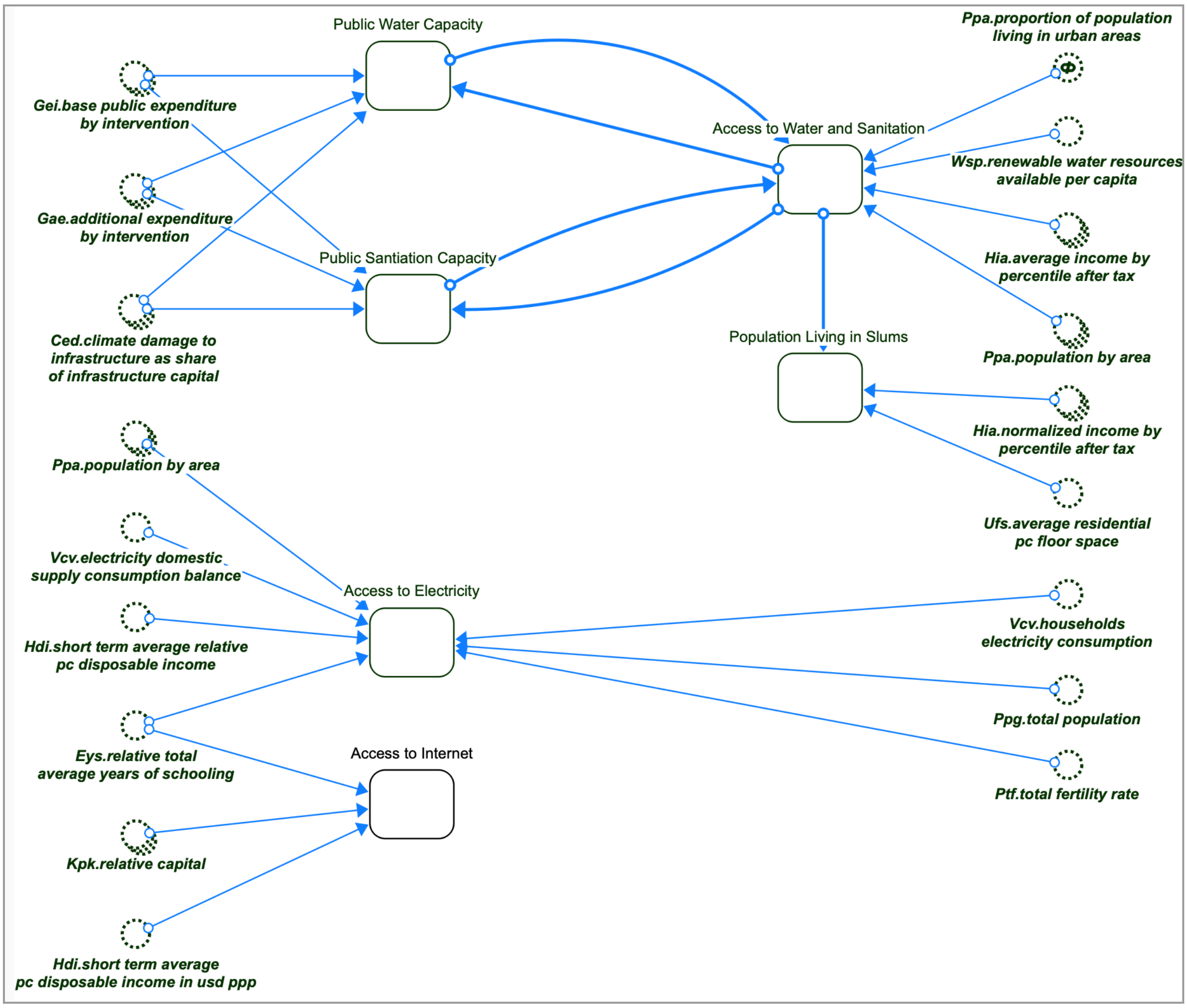
- Employment by sector (economic activity)
- Employment to adult population ratio (male and female)
- Labor force participation rate
- Female share of participation in managerial positions
- Proportion of youth not in education, employment or training (NEET)

References

Agwu, N.M., Nwankwo, E.E. and Anyanwu, C.I., 2014. Determinants of agricultural labor participation among youths in Abia State, Nigeria. *International Journal of Food and Agricultural Economics*, 2(1), pp.157–164.

Driver, C. and Temple, P., 1999. Overview: Investment, feedback and spillover. In: *Investment, Growth, and Employment: Perspectives for Policy*. London: Routledge.

[A] Access to basic services



Purpose, Perspective and Level of Aggregation

Access to basic services like potable water, sanitation, electricity or internet are paramount drivers of development, influencing behavior over time of key indicators in the productivity, education and health sectors.

In order to compute access to water and sanitation, we first compute **Public Water Capacity** as well as **Public Sanitation Capacity**, which are mainly driven by the public expenditure in these infrastructure types, their cost and their average life. Then we introduce factors influencing access to water and sanitation services, such as water scarcity, poverty and income, to determine **Access to Water and Sanitation**. Finally, we compute the proportion of the population living in slums in accordance with the definition provided by the UN SDG Database.

The calculation of **Access to Electricity** and **Access to Internet** are based on socio-economic factors such as average income and education level. For electricity, we also consider existing distribution infrastructure as well as decentralized electricity generation capacity. For access to internet, we adopt a diffusion model to represent subscriptions to fixed broadband and mobile data services, which in turn determine access to internet.

Values for proportion of population with access to electricity, water, and sanitation are disaggregated by area, distinguishing between rural and urban areas.

Main Assumptions

- Access to basic services includes access to water, sanitation, electricity services, and internet services; access to other services, such as education and health, are respectively assessed in the 'Education' and 'Health' and sectors.
- Unit cost of improved water source and sanitation facilities is based on WHO (2012)
- Includes access to electricity from decentralized coverage
- Access to internet is based on ITU data framework for access to fixed broadband and mobile data services. For mobile data coverage, an aggregate indicator is built, weighting access to different technologies (2G, 3G, ..., 5G) to account for the level of services available.

Main Limitations

In this sector, the model only differentiates between rural and urban areas when determining access to basic services. This does not allow for more precise location-specific planning of infrastructure and, more broadly, services provision.

Data Sources

Figures for average access to electricity (urban and rural) are sourced from the World Bank's World Development Indicators (WDI).

Figures for the following indicators are sourced from the WHO/UNICEF Joint Monitoring Programme for Water Supply, Sanitation and Hygiene:

- Basic access to water supply (urban and rural)
- Basic access to sanitation (urban and rural)
- Access to safely managed water supply (urban and rural)
- Access to safely managed sanitation (urban and rural)

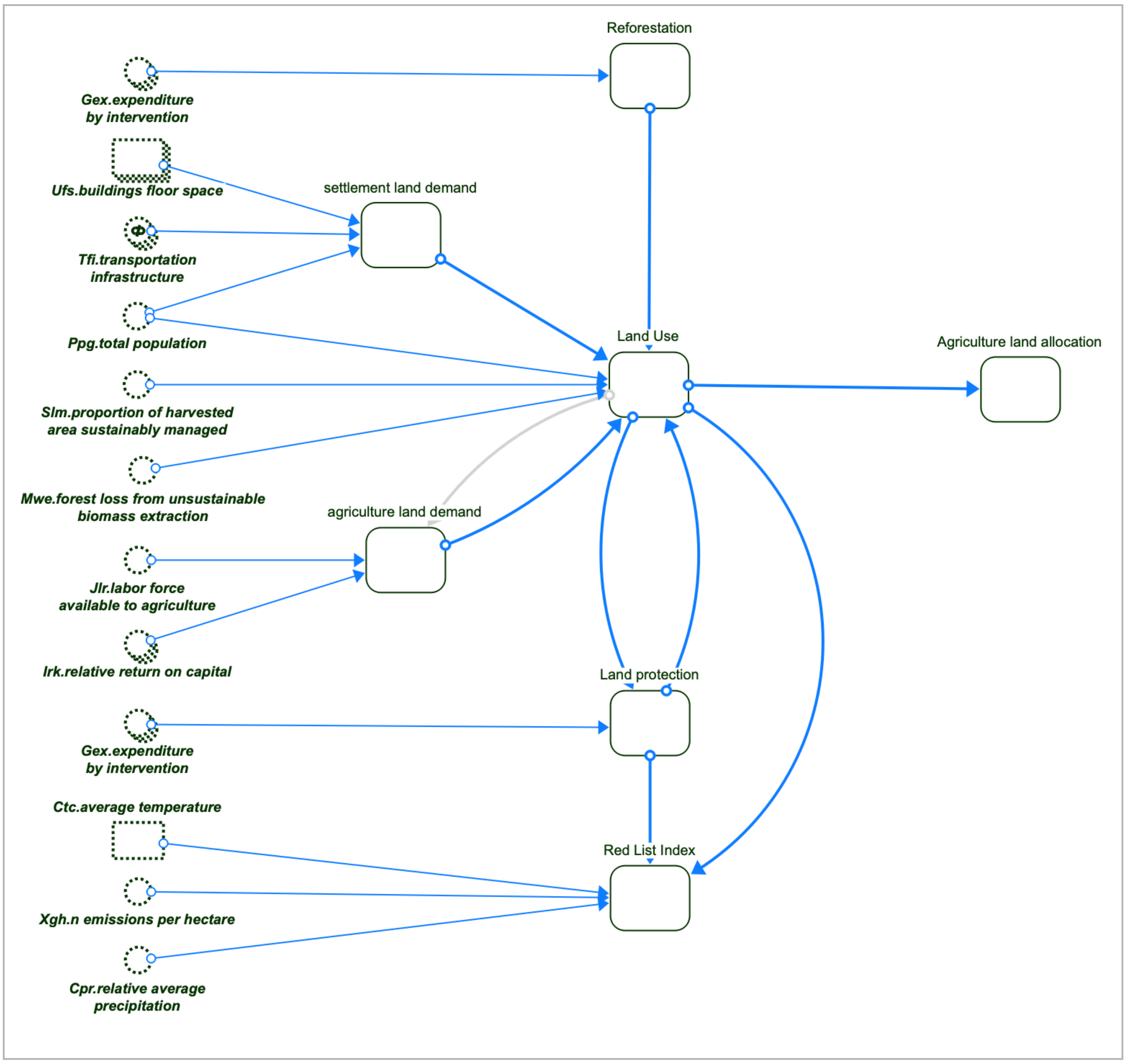
Indicators for coverage and access to internet services are sourced from ITU.

References

World Health Organization, 2012. *Global costs and benefits of drinking-water supply and sanitation interventions to reach the MDG target and universal coverage*. Geneva: World Health Organization.

Environmental Sectors

[L] Land



Purpose, Perspective and Level of Aggregation

The Land sector represents land allocation by use based on the Food and Agriculture Organization's standard land classification. The implications for development of land uses are wide, as this sector captures behavior over time of forest land and forest land protection, reforestation, agricultural land and thus, influences aspects such as food security, biodiversity and emissions from land use change.

Land Use is determined by first calculating **agriculture land demand** and **settlement land demand**, and then determining land shift from other uses accounting for physical limits and **Land protection** measures. The land sector also includes the calculation of the **Red-List index**, an aggregate measure of biodiversity, which is strongly affected by land-use change, among other factors.

The Land sector includes four categories of land use including agricultural land, settlement land, forest land and other land. Agriculture land is further divided into cropland and pastureland.

Main Assumptions

- Profitability of agriculture and livestock affect agriculture land demand (UNEP 2012; FAO 2002)
- Demographics and unemployment affect agriculture land demand (Wolman 1993; Malthus 1798)
- Agriculture land demand affects deforestation (Kissinger et al. 2012)
- Capital intensity negatively affects pasture land demand (FAO 2002)
- Unit costs for reforestation are estimated based on Varmoal 2002 and Durst et al 2011
- Unit costs for land protection are estimated based on James et al 1999 and James et al 2002
- There are no interactions among the various causes of biodiversity change (Sala et al 2000)
- Effects of the various causes of biodiversity change are represented via a power function (Preston 1962)
- Estimation of the intensity of the effect of the various causes of biodiversity change is based on Rosenzweig (1995)
- Changes in precipitation and temperature, deforestation, and nitrogen emissions affect biodiversity (Sala et al 2000)

Main Limitations

The model represents land use at national aggregated level, and therefore, in its initial configuration, does not allow for more specific geo-referencing. However, where useful, it is possible to make the land sector spatially explicit by the introduction of subscripts representing different provinces, or other subdivisions. Such detailed representation of land use can be useful when examining land use issues that are especially relevant at the local scale, but might not emerge from national scale analysis.

The model does not include other, generally less relevant, causes of biodiversity change such as biotic exchange and atmospheric CO_2 concentration (Sala et al. 2000). The formulation adopted to determine change in biodiversity is flexible so as to allow for the inclusion of such drivers should they be relevant in specific countries.

Data Sources

The following indicators are sourced from FAOSTAT:

- Land Area
- Agricultural Land
- Agricultural Land under Organic Agriculture
- Cropland
- Pasture Land
- Forest Land
- Artificial surfaces (CCI_LC) as proxy for Settlement Area

Figures for protected areas sourced from protectedplanet.net.

References

Durst, P.B., Sajise, P. and Leslie, R.N., 2011. *Forests beneath the grass*. In: Proceedings of the Regional Workshop on Advancing the Application of Assisted Natural Regeneration for Effective Low-Cost Restoration. Rome: FAO.

FAO (Food and Agriculture Organization), 1998. *Land Cover Classification System (LCCS): Classification Concepts and User Manual*. Rome: Food and Agriculture Organization of the United Nations.

FAO (Food and Agriculture Organization), 2002. *World agriculture: towards 2015/2030*. Rome: Food and Agriculture Organization of the United Nations.

James, A.N., Gaston, K.J. and Balmford, A., 2001. Can we afford to conserve biodiversity? *BioScience*, 51(1), pp.43–52.

James, A.N., Green, M.J.B. and Paine, J.R., 1999. *A global review of protected area budgets and staff*. WCMC Biodiversity Series No.10. Cambridge: World Conservation Monitoring Centre.

Kissinger, G., Herold, M. and De Sy, V., 2012. *Drivers of deforestation and forest degradation: A synthesis report for REDD+ policymakers*. Vancouver: Lexeme Consulting.

Malthus, T., 1798. *An essay on the principle of population*. Oxford: Oxford University Press.

Preston, F.W., 1962. The canonical distribution of commonness and rarity: Part I. *Ecology*, 43(2), pp.185–215.

Rosenzweig, M.L., 1995. *Species diversity in space and time*. Cambridge: Cambridge University Press.

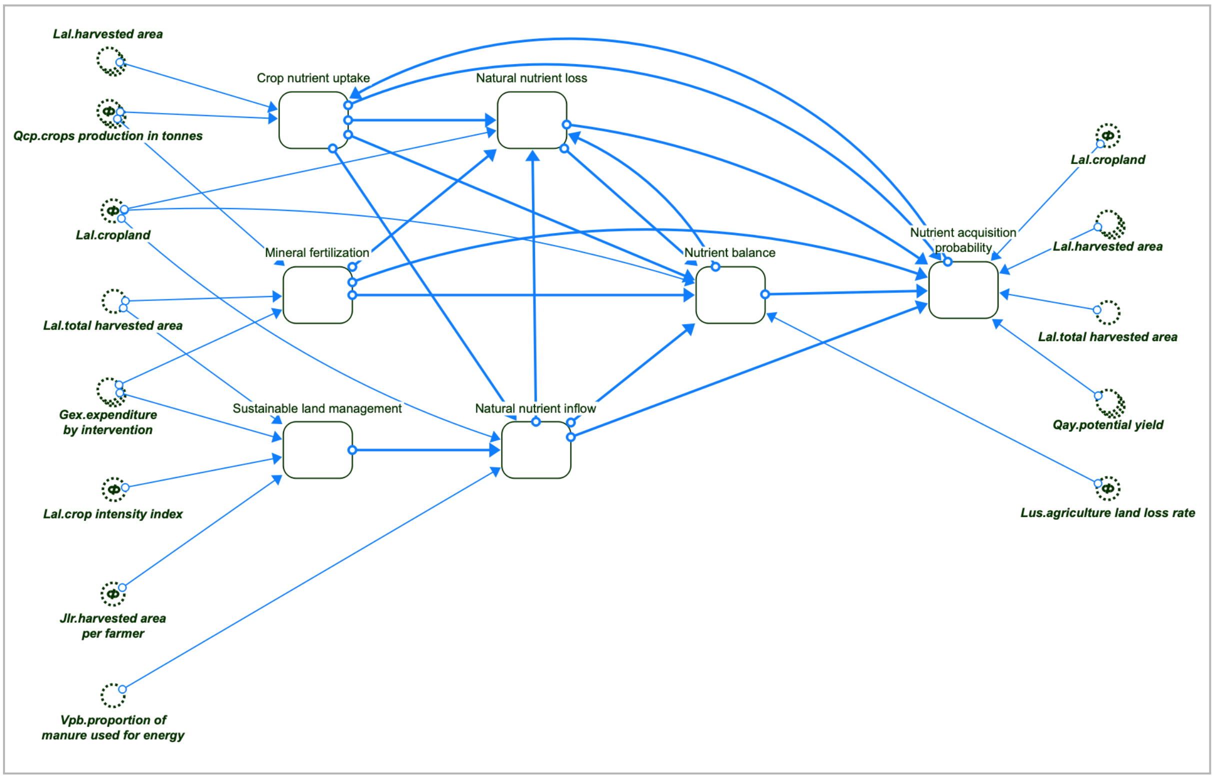
Sala, O.E., Chapin, F.S., Armesto, J.J., Berlow, E., Bloomfield, J., Dirzo, R., Huber-Sanwald, E., Huenneke, L.F., Jackson, R.B., Kinzig, A., Leemans, R., Lodge, D.M., Mooney, H.A., Oesterheld, M., Poff, N.L., Sykes, M.T., Walker, B.H., Walker, M. and Wall, D.H., 2000. Global biodiversity scenarios for the year 2100. *Science*, 287, pp.1770–1774.

UNEP (United Nations Environment Programme), 2012. *Global Environment Outlook 5: Environment for the future we want*. Nairobi: UNEP.

Varmola, M., 2002. Teak in Central America. *FAO forest plantations working papers*. Rome: FAO Forestry Department.

Wolman, M.G., 1993. Population, land use, and environment: a long history. In: *Population and land use in developing countries*. Washington, D.C.: National Research Council.

[S] Soil



Purpose, Perspective and Level of Aggregation

The Soil sector represents soil nutrient balances and their long-term impact on soil organic matter, and it is grounded in FAO's nutrients balance research.

In the model the addition of nutrients is captured through inflows of **Mineral Fertilization**, biological fixation, and deposition. We consider the outflows to be

Crop Nutrient Uptake and **Natural Nutrient Losses -** including leaching and gaseous losses. Finally, the resulting primary nitrogen balance affects soil organic matter.

The model accounts for the flows of the three major soil macronutrients (Nitrogen, Phosphorous, and Potassium) that relate to agricultural activities.

Main Assumptions

- Nutrient inflows include fertilization, biological fixation, deposition, and mineral weathering (Roy et al 2003, Andersson et al 1998, Kirkby et al 2011)
- Nutrient outflows include nutrient use and losses (Roy et al 2003)
- Nutrient imbalance is drawn from soil organic matter (Bot et al 2005)
- Mineralization rate estimated based on (Del Pino Machado, 2005)
- Soil management training unit cost estimated based on (Quizon 2001)

Main Limitations

The subscript [nutrient] is used to separately keep track of nutrient flows and balance for the three major nutrients: nitrogen, phosphorus, and potassium. This implies that deficiencies or, more broadly, imbalances in other nutrients cannot be assessed by the model. By expansion of such subscripts, further nutrients can be included in the analysis, where necessary. In addition, nutrients' balances are established at the average, national level, and therefore the model cannot be used to analyze policy interventions for specific locations.

Data Sources

Figures for the following indicators are sourced from FAOSTAT:

- Nutrient deposition and sedimentation
- Nutrient from manure application
- Biological fixation
- Nutrient uptake
- Fertilizer use

References

Andersson, F., Braekke, F.H. and Hallbäcken, L. (eds.), 1998. *Nutrition and growth of Norway spruce forests in a Nordic climatic and deposition gradient*. TemaNord. Copenhagen: Nordic Council of Ministers.

Bot, A. and Benites, J., 2005. *The importance of soil organic matter: key to drought-resistant soil and sustained food and production*. FAO Land and Plant Nutrition Management Service. Rome: Food and Agriculture Organization of the United Nations.

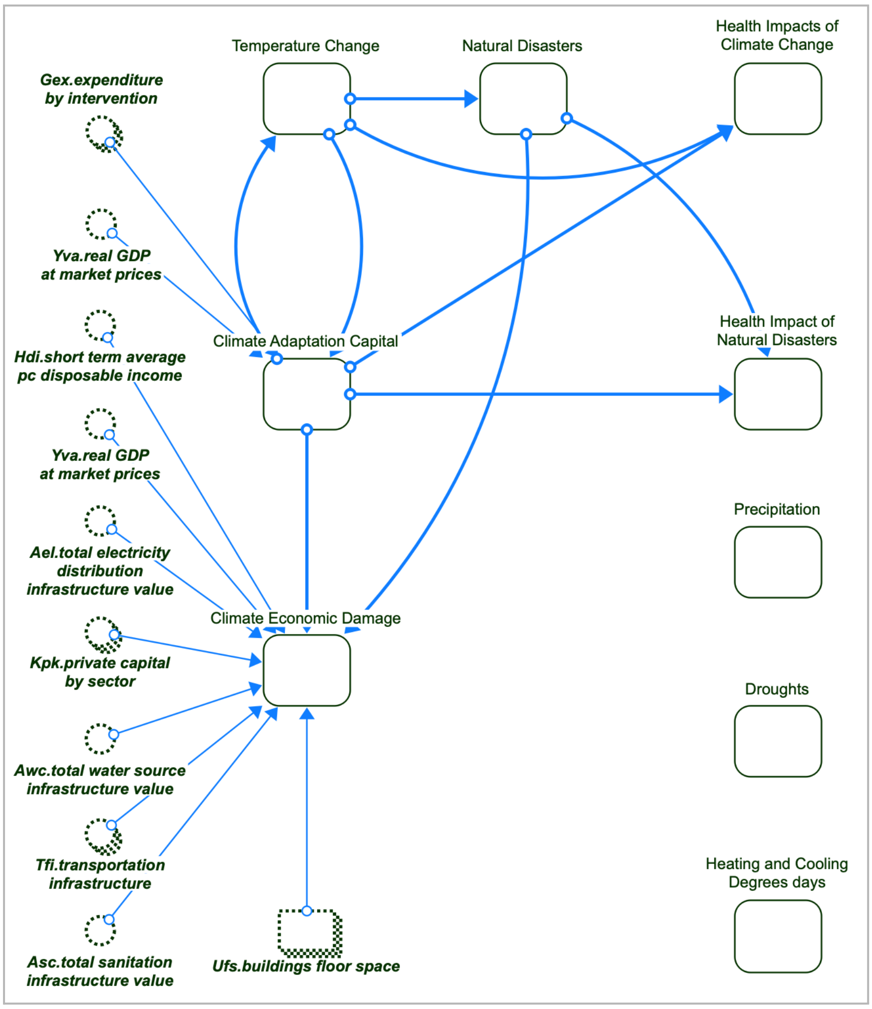
Del Pino Machado, A.S., 2005. *Estimating nitrogen mineralization potential of soils and the effect of water and temperature and crop residues on nitrogen net mineralization*. Göttingen: Cuvillier Verlag.

Kirkby, C.A., Kirkegaard, J.A., Richardson, A.E., Wade, L.J., Blanchard, C. and Batten, G., 2011. Stable soil organic matter: A comparison of C:N:P:S ratios in Australian and other world soils. *Geoderma*, 163, pp.197–208.

Quizon, J., Feder, G. and Murgai, R., 2001. *Fiscal sustainability of agricultural extension: the case of the Farmer Field School approach*. Washington, DC: World Bank.

Roy, R.N., Misra, R.V., Lesschen, J.P. and Smaling, E.M., 2003. *Assessment of soil nutrient balance*. FAO Land and Water Development Division. Rome: Food and Agriculture Organization of the United Nations.

[C] Climate



Purpose, Perspective and Level of Aggregation

The purpose of this sector is to account for climate impacts on a wide range of development aspects, including health, productivity, and infrastructure - directly through change in temperature and rainfall, and because of extreme events or natural disasters.

The fundamental climatic variables change over time in different climate scenarios. The average **Temperature Change**, **Precipitation**, **Heating and Cooling Degrees Days**, **Heavy Precipitation days** and the Standardized Precipitation Evapotranspiration (**SPEI) drought index** are exogenously determined by the scenario chosen: SSP1-1.9; SSP1-2.6; SSP2-4.5; SSP3-7.0; SSP5-8.5. In the data, the SPEI drought index, an indicator for drought severity, is a measure of normalized, accumulated rainfall anomalies relative to an annual running-mean that includes the effects of evapotranspiration. SPEI values less than -1 hence indicate drought conditions, with -2 or less being extremely dry, while SPEI values greater than 1 indicate wet conditions.

These climatic variables affect the intensity and frequency of natural disasters, droughts, water runoff, and energy demand for heating/cooling. Natural disasters are currently only represented as the frequency of occurrence of disaster events, however, further disaggregation can be introduced to capture more context-specific weather/climate events. Climate and natural disasters affect health outcomes, indirectly impacting mortality rates. Drought conditions further impact on water acquisition probability for crops, relative to the proportion of area irrigated in the model. The climate sector, and effects of temperature change, impact the economic sectors throughout the model. **Climate Economic Damage** measures the total economic damage on infrastructure including buildings, transport, water, sanitation and electricity infrastructure, as well as private capital, relative to indicated economic damage from natural disasters without adaptation.

Lastly, the climate sector also includes the calculation of investment requirements for **Climate Adaptation Capital** and their fulfillment through public investment. Adaptation requirements are further disaggregated based on UNEP, 2023 categorization of finance needs by sector (e.g. agriculture, human health, infrastructure, ecosystems, business and tourism etc.).

Main Assumptions

- Natural disasters frequency and intensity increases with climate change (IPCC 2012)
- The economic cost of climate change adaptation depends on the extent of temperature increase (UNEP 2014; 2023) and hence, adaptation capital requirements increase based on an increasing share of GDP (i.e. not fixed GDP over time).

- The share of damage to buildings is based on an economic valuation of the floor space (Bricogne et al, 2019)

Main Limitations

The model represents climate change through changes in temperature and precipitation, as well as in the frequency and intensity of natural disasters. Other implications of climate change, such as sea level rise, or glacier melting, are not considered in the initial version of the model, but can be included when relevant to the specific country under consideration. Model adaptation capital requirements represent estimates and should be substituted with country-specific information when available.

Data Sources

Figures for the following indicators are sourced from the World Bank Group's Climate Change Knowledge Portal (CCKP):

- Historical average temperature
- Historical average precipitation
- Historical number of days with very heavy precipitation
- Expected average temperature under the SSPs
- Expected average precipitation under the SSPs
- Expected number of days with very heavy precipitation under the SSPs
- Annual SPEI drought index

Figures for the following indicators are sourced from the International Disaster Database (EM-DAT):

- Number of yearly natural disasters
- Number of people affected by natural disasters
- Number of deaths by natural disasters
- Economic disasters due to natural disasters

References

Bricongne, Jean-Charles, Turrini, A. and Pontuch, P, 2019. Assessing House Prices: Insights from "Houselev", a Dataset of Price Level Estimates, Discussion Paper 101, European Commission, Directorate-General for Economic and Financial Affairs, ISSN 2443-8022 (online).

IPCC, 2012. *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change*. Field, C.B., Barros, V., Stocker, T.F., Qin, D., Dokken, D.J., Ebi, K.L., Mastrandrea, M.D., Mach, K.J., Plattner, G.-K., Allen, S.K., Tignor, M. and Midgley, P.M. (eds.). Cambridge and New York: Cambridge University Press.

Sala, O.E., Chapin, F.S., Armesto, J.J., Berlow, E., Bloomfield, J., Dirzo, R., Huber-Sanwald, E., Huenneke, L.F., Jackson, R.B., Kinzig, A., Leemans, R., Lodge, D.M., Mooney, H.A., Oesterheld, M., Poff, N.L., Sykes, M.T., Walker, B.H., Walker, M. and Wall, D.H., 2000. Global biodiversity scenarios for the year 2100. *Science*, 287, pp.1770–1774.

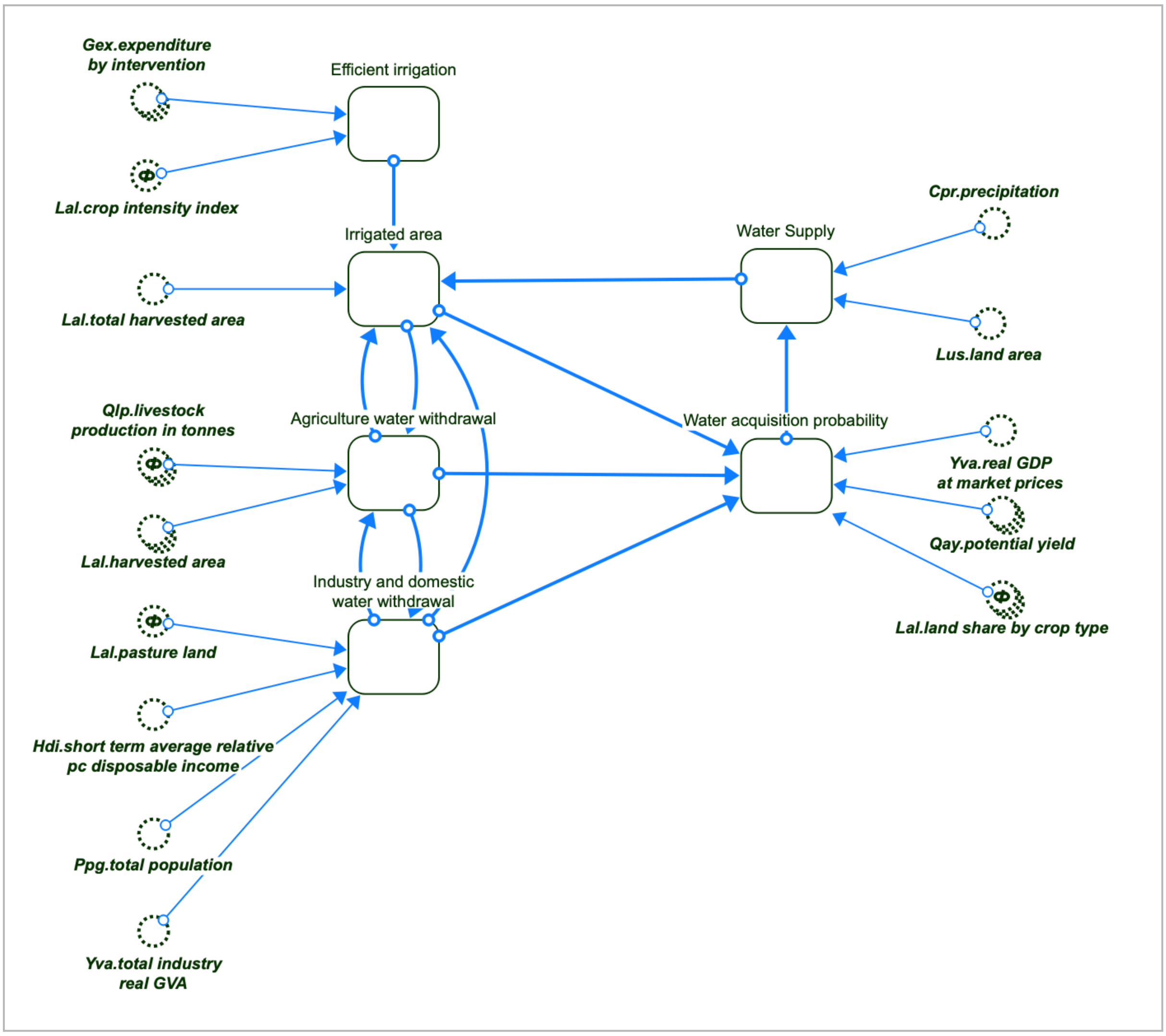
UNEP, 2014. *The Adaptation Gap Report 2014*. Nairobi: United Nations Environment Programme.

United Nations Environment Programme, 2023. *Adaptation Gap Report 2023: Underfinanced. Underprepared. Inadequate investment and planning on climate adaptation leaves world exposed*. Nairobi. Available at: https://doi.org/10.59117/20.500.11822/43796

Vicente-Serrano, S.M., Beguería, S. and López-Moreno, J.I., 2010. A multiscalar drought index sensitive to global warming: the standardized precipitation evapotranspiration index. *Journal of Climate*, 23(7), pp.1696–1718.

World Bank, 2025. *Climate Change Knowledge Portal*. Available at: https://climateknowledgeportal.worldbank.org/

[W] Water



Purpose, Perspective and Level of Aggregation

As one of the key elements supporting human life, water supply and consumption are paramount in understanding the behavior of various factors influencing primary production over time, such as crop and livestock production, as well as the capacity to irrigate land and the need for more efficient irrigation techniques.

The Water sector represents **Water Supply** and **Withdrawal** from different uses, according to FAO's Aquastat classification. **Water Supply** is characterized by precipitation and cross border inflows, where their future values are computed linearly from the expected values in 2050 according to the different Shared Socio-economic Pathways (SSP) chosen. The model accounts for **Agriculture Water Withdrawal** as well as **Industry and Domestic water withdrawal**. Water supply acts as a constraint to crops and livestock production and allows consideration of the effects of irrigation efficiency and dam capacity as measures to improve water management systems through Government expenditure.

As for the Primary production sector, the Water sector distinguishes between water demand from crop 1, crop 2 production and livestock production. The model also accounts for industrial, domestic and municipal withdrawals and precipitation and cross border inflows as major sources of supply.

Main Assumptions

- Water withdrawal for agriculture, industry and municipal/domestic use are the major components of total water withdrawal (FAO 2015)
- Domestic and municipal water demand is influenced by population and income (OECD 2012, WWAP 2015)
- Industry water demand is determined by production and its water efficiency (OECD 2012, WWAP 2015)
- Agriculture water demand is determined by the size of the irrigated harvested area and water crop demand (OECD 2012, WWAP 2015)
- We estimate water efficient irrigation cost per hectare based on (2030 WRG, 2009)
- Sources of water supply are structurally based on FAO, 2015
- The water resources vulnerability index is calculated based on (Raskin et al. 1997)
- Water scarcity threshold is based on Falkenmark's (1989), as a benchmark for water availability to affect access.

Main Limitations

By way of the subscript [product] water withdrawal is separately calculated for different crop categories. Such amounts are based on averaging water withdrawal within crop categories, and therefore can underestimate the change in water withdrawal due to shifting in varieties within crop categories.

Also, water scarcity is sometimes a problem for specific areas in a country, and not others. Given the level of aggregation used, the model does not support the analysis of location-specific water scarcity problems.

Data Sources

Figures on irrigated areas are sourced from FAOSTAT.

Figures for the following indicators are sourced from AQUASTAT:

- Total renewable water resources
- Cross border inflow
- Cross border outflow
- Dams capacity

- Total water withdrawal
- Municipal water withdrawal
- Agricultural water withdrawal
- Irrigation water withdrawal
- Industrial water withdrawal

References

2030 Water Resources Group, 2009. *Charting our water future: economic frameworks to inform decision-making*. McKinsey & Company.

FAO (Food and Agriculture Organization), 2015. *AQUASTAT database*. Rome: Food and Agriculture Organization of the United Nations.

Falkenmark, M., 1989. The massive water scarcity threatening Africa—why isn't it being addressed? *Ambio*, 18(2), pp.112–118.

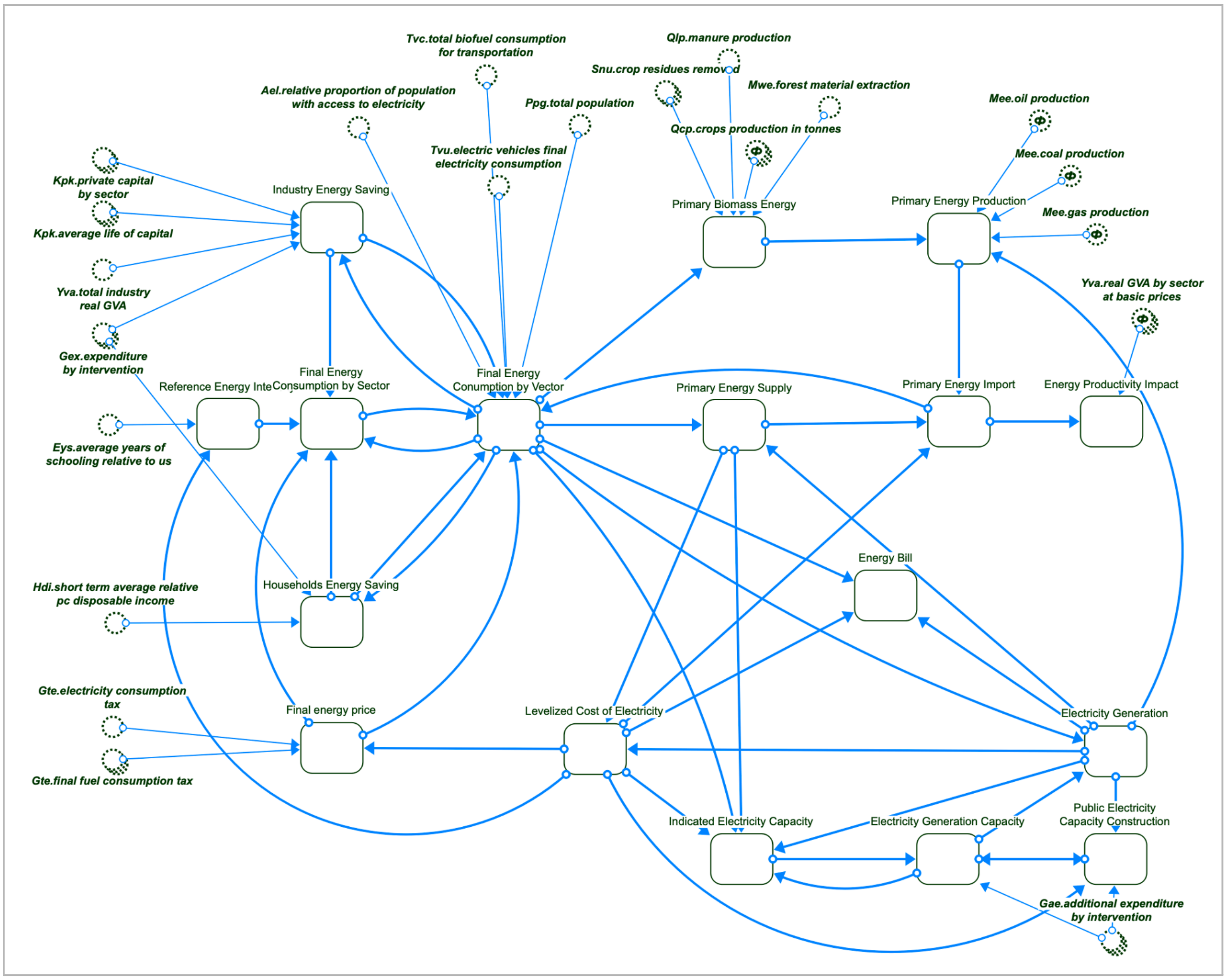
OECD (Organisation for Economic Co-operation and Development), 2012. *OECD Environmental Outlook to 2050*. Paris: OECD Publishing.

Raskin, P., Gleick, P., Kirshen, P., Pontius, G. and Strzepek, K., 1997. *Water futures: assessment of long-range patterns and prospects*. Stockholm: Stockholm Environment Institute.

WHO (World Health Organization), 2012. *Global costs and benefits of drinking-water supply and sanitation interventions to reach the MDG target and universal coverage*. Geneva: World Health Organization.

WWAP (United Nations World Water Assessment Programme), 2015. *The United Nations World Water Development Report 2015: Water for a sustainable world*. Paris: UNESCO.

[V] Energy



Purpose, Perspective and Level of Aggregation

Energy is the backbone of economic development as it is responsible for material transformation and transportation. It is also a supporting pillar to many energy producing countries. Moreover, fossil fuels, which are still the main source of primary energy in the world economy, are responsible for GHG emissions causing climate change and therefore, energy sources and energy uses are at the forefront of sustainable development.

The Energy sector is grounded on IEA energy balance models and computes Primary Energy Supply by source to include domestic production as well as the variation in stocks from imports. The model considers a demand driven energy supply and therefore, imports are the residual of Supply minus Production and Stock variation. Electricity Generation is also computed. Consumption is constrained by price, which includes taxation, and technological and political measures put in place to improve access and efficiency.

The model computes **Primary Energy Supply** by source for the following energy sources: Oil, Gas, Coal, Hydro, Wind, Solar, Nuclear, Biomass, Electricity and

Heat. **Electricity Generation** is also computed by generation infrastructure: Hydro, Wind, Solar and Nuclear; or burnt fuel: Oil, Gas, Coal or Biomass. Energy supply is driven by each sector's demand: agriculture, industry, services, residential, transportation and other.

Main Assumptions

- Residential electricity consumption depends on income, access to electricity, and population (IEA 2014)
- Energy consumption for productive uses depends on the volume of production (IEA 2014)
- Energy consumption for other uses depends on GDP and population (IEA 2014)
- Energy efficiency is estimated as function of global average energy efficiency (WDI 2015)
- Decision on electricity capacity construction are affected by the estimated levelized cost of electricity (IEA 2014)
- Biomass energy supply is based on crops production and forest products (Hoogwijk et al. 2003, FAO 2003)
- Energy transformation and transportation loss factors are based on IEA energy balances (IEA 2015)
- The difference between primary energy demand and primary energy production is filled by energy imports (IEA 2014)
- LCOE drives electricity consumption and affects investment in generation capacity, which gradually adapt to changes in LCOE

Main Limitations

Although energy imports are explicitly calculated, the amount of such imports does not affect the total import in the Balance of payments sector, which is calculated as a residual of the GDP equation. Such a limiting assumption is typically relaxed when the analysis of trade components is the focus of the study and data on imports by type of good/service is available.

Data Sources

Figures for the following indicators are either sourced directly from or derived from the International Energy Agency's (IEA) World Energy Balances and Extended Energy Balances datasets:

- Primary energy production - by energy source
- Primary energy net import - by energy source
- Primary energy supply - by energy source
- Primary energy stock variation - by energy source
- Energy transformation and losses - by energy source
- Final energy consumption - by sector and energy source

- Electricity generation - by energy source
- Electricity generation efficiency - by energy source
- Transmission loss factor

Figures for electricity generation capacity are sourced from the Energy Information Agency's (EIA) International Energy Statistics dataset.

Figures for the energy intensity level of primary energy are sourced from the World Bank Group's World Development Indicators (WDI).

References

FAO (Food and Agriculture Organization), 2003. *Wood volume and woody biomass: review of FRA2000 estimates*. Forestry Resources Assessment Programme, Working Paper 68. Rome: FAO.

IEA (International Energy Agency), 2014. *World Energy Model documentation: 2014 version*. Paris: International Energy Agency and OECD.

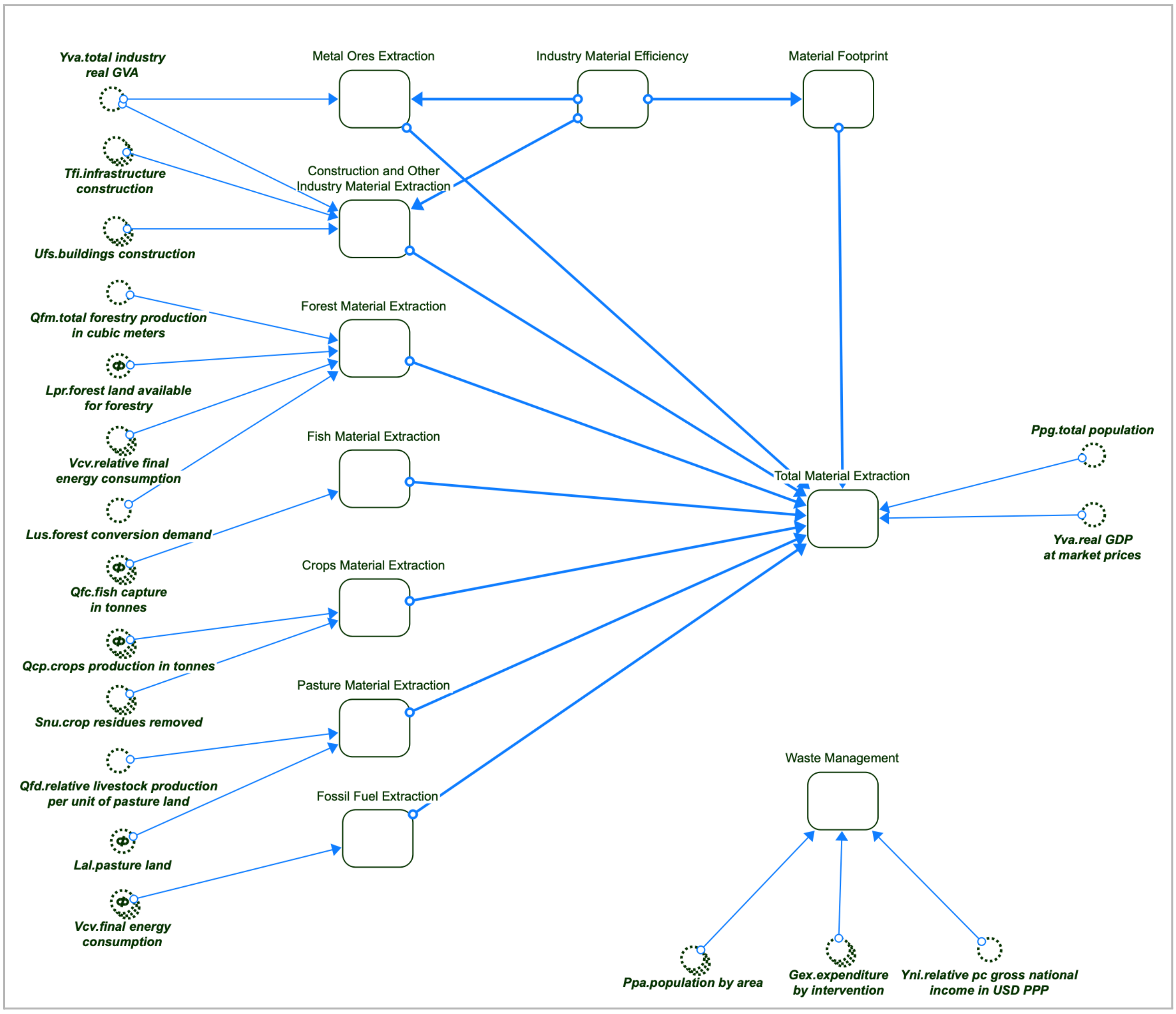
IEA (International Energy Agency), 2015. *World Energy Balances: 2015 Revised Edition*. Paris: International Energy Agency and OECD.

UN (United Nations), 2015. *UNData*. United Nations Statistics Division.

WDI (World Bank), 2015. *World Development Indicators database*. Washington D.C.: The World Bank Group.

[M] Materials

Purpose, Perspective and Level of Aggregation



Material flows are central to monitoring the changing patterns of resource use as global economies grow. They are essential for monitoring progress towards SDG targets 8.4 'Resource Productivity' and 12.2 'Sustainable Use of Natural Resources'. These indicators provide a basis for policies to decouple the growth of the economy from the use of natural resources so as to achieve a reduction of environmental degradation resulting from primary production, material processing, manufacturing and waste disposal.

The Materials sector represents the **Total Material Extraction** and **Domestic Material Consumption** from a wide range of sources and their respective drivers. The sector considers biomass material flows as well as non organic material flows, based on the classification of the GMF - Global Material Flows database, published by the The International Resource Panel (IRP) from the UNEP. In addition, the module represents waste generation and management by area.

The biomass material flows considered are pasture, crops, fish, forest, and the non organic material flows considered are metal ores, fossil fuels, construction and other industries material extraction. Whenever a variable is expressed by area, we distinguish between urban and rural areas.

Main Assumptions

- Metal ores, Construction, and Biomass material flows are income driven (Wiedmann et al. 2008)
- Per capita cement demand depends on income (De Vries et al. 2006)
- Material extraction and consumption factors are based on data from (Lutter et al. 2016, Giljum et al. 2014)
- Waste collection and disposable unit cost are estimated based on (WB 2012)

Main Limitations

The structure of this sector is kept to a low degree of detail in order to represent the major components of material extraction and consumption, and their main drivers. Data on material consumption and trade by type of material is not available to a high level of detail in many countries. Should such data be available, the structure of this sector can be modified to allow for more detail and a larger number of explanatory variables for material consumption.

For fossil fuel extraction, resource classification is based on the McKelvey Box (McKelvey 1972). For applications that focus on fossil fuel production strategies, the sector can be expanded to explicitly include production capacity and demand factors affecting production, as in (Davidsen et al 1990).

Data Sources

Figures for the following indicators are sourced from the Global Material Flows Database (GMF), maintained by the International Resource Panel:

- Domestic Material Extraction by category
- Domestic Material Consumption by category
- Material Footprint by category

Figures on cement production are estimated based on data from the Global Carbon Project.

Figures on waste generation and collection are sourced from What a Waste Global Database.

References

Davidsen, P.I., Sterman, J.D. & Richardson, G.P., 1990. A petroleum life cycle model for the United States with endogenous technology, exploration, recovery, and demand. *System Dynamics Review*, 6(1).

De Vries, H.J.M. et al., 2006. Assessment of the interaction between economic and physical growth. EPIST project report UCE-34, Netherlands Research Programme on Scientific Assessment and Policy Analysis for Climate Change, University of Utrecht.

Giljum, S., Dittrich, M., Lieber, M. & Lutter, S., 2014. Global patterns of material flows and their socio-economic and environmental implications: A MFA study on all countries world-wide from 1980 to 2009. *Resources*, 3, pp.319–339.

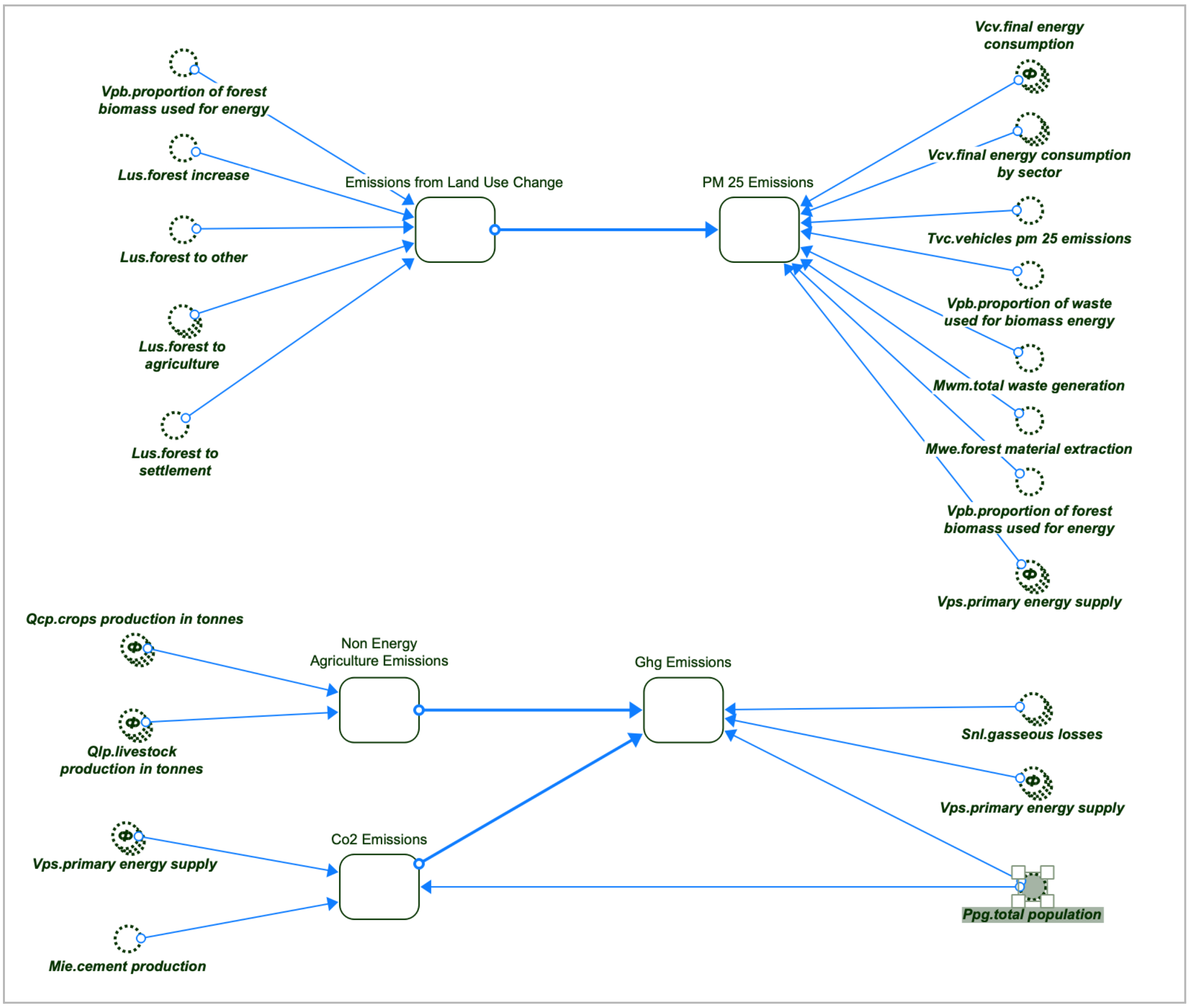
Lutter, S., Lieber, M. & Giljum, S., 2016. Global Material Flow database, Material extraction data, Technical Report, Version 2015.1. Institute for Ecological Economics / Vienna University of Economics and Business (WU).

McKelvey, V.E., 1972. Mineral resource estimates and public policy. *American Scientist*, 60, pp.32–40.

Wiedmann, T.O. et al., 2008. The material footprint of nations. *Proceedings of the National Academy of Sciences*, 112(20), pp.6271–6276.

World Bank (WB), 2012. What a waste: a global review of solid waste management. Urban Development Series. Washington, D.C.: World Bank.

[X] Emissions



Purpose, Perspective and Level of Aggregation

The Emissions sector' purpose is to account for GHG emissions' inventories in order to track down national contributions to climate change. However, as temperature rise is a global phenomena, national GHG emissions can not be directly linked to it. Therefore, temperature change remains an exogenous parameter in the range of the values proposed in the different SSPs scenarios.

The Emissions sector represents **CO2 Emissions** from cement production and fossil fuels, as well as other GHG pollutants (namely NO2 and CH4) and those produced by **Non Energy agricultural** activities (crops and livestock' emissions), all aggregated to compute total GHG emissions in CO2 equivalent tonnes per year. The sector also represents **Emissions from Land Use Change,** thus capturing a sink for CO2 emissions through the absorption of forest land. Lastly, **PM 2.5 Emissions** from transport and biomass (forest and waste), burnt for energy and non-energy uses, are also included. These emissions are then used to calculate the knock-on effects on health relative to particulate matter exposure.

Overall, CH4, CO2 and NO2 emissions are disaggregated by fossil fuel source, and then converted into CO2 equivalent potential, before adding those CO2 emissions generated by cement production and the non-energy agricultural emissions. PM 2.5 emissions are also disaggregated per fossil fuel source and then added to those coming from energy and non-energy uses of biomass, as well as those coming from vehicle combustion engines.

Main Assumptions

- PM2.5 emission parameters for fossil fuels and vehicles are based on (Klimont et al 2002)
- PM2.5 emission parameters for biomass are based on (Nussbaumer et al 2008)
- CO2, N2O and CH4 are the major contributors to total emission of greenhouse gases (IPCC 2006)
- Pollutants are aggregated into CO2 equivalent units based on the IPCC SAR 100-year global warming potentials (IPCC, 1995)
- Emissions from land use change are based on (IPCC 2000)

Main Limitations

In order to calculate future emissions in CO2 equivalent we use constant conversion factors. In reality, such factors can change based on the properties of the fuels being used. Should such information about future fuel quality be available, the model can flexibly accept time-varying conversion parameters.

Data Sources

- Global Carbon Project 2021
- WDI, World Population Prospects 2022 Revision
- FAO

References

IPCC, 1995. *IPCC second assessment. A report of the Intergovernmental Panel on Climate Change*. WMO-UNEP.

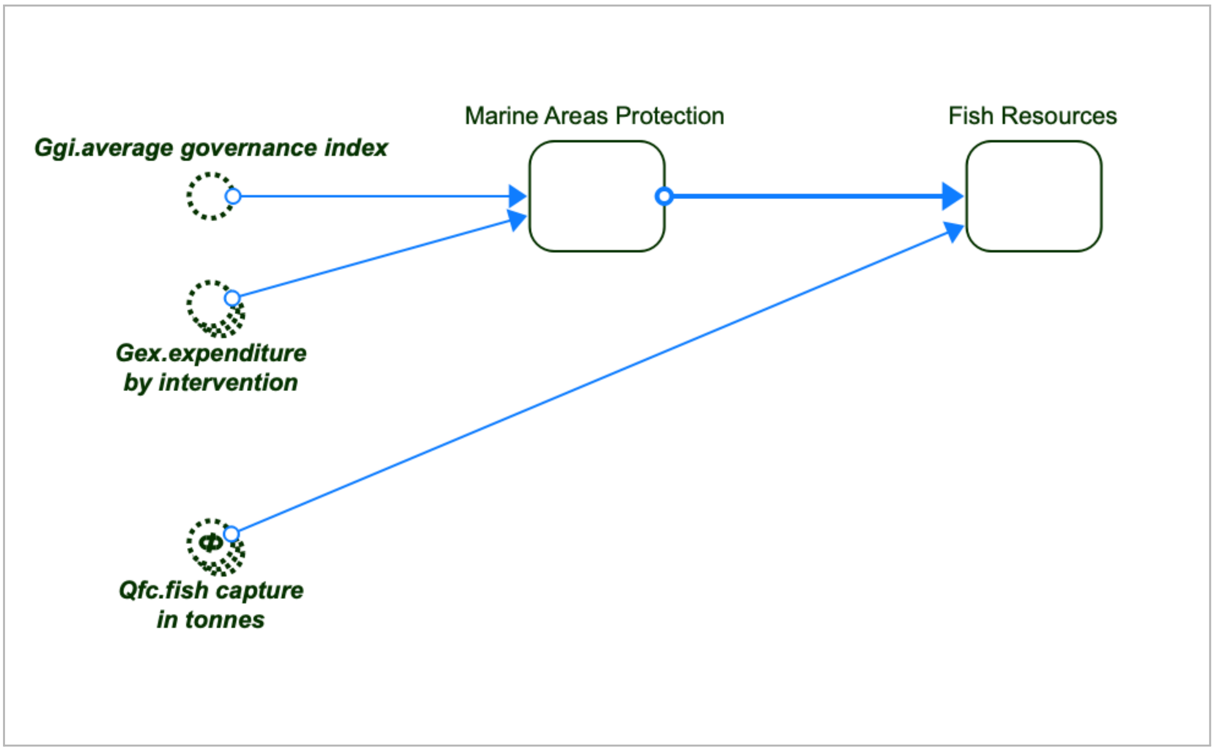
IPCC, 2000. Watson, R.T., Noble, I.R., Bolin, B., Ravindranath, N.H., Verardo, D.J. & Dokken, D.J. (eds). *Cambridge University Press*, UK, pp. 375.

IPCC, 2006. *2006 IPCC guidelines for national greenhouse gas inventories*. Prepared by the National Greenhouse Gas Inventories Programme, Eggleston, H.S., Buendia, L., Miwa, K., Ngara, T. & Tanabe, K. (eds). IGES, Japan.

Klimont, Z., Cofala, J., Bertok, I., Amann, M., Heyes, C. & Gyarfas, F., 2002. Modelling particulate emissions in Europe: A framework to estimate reduction potential and control costs. *IIASA Interim Report*, IR-02-076.

Nussbaumer, T., Czasch, C., Klippel, N., Johansson, L. & Tullin, C., 2008. Particulate emissions from biomass combustion in IEA countries: Survey on measurements and emission factors. *IEA Bioenergy Task 32*, January 2008.

[O] Oceans



Purpose, Perspective and Level of Aggregation

Another pillar of environmental sustainability and essential to SDG 14 'life below water' is oceans, seas and marine resources. The purpose of the Oceans sector is to account for marine ecosystem health, especially from the perspective of food provisioning and marine protection services.

The Oceans sector thereby represents **Fish Resources** in national waters and the key drivers responsible for its dynamics. These are mainly fish capture in tonnes and protected marine areas (**Marine Areas Protection**) through public spending. Another factor influencing SDG 14 is the proportion of fish stocks sustainably exploited. Fish resources availability is then used as a constraint to fish capture in the Primary Production sector.

The sector is disaggregated in a single fish category, but can be further subdivided if a species requires special attention.

Main Assumptions

- In the absence of comprehensive data on fish biomass levels at a national and aggregate species level, sustainability of the fish resource is measured through catch stock plots (SeaAroundUs.org)
- Fish capture includes both domestic catch (i.e. caught by the country's own fishing fleet) and foreign catch (i.e. caught by foreign vessels) in the country's national waters, dependent on data availability.

- Marine protection depends on public expenditure and the level of governance enforcement, measured through an aggregate governance index.
- In the model, the 'proportion of marine areas formally protected' is calculated as ratio between the protected marine area in relation to total area of the national waters (i.e. EEZ). This is consistent with the definition of marine protection at a national governance level and accounts for offshore marine protected areas. However, this is in contrast to the definition of SDG 14.5.01, which defines this indicator as the average proportion of marine key biodiversity areas (KBAs) covered by protected areas. The latter provides a much larger relative estimate, which hence inflates the perception of marine protection as it is only relative to a small portion of the national waters.

Main Limitations

The model only accounts for reported catch and hence does not incorporate catch from Illegal, unreported and unregulated fishing activities, which can often compromise the sustainability of the fish stock.

The model also does not incorporate fish capture by the domestic fleet in foreign waters (i.e. the impact of the country's fishing fleet fishing in other countries' waters or in the high seas).

Data Sources

Figures on protected marine areas are sourced from the Global SDG Database & https://www.keybiodiversityareas.org/kba-data.

Figures on proportion of fish stocks sustainably exploited are estimated based on stock status plots from SeaAroundUs.org.

FAO: fisheries division. https://www.fao.org/fishery/en/fishstat/collections

References

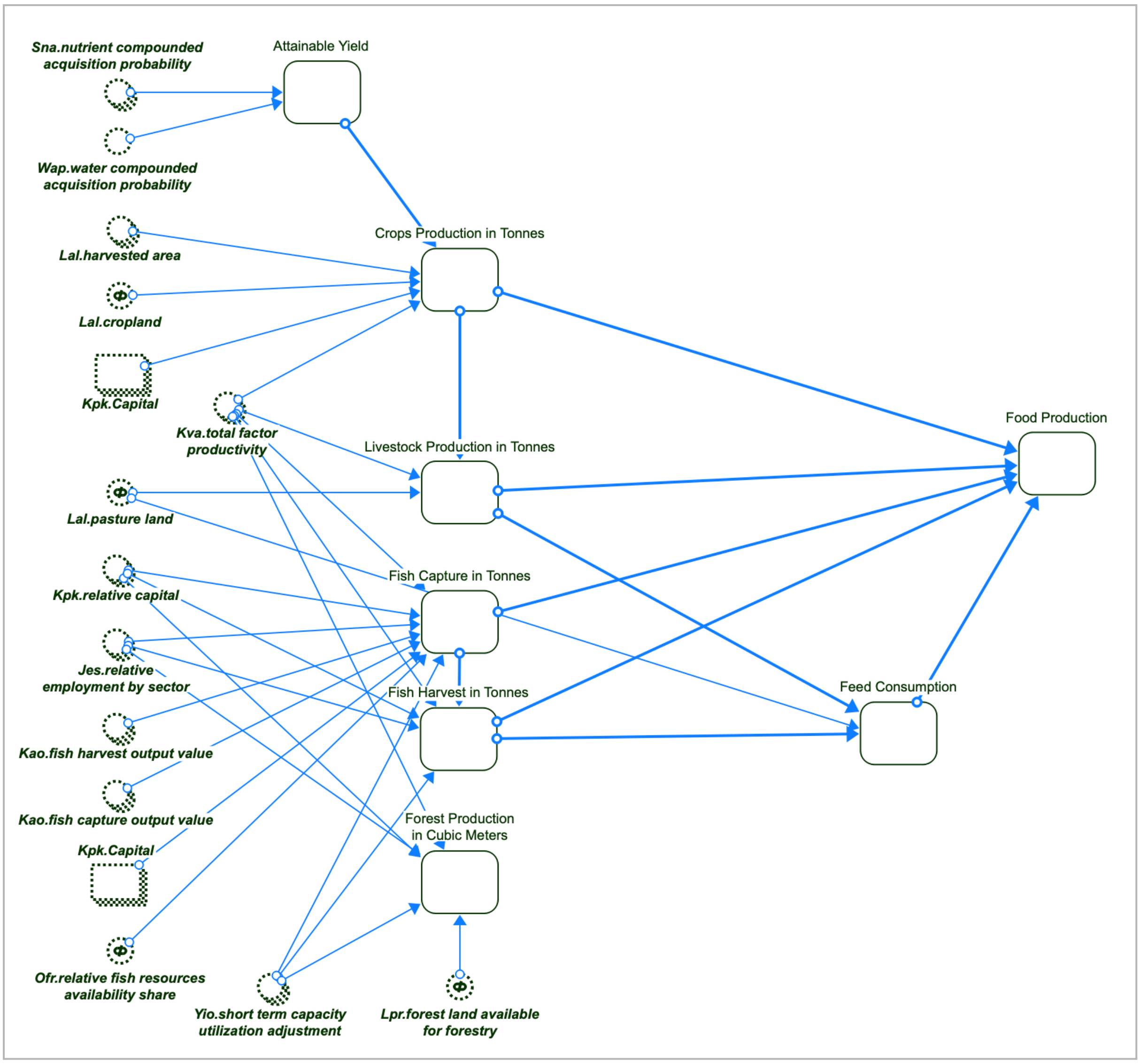
Balmford, A., Gravestock, P., Hockley, N., McClean, C.J. & Roberts, C.M., 2004. The worldwide costs of marine protected areas. *Proceedings of the National Academy of Sciences*.

McCrea-Strub, A., Zeller, D., Sumaila, U.R., Nelson, J., Balmford, A. & Pauly, D., 2011. Understanding the cost of establishing marine protected areas. *Marine Policy*, 35, pp.1–9.

Pauly, D. & Zeller, D., 2015. So long, and thanks for all the fish: The Sea Around Us, 1999-2014, A fifteen year retrospective. *Sea Around Us*, Fisheries Centre, The University of British Columbia, Vancouver. Data available from seaaroundus.org.

Economic Sectors

[Q] Primary Production



Purpose, Perspective and Level of Aggregation

The Primary production sector is grounded in FAO's food balance sheets, which presents a comprehensive picture of a country's food supply during a specified reference period. It covers the Primary production, expressed in tonnes, of **Crops, Livestock and Fish. Fish Capture** and **Fish Harvest** (i.e fisheries and aquaculture) are represented separately. Additionally, this sector also covers **Forestry Production**, expressed in cubic meters of wood.

Crops Production is determined by the harvested area and the yield. Yield, in turn, is determined by water availability and nutrient availability, and a Cobb Douglas production function accounting for capital and employment per hectare, as well as for total factor productivity.

Livestock Production is determined by a simpler formulation involving the available pasture land and a Cobb Douglas production function accounting for capital and employment per hectare, as well as for total factor productivity.

The formulation for **Fish Capture** is similar to that of **Livestock Production**, but the limiting factor is not the available pasture land, but the availability of fish resources (fish stocks).

Fish Harvest is determined by an even simpler Cobb Douglas function, involving only capital, employment and total factor productivity.

The **Feed Consumption** component is calculated separately for each food source. **Food Production** is computed as the residual of the separate production of each food source and **Feed Consumption.**

By default, crops are disaggregated into two categories - cereals and other crops-, while livestock and fish are aggregated in a single category. Additionally, while fish capture and fish harvest are computed separately, they are treated as a single category at the level of **Food Production.** The categories of food sources may be further disaggregated and regrouped as required.

Forestry Production is determined by a Cobb Douglas function accounting for capital, employment and total factor productivity. In addition, the availability of forested areas for forestry is a limiting factor for the production of wood.

Main Assumptions

- **Attainable yield** depends on the potential yield and the availability of water and macro-nutrients (Steduto et al 2012; Tan et al 2005)
- Production factors include land, capital and labor (Bosworth et al 1995; Senhadji 1999)
- Total factor productivity (TFP) depends on the level of:
    - infrastructure (Calderón & Servén 2004; Canning 1999)
    - education (Barro 2001; Nelson & Phelps 1966; Romer 1990)
    - health (Bloom et al 2001; Howitt 2005; López-Casasnovas et al 2005)
    - governance (Kaufmann et al 2002)
    - access to electricity (Calderón & Servén 2004)
    - macroeconomic stability (Bruno 1998; Fischer 1993)
    - female participation in the workforce (Boileau & Diouf 2009; Cuberes & Teignier 2012; FAO 2011)
    - openness to trade (Edwards 1998; Yanikkaya 2003)
    - climate change (temperature & precipitation) (Burke et al 2015)
    - energy prices (Arezki & Blanchard 2014; Jimenez-Rodriguez & Sanchez 2005; Peersman & Van Robays 2012)
    - public expenditure in agriculture (Mogues et al 2012)

- As production factors and their productivity increases, the gap between actual yield and attainable yield is reduced (Pedercini et al 2015)

Main Limitations

The level of sectoral detail used in the Primary Production sector (expressed in Tonnes/Cubic meters of commodities) is higher than that for agriculture in the Firms sector, expressed in terms of Value Added. By default, the model covers the following divisions of economic activities (ISIC Rev. 4):

A 01 - Crop and animal production, hunting and related service activities

A 02 - Forestry and logging

A 03 - Fishing and aquaculture

The implication of this is that the same capital and employment values are used in the production function of multiple commodities. The capital and employment values of A01 are used in the production functions of both **Crop Production** and **Livestock Production**, while the capital and employment values of A03 are used in the production functions of both **Fish Capture** and **Fish Harvest.** These mappings are accounted for in the model through parameters that allocate a proportion of the capital to either commodity group Crops vs. Livestock and Captured/Harvested Fish. If the commodity groups are further disaggregated, as in the case of crops (cereals vs other crops), the same capital and employment figures are used for that commodity group with different elasticities. Meanwhile, A02 - Forestry and logging covers other commodities besides wood, so the production of wood constitutes a proxy for the entire sector. This limitation can be overcome in specific applications with more disaggregated national accounts data.

A second limitation is that no other uses of agriculture production are considered other than Food and Feed, for instance Seed, Tourist Consumption or Losses; nor are Imports and Exports considered in the calculation of Food Production as a residual. This may result in a mismatch between the final values of modeled and observed Food Production, though not at the level of commodity production.

A third limitation concerns the exclusion of fodder crops from both **Crop Production** and from **Feed Consumption**. While crops grown primarily for human consumption that are used as feed are accounted for, crops grown primarily for animal consumption (fodder crops) are not considered in the model. This is not a structural limitation of the model, but rather a limitation concerning data availability, as FAOSTAT does not cover fodder crops. This limitation can be overcome through the inclusion of fodder crops either as a separate commodity group within **Crop Production**, or by including it in the 'other crops' category.

Data Sources

Figures for the following indicators are sourced from FAOSTAT:

- Crop production in tonnes by crop
- Harvested area by crop
- Livestock production in tonnes by livestock
- Value of crop production by crop
- Value of livestock production by livestock
- Feed and food supply by source
- Forestry production in cubic meters

Additionally, figures for fish capture and fish harvest in tonnes is sourced from FAO's Fisheries Division.

References

Arezki, R. & Blanchard, O., 2014. Seven Questions about the Recent Oil Price Slump. *IMFdirect - The IMF Blog*, 22 December 2014.

Barro, R.J., 2001. Human Capital and Growth. *American Economic Review*, AEA P&P, 91(2), pp.12–17.

Bloom, D.E., Canning, D. et al., 2001. The Effect of Health on Economic Growth: Theory and Evidence. *NBER Working Paper Series*, (WP8587). Cambridge, MA: National Bureau of Economic Research.

Boileau, L. & Diouf, M.A., 2009. Revisiting the Determinants of Productivity Growth: What's New? *IMF Working Paper* WP/09/225. Washington, DC: International Monetary Fund.

Bosworth, B., Collins, S.M. et al., 1995. Accounting for Differences in Economic Growth. *Discussion Papers Series*, 115. Cambridge, MA: Brookings Institution.

Bruno, M. & Easterly, W., 1998. Inflation crises and long-run growth. *Journal of Monetary Economics*, 41, pp.3–26.

Burke, M., Hsiang, S.M. & Miguel, E., 2015. Global non-linear effect of temperature on economic production. *Nature*, 527, pp.235–239.

Calderón, C. & Servén, L., 2004. The Effects of Infrastructure Development on Growth and Income Distribution. *World Bank Working Paper*, (WPS3400). Washington, DC: World Bank.

Canning, D., 1999. The Contribution of Infrastructure to Aggregate Output. *World Bank Policy Research Working Paper Series*, (2246). Washington, DC: World Bank.

Cuberes, D. & Teignier, M., 2012. Gender gaps in the labor market and aggregate productivity. *Sheffield Economic Research Paper Series*. Sheffield, UK: University of Sheffield.

Edwards, S., 1998. Openness, productivity and growth: What do we really know? *The Economic Journal*, 108(447), pp.383–398.

Fischer, S., 1993. The Role of Macroeconomic Factors in Growth. *Journal of Monetary Economics*, 32, pp.485–512.

Food and Agriculture Organization, 2011. *The state of food and agriculture 2012-11*. Rome: Food and Agriculture Organization of the United Nations.

Howitt, P., 2005. Health, Human Capital and Economic Growth: A Schumpeterian Perspective. In: G. López-Casanovas, B. Rivera & L. Currais, eds. *Health and Economic Growth: Findings and Policy Implications*. Cambridge, MA: MIT Press.

Jimenez-Rodriguez, R. & Sanchez, M., 2005. Oil Price Shocks and Real GDP Growth: Empirical Evidence for Some OECD Countries. *Applied Economics*, 37(2), pp.201–228.

Kaufmann, D., Kraay, A. et al., 2002. Governance Matters II, Updated Indicators for 2000/01. *Policy Research Working Paper*, (2772). Washington, DC: World Bank.

López-Casasnovas, G., Rivera, B. et al., 2005. Introduction: The Role Health Plays in Economic Growth. In: G. López-Casanovas, B. Rivera & L. Currais, eds. *Health and Economic Growth: Findings and Policy Implications*. Cambridge, MA: MIT Press.

Mogues, T., Yu, B., Fan, S. & McBride, L., 2012. The impacts of public investment in and for agriculture: Synthesis of the existing evidence. *ESA Working Paper* No. 12-07, October 2012. Agricultural Development Economics Division, Food and Agriculture Organization of the United Nations.

Nelson, R.R. & Phelps, E.S., 1966. Investment in Humans, Technological Diffusion, and Economic Growth. *American Economic Review*, 56(1/2), pp.69–75.

Pedercini, M., Dianati, K. & Baumgärtner, J., 2015. Development and evaluation of a biophysical crop production function for regional policy support in the tropics and subtropics.

Peersman, G. & Van Robays, I., 2012. Cross-country differences in the effects of oil shocks. *Energy Economics*, 34(5), pp.1532–1547.

Romer, P., 1990. Endogenous Technological Change. *Journal of Political Economy*, 98(5), pp.s71–s102.

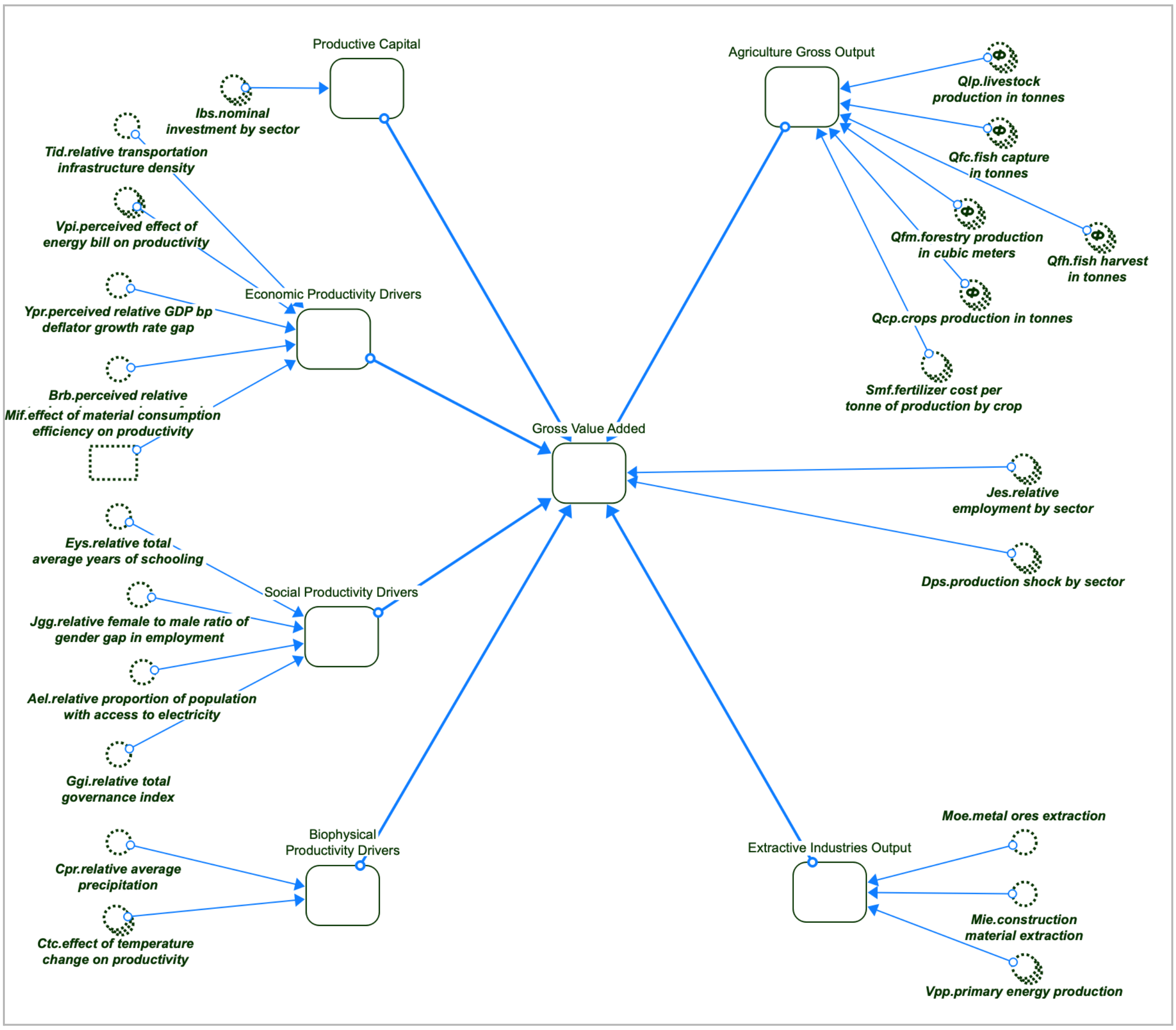
Senhadji, A., 1999. Sources of Economic Growth: An Extensive Growth Accounting Exercise. *IMF Working Paper Series*, (WP/99/77). Washington, DC: International Monetary Fund.

Steduto, P., Hsiao, T.C., Fereres, E. & Raes, D., 2012. *Crop yield response to water*, vol. 1028. Rome: Food and Agriculture Organization of the United Nations.

Tan, Z.X., Lai, R. & Wiebe, K.D., 2005. Global soil nutrient depletion and yield reduction. *Journal of Sustainable Agriculture*, 26(1), pp.123–146.

Yanikkaya, H., 2003. Trade Openness and Economic Growth: A Cross-Country Empirical Investigation. *Journal of Development Economics*, 72(1), pp.57–89.

[K] Firms



Purpose, Perspective and Level of Aggregation

The Firms sector tracks the real **Gross Value Added** of all economic sectors and therefore constitutes the basis to compute GDP and GDP growth in the model. As such, it influences the behavior of many factors across the model, such as households income and government revenue.

Gross Value Added is calculated separately for each economic activity. By default, the following economic activities are considered, based on ISIC Rev. 4:

A 01 - Crop and animal production, hunting and related service activities
A 02 - Forestry and logging
A 03 - Fishing and aquaculture
B 05–09 - Mining and quarrying
C 10–33 - Manufacturing
D 35 - Electricity, gas, steam and air conditioning supply
E 36–39 - Water supply; sewerage, waste management and remediation activities
F 41–43 - Construction

G 45–47 - Wholesale and retail trade; repair of motor vehicles and motorcycles
H 49–53 - Transportation and storage
I 55–56 - Accommodation and food service activities
J 58–63 - Information and communication
K 64–66 - Financial and insurance activities
L 68 - Real estate activities
M 69–75 - Professional, scientific and technical activities
N 77–82 - Administrative and support service activities
O 84 - Public administration and defense; compulsory social security
P 85 - Education
Q 86–88 - Human health and social work activities
R 90–93 - Arts, entertainment and recreation
S 94–96 - Other service activities
T 97–98 Activities of households as employers; undifferentiated goods- and services-producing activities of households for own use
U 99 Activities of extraterritorial organizations and bodies

However, based on data availability these economic activities may be further grouped or disaggregated. For example, data may only be available for economic activities R, S, T, U as one aggregate figure, or separate figures may be available for the various economic activities that make up H.

Gross Value Added is computed using extended Cobb-Douglas production functions for every economic activity. Growth in production is driven by the increase in availability of the necessary production factors or by the increase in their productivity.

Exceptions are the Agriculture, Forestry and Fisheries sectors (A01, A02, A03), for which the Cobb-Douglas functions are used at the commodity level, and **Gross Value Added** is calculated based on **Agriculture Gross Output**. Another exception is the Mining and Quarrying sector (B), for which the **Gross Value Added** is calculated based not only on total factor productivity, but also on **Extractive Industries Output**.

Total factor productivity is made up of **Economic Productivity Drivers**, **Social Productivity Drivers** and **Biophysical Productivity Drivers**. **Economic Productivity Drivers** include trade, inflation, infrastructure density, the cost of energy and the efficiency of material consumption. **Social Productivity Drivers** include governance, health, education, female participation in the labor market and access to electricity. **Biophysical Productivity Drivers** include changes in precipitation, energy prices, and temperature.

Main Assumptions

- Production factors include capital and labor, and are treated in a Cobb-Douglas production function (Cobb & Douglas 1928; Bosworth et al 1995; Senhadji 1999)
- Capital can be damaged by extreme events (IPCC 2012)
- Total factor productivity (TFP) depends on the level of:
    - infrastructure (Calderón & Servén 2004; Canning 1999)
    - education (Barro 2001; Nelson & Phelps 1966; Romer 1990)
    - health (Bloom et al 2001; Howitt 2005; López-Casasnovas et al 2005)
    - governance (Kaufmann et al 2002)
    - access to electricity (Calderón & Servén 2004)
    - macroeconomic stability (Bruno 1998; Fischer 1993)
    - female participation in the workforce (Boileau & Diouf 2009; Cuberes & Teignier 2012; FAO 2011)
    - openness to trade (Edwards 1998; Yanikkaya 2003)
    - climate change (Burke et al 2015)
    - energy prices (Arezki & Blanchard 2014; Jimenez-Rodriguez & Sanchez 2005; Peersman & Van Robays 2012)

Main Limitations

Many of the typical limitations of the Cobb-Douglas production function are overcome in the iSD model due to the inclusion of additional structures. Some of the general limitations of the Cobb-Douglas production function remain, however.

The first limitation is that the output elasticities of capital and labor are constant, meaning that they do not take into account changing technological conditions. The longer the time horizon of the simulation, the less adequate constant elasticities become. This limitation can be overcome by including scenarios for technological conditions that are reflected in the assumptions regarding changes in output elasticities.

The second limitation is that capital and labour are perfectly substitutable. If this limitation is of significant importance in a specific application, it can be overcome through the inclusion of separate, non-substitutable capital and labour inputs with specific output elasticities.

Another usual limitation of the Cobb-Douglas function is that demand factors are not considered in the calculation of production, and prices are treated exogenously. Such a production function is still suitable for representing the long-term pattern of production growth, which is our main interest with the iSD model, but it is not suitable for representing short–term fluctuations in production. This limitation is partially overcome in the model through the inclusion of endogenous effects of production on prices through an Input Output Table structure. The effects of inventory fluctuations, however, are not considered.

Data Sources

GVA, Capital, Gross Capital Formation - UN Statistics: http://data.un.org/Explorer.aspx. Where available, we prioritize ISIC Rev. 4 data, else we aggregate economic sectors.

References

Arezki, R. & Blanchard, O., 2014. *Seven Questions about the Recent Oil Price Slump*. IMFdirect - The IMF Blog, 22 December.

Barro, R.J., 2001. Human Capital and Growth. *American Economic Review*, 91(2), pp.12–17.

Bloom, D.E., Canning, D. et al., 2001. *The Effect of Health on Economic Growth: Theory and Evidence*. NBER Working Paper Series, No. WP8587. Cambridge, MA: National Bureau of Economic Research.

Boileau, L. & Diouf, M.A., 2009. *Revisiting the Determinants of Productivity Growth: What's New?* IMF Working Paper No. WP/09/225. Washington, DC: International Monetary Fund.

Bosworth, B., Collins, S.M. et al., 1995. *Accounting for Differences in Economic Growth*. Discussion Papers Series, No. 115. Cambridge, MA: Brookings Institution.

Bruno, M. & Easterly, W., 1998. Inflation crises and long-run growth. *Journal of Monetary Economics*, 41, pp.3–26.

Burke, M., Hsiang, S.M. & Miguel, E., 2015. Global non-linear effect of temperature on economic production. *Nature*, 527, pp.235–239.

Calderón, C. & Servén, L., 2004. *The Effects of Infrastructure Development on Growth and Income Distribution*. World Bank Working Paper No. WPS3400. Washington, DC: World Bank.

Canning, D., 1999. *The Contribution of Infrastructure to Aggregate Output*. World Bank Policy Research Working Paper Series, No. 2246. Washington, DC: World Bank.

Cobb, C.W. & Douglas, P.H., 1928. A Theory of Production. *American Economic Review*, 18(1), pp.139–165.

Cuberes, D. & Teignier, M., 2012. Gender gaps in the labor market and aggregate productivity. *Sheffield Economic Research Paper Series*. Sheffield, UK: University of Sheffield.

Edwards, S., 1998. Openness, productivity and growth: What do we really know? *The Economic Journal*, 108(447), pp.383–398.

Fischer, S., 1993. The Role of Macroeconomic Factors in Growth. *Journal of Monetary Economics*, 32, pp.485–512.

Food and Agriculture Organization, 2011. *The State of Food and Agriculture 2012-11*. Rome: Food and Agriculture Organization of the United Nations.

Howitt, P., 2005. Health, Human Capital and Economic Growth: A Schumpeterian Perspective. In: G. López-Casanovas, B. Rivera & L. Currais, eds. *Health and Economic Growth: Findings and Policy Implications*. Cambridge, MA: MIT Press.

Intergovernmental Panel on Climate Change, 2012. *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation*. A Special Report of Working Groups I and II of the IPCC [Field, C.B., Barros, V., Stocker, T.F., Qin, D., Dokken, D.F., Ebi, K.L., Mastrandrea, M.D. et al., eds.]. Cambridge, UK and New York, NY: Cambridge University Press.

Jimenez-Rodriguez, R. & Sanchez, M., 2005. Oil Price Shocks and Real GDP Growth: Empirical Evidence for Some OECD Countries. *Applied Economics*, 37(2), pp.201–228.

Kaufmann, D., Kraay, A. et al., 2002. *Governance Matters II: Updated Indicators for 2000/01*. Policy Research Working Paper No. 2772. Washington, DC: World Bank.

López-Casasnovas, G., Rivera, B. et al., 2005. Introduction: The Role Health Plays in Economic Growth. In: G. López-Casanovas, B. Rivera & L. Currais, eds. *Health and Economic Growth: Findings and Policy Implications*. Cambridge, MA: MIT Press.

Nelson, R.R. & Phelps, E.S., 1966. Investment in Humans, Technological Diffusion, and Economic Growth. *American Economic Review*, 56(1/2), pp.69–75.

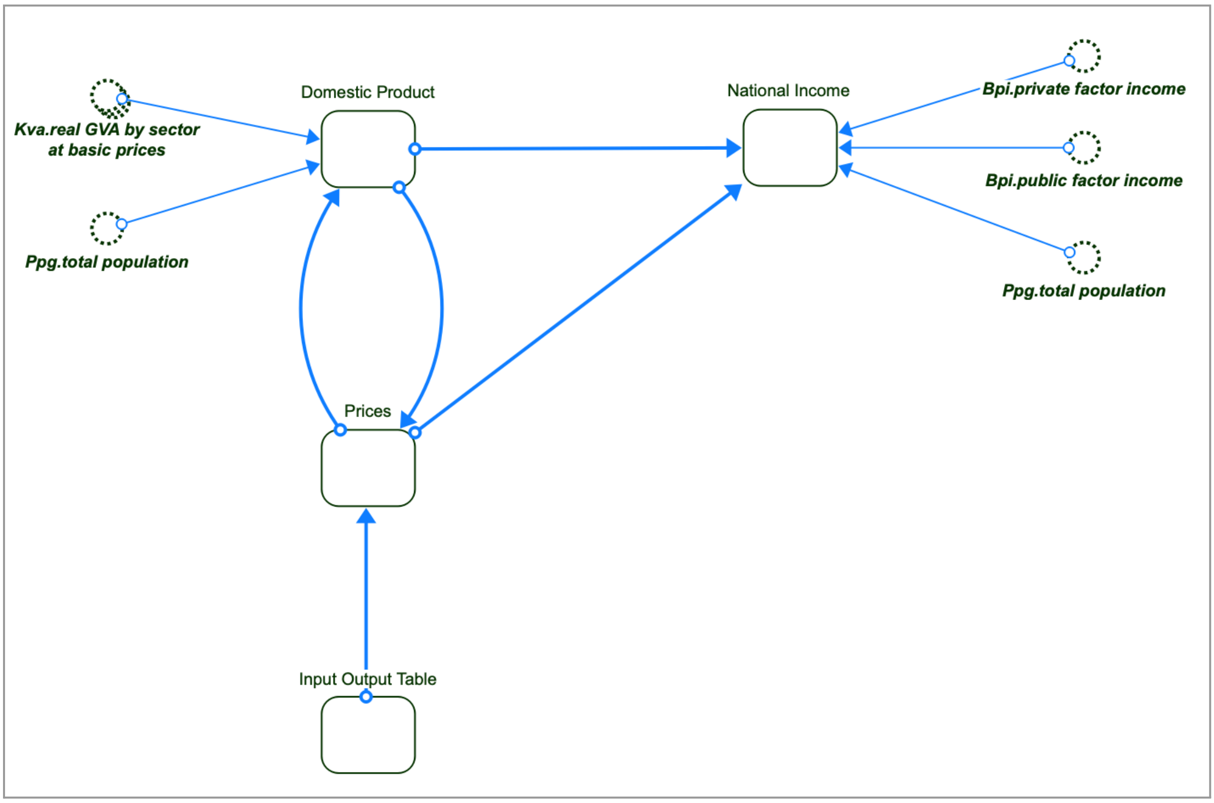
Peersman, G. & Van Robays, I., 2012. Cross-country differences in the effects of oil shocks. *Energy Economics*, 34(5), pp.1532–1547.

Romer, P., 1990. Endogenous Technological Change. *Journal of Political Economy*, 98(5), pp.S71–S102.

Senhadji, A., 1999. *Sources of Economic Growth: An Extensive Growth Accounting Exercise*. IMF Working Paper Series, No. WP/99/77. Washington, DC: International Monetary Fund.

Yanikkaya, H., 2003. Trade Openness and Economic Growth: A Cross-Country Empirical Investigation. *Journal of Development Economics*, 72(1), pp.57–89.

[Y] Gross Domestic Product



Purpose, Perspective and Level of Aggregation

The **GDP** sector is, for the most part, an accounting structure based on the System of National Accounts 2008 (UN, 2009). The sector differentiates between **Gross Domestic Product** at basic prices and **Gross Domestic Product** at market prices. **Gross Domestic Product** at basic prices is the sum of **Gross Value Added** at basic prices of each economic activity. Taxes less subsidies on products are then added to arrive at **Gross Domestic Product** at market prices.

The model structure computes **Gross Value Added** in real terms, at constant prices, therefore **Gross Domestic Product** is also first calculated in real terms. It is then calculated in nominal terms based on changes in **Prices**, by applying a deflator.

Gross National Income is calculated based on **Gross Domestic Product** at market prices**,** private factor income and public factor income.

When data is available, the GDP sector accounts for an **Input Output Table**, describing the sale and purchase relationships between producers and consumers within an economy. It shows flows of final and intermediate goods and services defined according to industry outputs (it is an industry × industry table). The effect of demand and supply computed from this subsection is then used to calculate the effects of **Prices** in GDP, through a GDP deflator. Real GDP is computed from real Gross Value Added. We then use the deflator to calculate GDP in nominal terms.

Main Assumptions

- Prices are affected by the ratio between intermediate demand and supply
- The short term capacity utilization of both labor and capital is affected by the ratio between intermediate demand and supply

Main Limitations

One limitation is that only the impact of demand for intermediate consumption on prices is included, the impact of demand for final consumption on prices is not included.

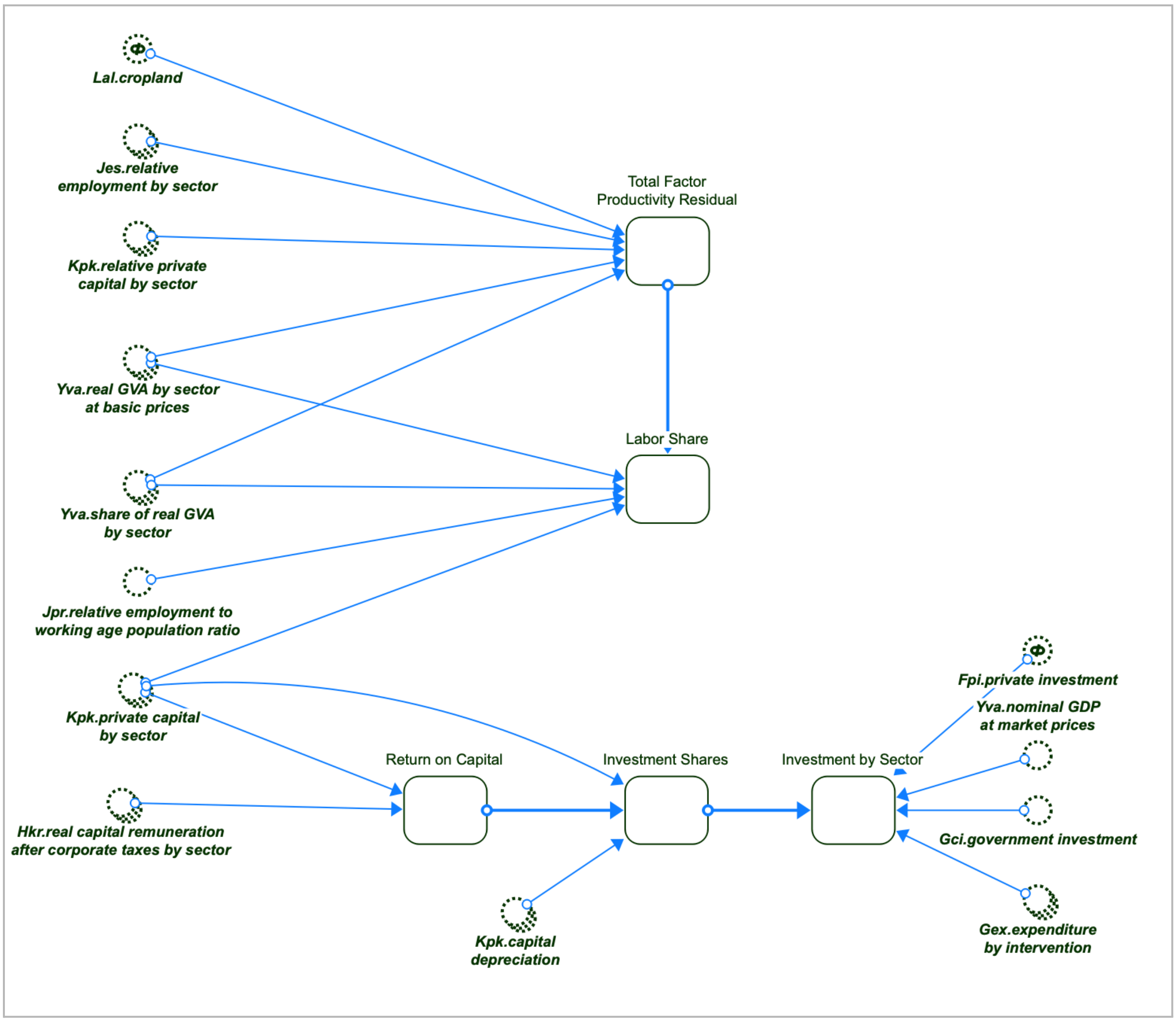
Data Sources

GDP at market prices, GDP at basic prices (nominal/real), Gross national income, deflators- UN Statistics: http://data.un.org/Explorer.aspx.

References

United Nations, European Commission, International Monetary Fund, Organisation for Economic Co-operation and Development, & World Bank. (2009). *System of National Accounts 2008*. New York, NY: United Nations.

[I] Investment



Purpose, Perspective and Level of Aggregation

Investment is the means by which capital in each economic sector can increase. Investment therefore, is a key part of the mechanism driving economic growth in societies and is important to have a structure in the model designated to capture its dynamics. The Investment sector represents the mechanism of allocation of private investment among the production sectors.

The **Investment by Sector** is computed from **Return on Capital** and the **Investment Shares**, which are the shares of investment per activity adjusted for the capital depreciation by sector. Additionally, the sector also computes **Total Factor Productivity Residual** and **Labor Share.**

As for all other economic sectors in the model, the level of aggregation of economic activities is designated by the ISIC4 classification of economic activity.

Main Assumptions

- Investment allocation in each sector depends on the rate of return on investment (Arrow 1964)
- Labor share is a function of total factor productivity and capital-output ratio (ILO 2013, OECD 2012, NBER 2013)

Main Limitations

The first limitation is that ROI is the sole driver of investment shares. Other factors that may influence investment decisions are not included.

The second limitation is that only empirical observations impact the decisions regarding investment shares. In other words, it is assumed that expectations about the future are entirely based on past observations.

Data Sources

Nominal investment by sector, total investment - UN Statistics: http://data.un.org/Explorer.aspx.

References

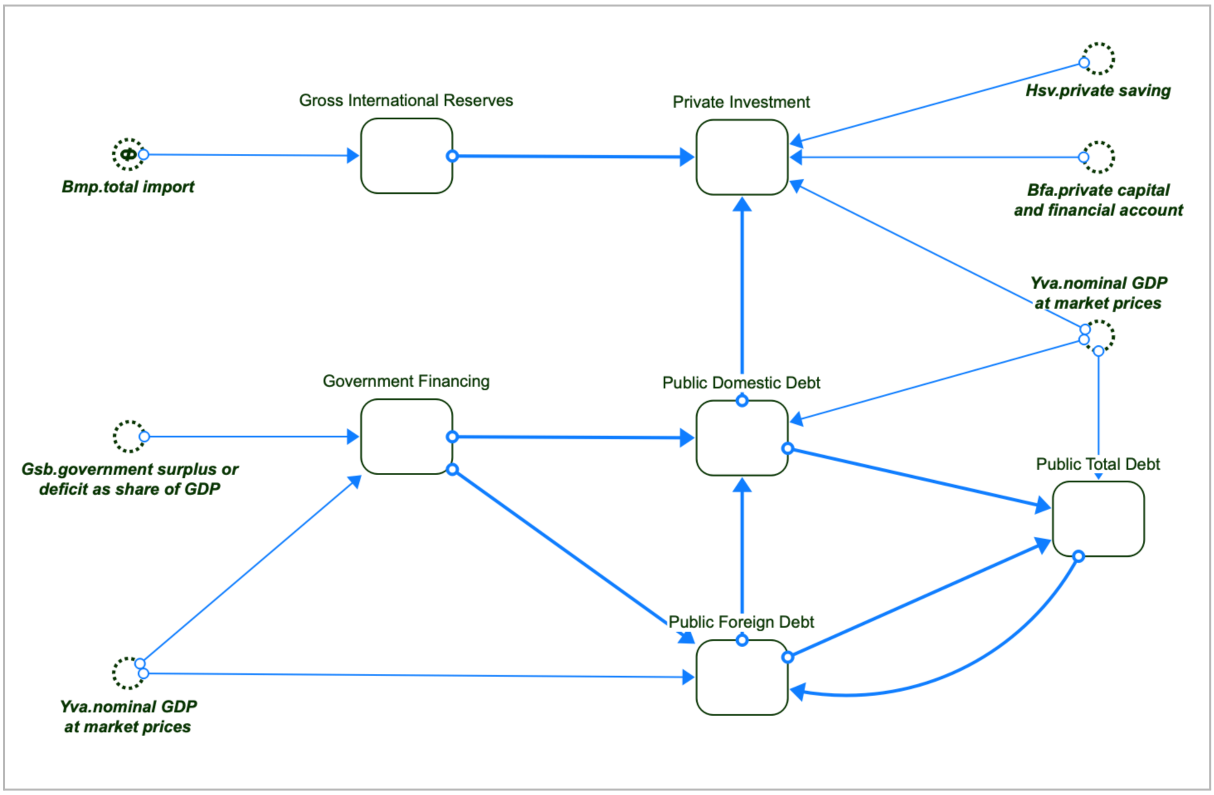
Arrow, K.J., 1964. Optimal capital policy, the cost of capital, and myopic decision rules. *Annals of the Institute of Statistical Mathematics*, 16(1), pp.21–30.

International Labour Organization (ILO), 2013. *Global wage report 2012/13: Wages and equitable growth*. Geneva: International Labour Office.

Karabarbounis, L. and Neiman, B., 2013. *The global decline of the labor share*. NBER Working Paper No. 19136. Cambridge, MA: National Bureau of Economic Research.

Organisation for Economic Co-operation and Development (OECD), 2012. Labour losing to capital: What explains the declining labour share?. *Employment Outlook*. Paris: OECD Publishing.

[F] Finance



Purpose, Perspective and Level of Aggregation

Public debt is an important indicator of economic sustainability. Often, governments require additional public investment to advance their development agendas, but do not want or have the capacity to raise resources through taxation. Financing investment through debt can enable development if well-used, but can lead countries into debt traps if investment does not yield the expected outcomes.

In the Finance sector, the government surplus or deficit is used to compute **Government Financing** needs. From there and considering the cost of capital in international markets as well as expected share of domestic debt, we are able to determine **Public Foreign Debt** and **Public Domestic Debt**. This latter is especially important in determining private investment, as the issue of government bonds absorbs liquidity that could otherwise be used for private investment. Additionally, the accumulation of **Gross International Reserve**s similarly absorbs **private savings** and contribute to the computation of Private Investment.

Public Domestic and Foreign debt are the two categories of aggregation.

Main Assumptions

- The banking system manages the international reserves towards maintaining a given coverage in months of imports (Rodrik 2006)

Main Limitations

The first limitation is that the model structure distinguishes only between the domestic and foreign debt of the general government. The model structure does not distinguish between the debt stocks of the various levels of government, nor does it distinguish between debt by lender, nor does it distinguish between different debt instruments (Dippelsman et al 2012).

The second limitation is that financial assets of the general government are not represented explicitly. Since net financing is directly related to the surplus or deficit of the government, and it consists of changes in both assets and liabilities, it implies that changes in assets must be accounted for when linking changes in liabilities (debt) to government surplus or deficit. While this is accounted for in the model, representing the stock of assets explicitly would ensure a better overview of the financial instruments available for handling deficits. If this is important for specific applications, it can be implemented by representing the flows and stock in assets and liabilities separately.

Data Sources

Figures for the following indicators are sourced from the International Monetary Fund's (IMF) Government Finance Statistics datasets and from the World Bank Group's International Debt Statistics datasets:

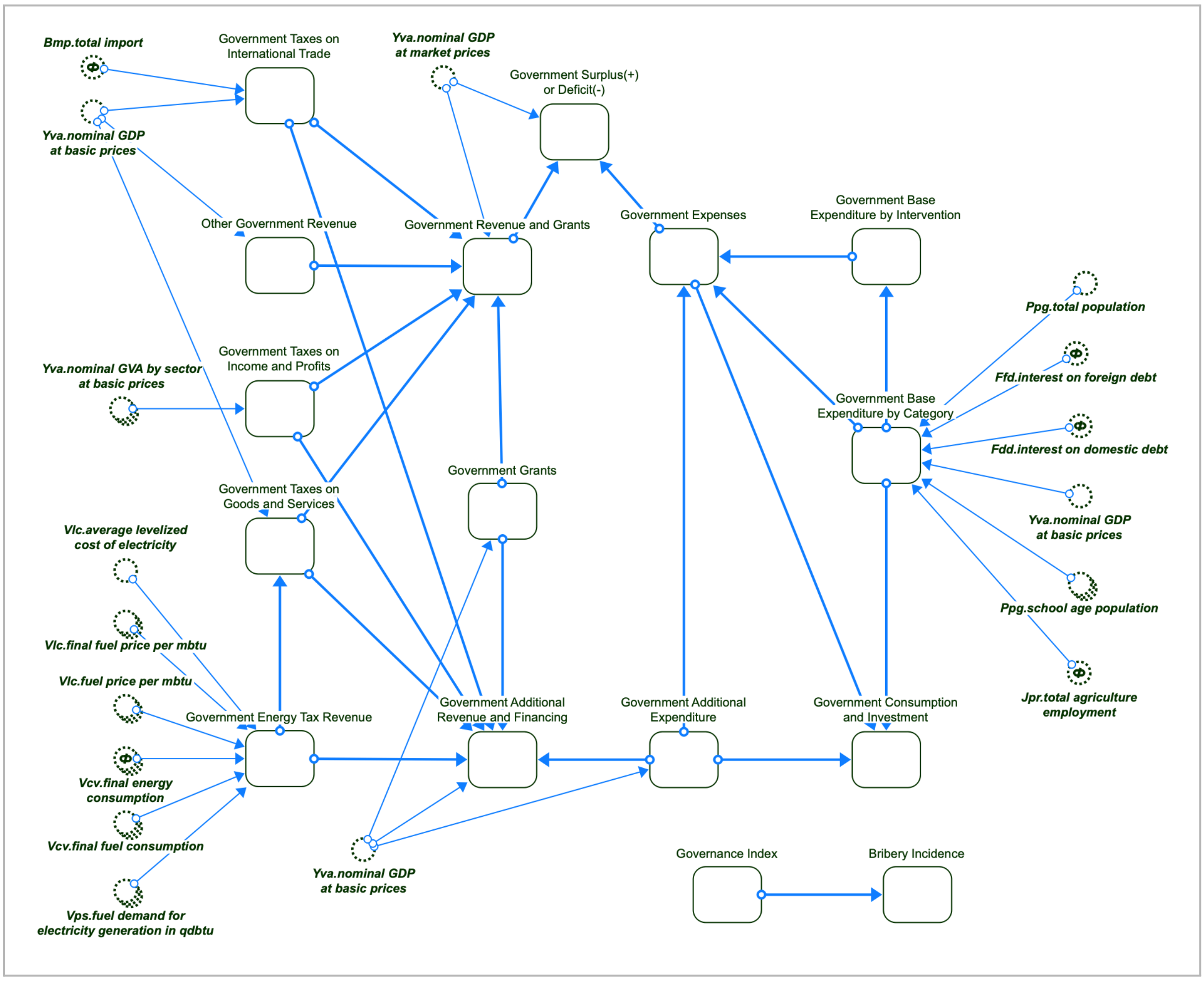
- Foreign public debt
- Domestic public debt
- Interest payments on foreign debt
- Interest payments on domestic debt
- Foreign financing
- Domestic financing

References

Dippelsman, R., Dziobek, C. and Gutiérrez Mangas, C.A., 2012. What lies beneath: The statistical definition of public sector debt. *IMF Staff Discussion Note*, SDN/12/09. Washington, DC: International Monetary Fund.

Rodrik, D., 2006. The social cost of foreign exchange reserves. *International Economic Journal*, 20(3), pp.253–266.

[G] Government



Purpose, Perspective and Level of Aggregation

As a Public Policy simulation tool, the Government sector is one of the most important ones in the model. It is here where the different political scenarios to be simulated are to be characterized, affecting all sectors where public expenditure is engaged.

The Government Sector computes both, **Government Revenue and Grants** as well as **Government Expenses** with the aim of computing the **Government Surplus or Deficit**. Revenue comes from **Government Taxes on International Trade**, **Government Taxes on Income and Profits**, **Government Taxes on Goods and Services**, **Government Energy Taxes Revenue** and **other Government Revenue**. Government Expenses comes from the **Government Base Expenditure by Intervention** and **Government Additional Expenditure,** where the values to be simulated are to be introduced.

The Government Sector uses different levels of aggregation, one is the Expenditure line, that distinguishes 16 main categories of expenditure, namely:

- social benefits and transfers
- administrative etc
- interest payment
- health
- education
- transportation
- energy
- agriculture
- water
- land protection
- marine protection
- adaptation
- waste
- grants
- other
- sanitation

The second level of aggregation is the Interventions, obtained by determining the share of money within a main category of expenditure dedicated to a specific policy. The model identifies 27 fixed interventions and allows for 5 more to be determined by the users (A to E) without having to take care of dimension consistency across the model:

- general education
- general health
- family planning
- general agriculture
- fertilizer subsidies
- water access
- sanitation access
- roads a
- roads b
- railways
- waste management
- land protection
- marine protection
- reforestation
- small photovoltaic
- large photovoltaic
- small hydropower
- large hydropower
- large wind
- large biomass
- vehicles efficiency
- industry energy
- households energy
- water efficiency
- general transfers
- climate adaptation
- agriculture training
- Other A
- Other B
- Other C
- Other D
- Other E

Main Assumptions

- It is possible to calculate the government surplus/deficit and financing in two different ways. By default, government financing is the residual in government accounts, there are no explicit limits to the level of expenditure the government can sustain, and any imbalance in government accounts is always financed through domestic or foreign sources. However, it is possible to reverse this logic to make expenditures the residual, by setting the target level of surplus/deficit. The choice of the closure to be adopted depends on the purpose of the analysis: setting a target surplus/deficit is especially useful when analyzing resources allocation within a fixed budget ceiling; while using financing as residual allows to explore a broad range of revenue and expenditure policies.
- When data is not available, it is assumed that all categories of functional expenditure have the same distributions when considering the cross classification of functional and economic classifications of expenditure - i.e. the expenditure in any two functional categories, such as health or agriculture, would be distributed the same way across the economic categories, such as compensation of employees or use of goods and services. This implies that the capital intensity of expenditures will be

overestimated or underestimated for some functional expenditure categories.

- It is assumed that none of the functional expenditure categories include outgoing grants, interest payments or social benefits and transfers in cash paid by the general government. Outgoing grants, interest payments, and social benefits and transfers in cash are represented as functional expenditures.
- World Government Indicators are used as a proxy for the level of governance in a country (Kaufmann et al 2010)

Main Limitations

In the model, the Government Accounts and National Accounts are linked. The government final consumption expenditure is approximated by compensation of employees, plus the use of goods and services plus social benefits in kind (IMF 2001). The sales of goods and services, the purchases for direct transfer to households other than social benefits in kind, and the consumption of fixed capital is excluded from this approximation. Additionally, subsidies are also included under government consumption, even though it is not a consumption item. This is because the impacts that functional expenditures have on economic outcomes are greater when those functional expenditures grow, regardless of whether they are subsidies or not. Thus, it is a simplifying assumption in the model structure, in lieu of regularly available data at the granularity required for more detailed structures explicitly representing subsidies. As a result, the approximation for government final consumption expenditure may differ from the values found in the National Accounts datasets.

Data Sources

Figures for the following indicators are sourced from the International Monetary Fund's (IMF) Government Finance Statistics datasets and World Economic Outlook dataset:

- Government revenues and its breakdown:
    - Taxes on income, profits and capital gains
    - Taxes on goods and services
    - Taxes on international trade
    - Grants
    - Other government revenue
- Government expenditure and its breakdown:
    - Use of goods and services
    - Subsidies
    - Compensation of employees
    - Grants
    - Interest payments

    - Social benefits and transfers (cash/in-kind)
    - Gross capital formation
- Government surplus(+) or deficit(-)
- Government expenditure by function of government (COFOG):
    - Agriculture
    - Education (by level of education)
    - Energy
    - Health
    - Sanitation
    - Transport
    - Waste management
    - Water supply

Additional expenditure figures in the Education sector by level of education are sourced from UNESCO Institute of Statistics.

Figures on governance indicators are sourced from the Worldwide Governance Indicators (WGI) dataset.

Figures on bribery incidence are sourced from the World Development Indicators (WDI) dataset.

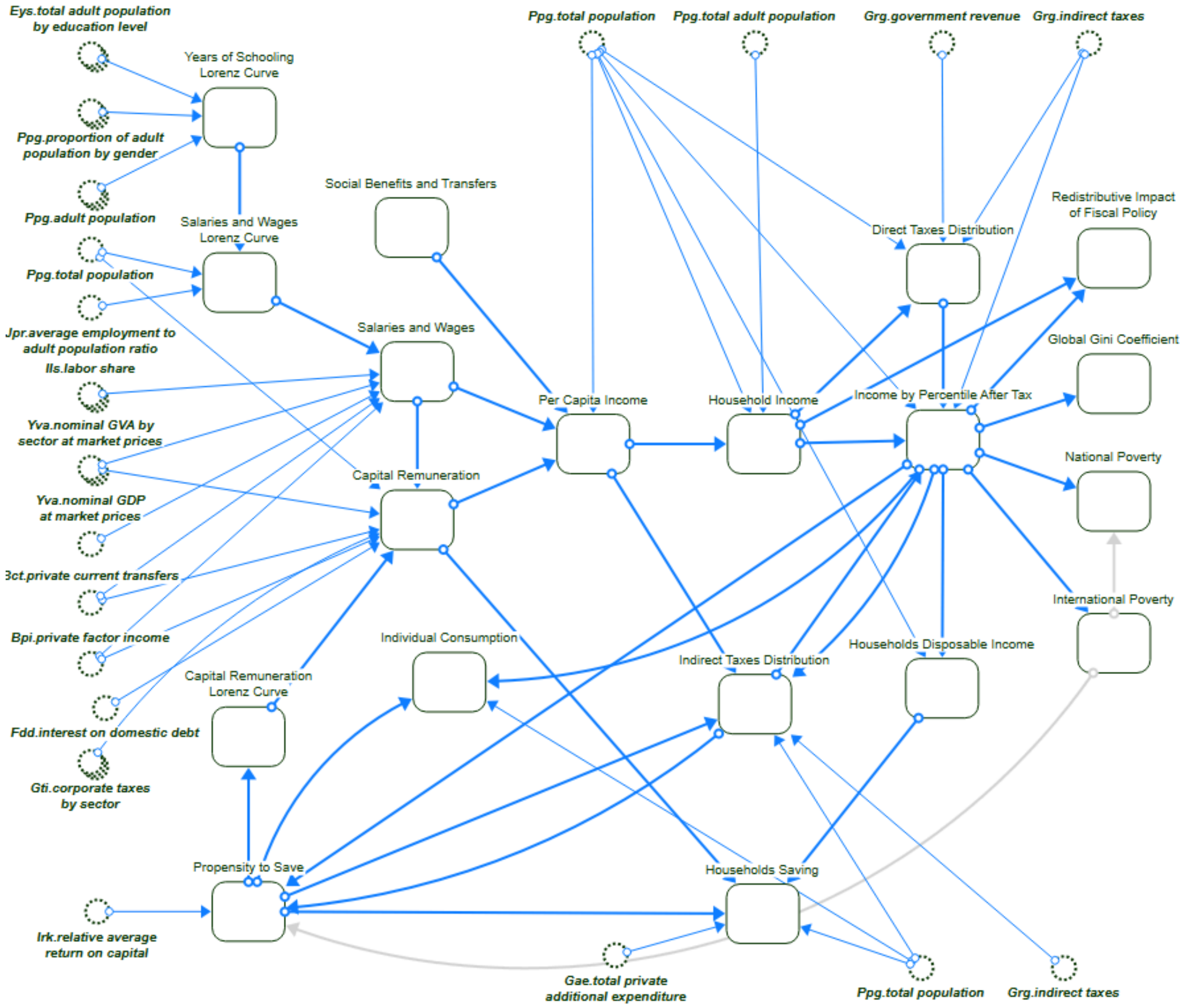
References

International Monetary Fund, 2001. *Government finance statistics manual 2001*. Washington, D.C.: International Monetary Fund.

International Monetary Fund, 2014. *Government finance statistics manual 2014*. Washington, D.C.: International Monetary Fund.

Kaufmann, D., Kraay, A. and Mastruzzi, M., 2010. The Worldwide Governance Indicators: Methodology and analytical issues. *World Bank Policy Research Working Paper*, No. 5430.

[H] Households



Purpose, Perspective and Level of Aggregation

The households sector accounts for households' income and savings, poverty and other inequality measures like the Gini coefficient to account for income distribution. It is therefore a paramount indicator of development at the national level.

The Households Sector computes **Per Capita Income** and **Household Income** from **Salaries and Wages, Capital Remuneration** and **Social Benefits**. Then, using **Direct Tax Distribution** and **Indirect Tax Distribution**, **Income by Percentile After Tax** and **Household Disposable Income** is calculated. Based on these dynamics, the sector additionally calculates **Households Savings** and **Individual Consumption,** disaggregated by SNA 93 categories. These variables are further used to assess measures of inequality and poverty such as the **Global Gini Coefficient,** the proportion of population under national and international poverty lines and outcomes thereof in terms of Access to Education and Health.

The level of aggregation used in the variables of this sector is the percentiles of Income distribution.

Main Assumptions

- Per capita income level affects the propensity to save (Dynan et al., 2004)
- Average return on investment affects the propensity to save (Arrow, 1964)
- The distribution of salaries and wages are primarily influenced by the distribution of education across the population (World Bank, 2007; Tilak, 1989)
- The distribution of capital remuneration is an exponential lag of the saving distribution (Dobrinski, 2005; Deaton, 1999)
- Part of private factor income (proportional to the share of salaries and wages over total GDP) is distributed based on education distribution; the rest based on capital distribution (Rima, 2009)
- Part of private current transfers (proportional to the share of salaries and wages over total GDP) is distributed based on education distribution; the rest based on capital distribution (Shreshta, 2012)
- Individual Consumption calculates categories shares according to an initial value, and then applies an elasticity to determine income variation across percentiles.

Main Limitations

The assumption that households with higher income have both higher levels of salaries and higher level of financial assets, implies a more unequal distribution than could be the case in reality. For instance, circumstances of high-income households that do not receive any salary compensation are not accounted for in the model, although such situations can be addressed by introducing a cross-percentile income mixing factor, if necessary.

Data Sources

The following indicators are sourced the World Development Indicators (WDI) dataset:

- Gini coefficient
- Income share by quintile
- Poverty headcount ratio at national poverty line
- Poverty headcount ratio at $2.15 a day (2017 PPP) (international poverty line)
- Price level ratio of PPP conversion factor (GDP) to market exchange rate

References

Arrow, K.J., 1964. Optimal capital policy, the cost of capital, and myopic decision rules. *Annals of the Institute of Statistical Mathematics*, 16(1), pp.21–30.

Deaton, A., 1999. Saving and growth. In: K. Schmidt-Hebbel and L. Servén, eds. *The Economics of Saving and Growth: Theory, Evidence, and Implications for Growth*. Cambridge, UK: Cambridge University Press.

Dobrinski, R., 2005. *Domestic savings and the driving forces of investment in the ECE developing market economies*. Occasional Paper No. 4. Economic Commission for Europe.

Dynan, K.E., Skinner, J. and Zeldes, S.P., 2004. Do the rich save more? *Journal of Political Economy*, 112, pp.397–444.

Pedercini, M. and Qureshi, M.A., 2010. A resource-based approach to the modeling and simulation of income distribution: The case of Pakistan. *Journal of Income Distribution*, 19(3–4), pp.68–86.

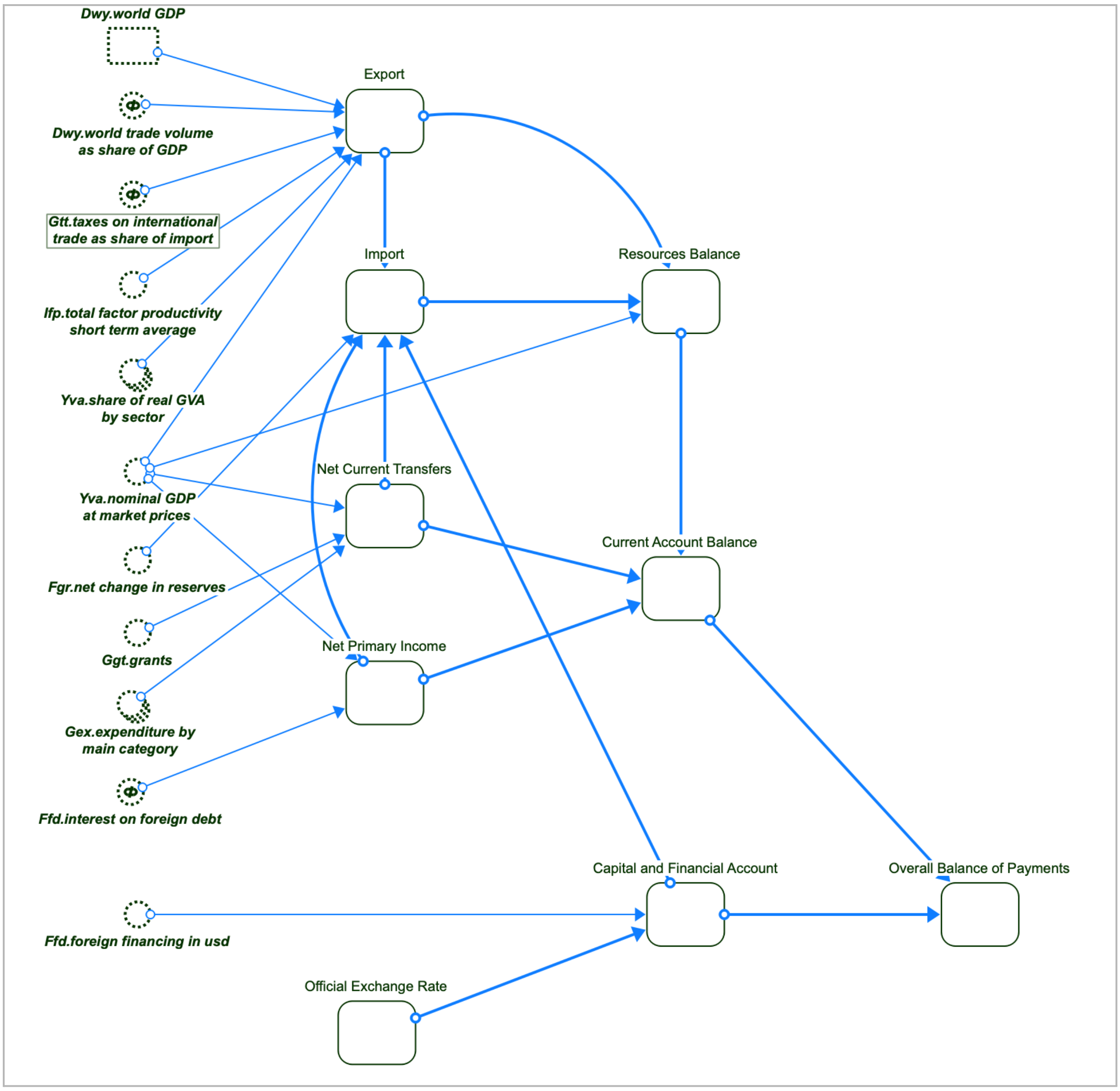
Rima, I., 2009. *Development of Economic Analysis*. 7th ed. New York: Routledge.

Shrestha, M., Min, R. and Fassler, S., 2012. *An Integrated Framework for Financial Positions and Flows on a From-Whom-to-Whom Basis: Concepts, Status, and Prospects*. IMF Working Paper WP/12/57. Washington, DC: International Monetary Fund.

Tilak, J.B.G., 1989. *Education and its relation to economic growth, poverty, and income distribution: Past evidence and further analysis*. World Bank Discussion Paper 46. Washington, DC: World Bank.

World Bank, 2007. *Income distribution, inequality, and those left behind*. *Global Economic Prospects*. Washington, DC: World Bank.

[B] Balance of payments



Purpose, Perspective and Level of Aggregation

The Balance of Payments sector accounts for the balance in international trade, which influences the strength of the local currency and the confidence investors deposit in a country's economy.

Export is computed from the initial total export share of GDP adjusted by a set of factors such as productivity, taxes on international trade and the health of the world economy. **Import** is computed as the residual value from subtracting net change in reserves from the addition of exports, net current transfers, net primary income and capital and financial account balance. **Resources Balance** can be then computed from Export and Import, and then **Current Account Balance** can be also computed by adding to the Resources Balance the **Net Primary income** and the **Net Current Transfers**. By adding to the **Current**

Account Balance again the **Capital and Financial Accoun**t, we obtain the **Overall Balance of Payments**.

The data in this sector is aggregated at the highest possible level, with no distinction between different economic activities but for the economy as a whole.

Main Assumptions

- Level of productivity affects amount of export as share of GDP (Wagner, 2007)
- Taxes on international trade affect the amount of export as share of GDP (Santos-Paulino, 2004)
- Only major items of the categories of flows from the IMF balance of payments manual are considered (IMF, 2008)

Main Limitations

Although the sector covers all major categories of the balance of payments, it does not include all items of cross-border financial flows, but only the major flows that are relevant to the other sectors of the model. For instance, in the public capital financial account we only account for foreign financing, a key flow in the finance sector. Similarly, among public current transfers, we only consider grants.

Data Sources

The following indicators are sourced from the International Monetary Fund's (IMF) Balance of Payments dataset:

- Annual average exchange rate
- Net primary income
- Net capital account
- Net financial account

References

International Monetary Fund (IMF), 2008. *Balance of payments and investment position manual*. Washington, D.C.: International Monetary Fund.

Santos-Paulino, A. and Thirlwall, A.P., 2004. The impact of trade liberalization on exports, imports and the balance of payments of developing countries. *The Economic Journal*, 114(493), pp.F50–F72.

Wagner, J., 2007. Exports and productivity: A survey of the evidence from firm-level data. *The World Economy*, 30(1), pp.60–82.

Appendix I: List of Modules and Prefixes

Access to Basic Services [A]	**Finance [F]**	**Investment [I]**
Access to Electricity [Ael]	Government Financing [Fgf]	Investment by Sector [Ibs]
Access to Internet [Ait]	Gross International Reserves [Fgr]	Investment Shares [Ins]
Access to Water and Sanitation [Aws]	Private Investment [Fpi]	Labor Share [Ils]
Population Living in Slums [Asl]	Public Domestic Debt [Fdd]	Return on Capital [Irk]
Public Sanitation Capacity [Asc]	Public Foreign Debt [Ffd]	Total Factor Productivity Residual [Ifp]
Public Water Capacity [Awc]	Public Total Debt [Ftd]	**Land [L]**
Balance of Payments [B]	**Firms [K]**	Agriculture land allocation [Lal]
Capital and Financial Account [Bfa]	Agriculture Gross Output [Kao]	Agriculture land demand [Lad]
Current Account Balance [Bca]	Biophysical Productivity Drivers [Kbd]	Land protection [Lpr]
Export [Bxp]	Economic Productivity Drivers [Ked]	Land Use [Lus]
Import [Bmp]	Extractive Industries Output [Kei]	Red List Index [Lrl]
Net Current Transfers [Bct]	Gross Value Added [Kva]	Reforestation [Lrf]
Net Primary Income [Bpi]	Productive Capital [Kpk]	Settlement Land Demand [Lsl]
Official Exchange Rate [Bfx]	Social Productivity Drivers [Ksd]	**Material Flows [M]**
Overall Balance of Payments [Bop]	**Government [G]**	Construction and Other Industry Mat. Extraction [Mie]
Resources Balance [Brb]	Bribery Incidence [Gbi]	Crops Material Extraction [Mce]
Buildings [U]	Governance Index [Ggi]	Fish Material Extraction [Mfe]
Buildings Energy Consumption [Uec]	Government Additional Expenditure [Gae]	Forest Material Extraction [Mwe]
Floor space [Ufs]	Government Additional Revenue and Financing [Gra]	Fossil Fuel Extraction [Mee]
Transmittance [Uvl]	Government Base Expenditure by Category [Gec]	Industry Material Efficiency [Mif]
Climate [C]	Government Base Expenditure by Intervention [Gei]	Material Footprint [Mfp]
Climate Adaptation Capital [Cak]	Government Consumption and Investment [Gci]	Metal Ores Extraction [Moe]
Climate Economic Damage [Ced]	Government Energy Tax Revenue [Gte]	Pasture Material Extraction [Mpe]
Droughts [Cdr]	Government Expenses [Gex]	Total Material Extraction [Mte]
Health Impact of Natural Disasters [Cdi]	Government Grants [Ggt]	Waste Management [Mwm]
Health Impact of Climate Change [Chi]	Government Revenue and Grants [Grg]	**Nutrition [N]**

Heating degrees days [Chd]	Government Surplus[+] or Deficit[-] [Gsb]	Calories Production [Ncp]
Natural Disasters [Cnd]	Government Taxes on Goods and Services [Gtg]	Food Poverty [Nfp]
Precipitation [Cpr]	Government Taxes on Income and Profits [Gti]	Overweight [Now]
Temperature Change [Ctc]	Government Taxes on International Trade [Gtt]	**Oceans [O]**
Dashboard [D]	Other Government Revenue [Gor]	Fish Resources [Ofr]
Conversion Parameters [Dcp]	**GDP [Y]**	Marina Areas Protection [Omp]
Country Identification [Dci]	Gross Domestic Product [Yva]	**Population [P]**
Education Consistency Checks [Dec]	Gross National Income [Yni]	Contraception [Pcn]
Energy Consistency Checks [Dvc]	Input Output Table [Yio]	Desired Number of Children [Pdc]
Financial Consistency Checks [Dfc]	Prices [Ypr]	Family Planning [Pfp]
Income Consistency Checks [Dic]	**Health [R]**	Fertility Distribution by Age [Pfd]
Initialization [Din]	Access to Basic Healthcare [Rba]	Life Expectancy [Ple]
Interface Switches [Dis]	Exposure to PM 2.5 [Rpm]	Migration [Pmg]
Population Consistency Checks [Dpc]	Health Expenditure Coverage [Rec]	Population [Ppl]
Production Shock [Dps]	Health Impact of Access to Electricity [Rae]	Population by Area [Ppa]
Scenario Control [Dsc]	Health Impact of Access to Water and Sanitation [Rws]	Population Groups [Ppg]
Subscript Handlers [Dsh]	Health Impact of Fertility Rate [Rtf]	Total Fertility Rate [Ptf]
Tables for Export [Dte]	Health Impacts of Overweight [Rio]	Total Mortality Rates [Ptm]
Time Control [Dtc]	Health Impacts of PM 2.5 Exposure [Rpe]	Unmet Need for Family Planning [Pun]
World GDP [Dwy]	Health Impacts of Violence [Rvi]	**Primary Production [Q]**
Education [E]	Initial Mortality Rates [Rim]	Attainable Yield [Qay]
Education Access by Income [Eai]	Mortality GDP Index [Rgi]	Crops Production in Tonnes [Qcp]
Education Dropout [Edr]	Mortality Rates by Cause [Rmr]	Feed Consumption [Qfd]
Education Enrollment [Enr]	Road Fatalities [Prf]	Fish Capture in Tonnes [Qfc]
Education Expenditure [Eex]	**Households [H]**	Fish Harvest in Tonnes [Qfh]
Education Gender Bias [Egb]	Capital Remuneration [Hkr]	Food Production [Qfp]
Initial Education Distribution [Eid]	Capital Remuneration Lorenz Curve [Hkl]	Forest Production in Cubic Meters [Qfm]
Population by Education Level [Epl]	Direct Taxes Distribution [Hdt]	Livestock Production in Tonnes [Qlp]
Private Education [Epe]	Global Gini Coefficient [Hgn]	**Soil [S]**
Public Education Capacity [Edc]	Household Income [Hin]	Crop nutrient uptake [Snu]
Years of Schooling [Eys]	Households Disposable Income [Hdi]	Mineral fertilization [Smf]
Emissions [X]	Households Saving [Hsv]	Natural nutrient inflow [Sni]
Co2 Emissions [Xco]	Income by Percentile After Tax [Hia]	Natural nutrient loss [Snl]
Emissions from Land Use Change [Xlc]	Indirect Taxes Distribution [Hit]	Nutrient acquisition probability [Sna]
Ghg Emissions [Xgh]	Individual Consumption [Hic]	Nutrient balance [Snb]
Non Energy Agriculture Emissions [Xan]	International Poverty [Hip]	Sustainable land management [Sim]
PM 25 Emissions [Xpm]	National Poverty [Hnp]	**Transport [T]**
Employment [J]	Per Capita Income [Hpi]	Functioning Infrastructure [Tfi]

Capital Labor Ratio [Jkr]	Propensity to Save [Hps]	Goods Mobility [Tgm]
Employment by Sector [Jes]	Redistributive Impact of Fiscal Policy [Hri]	Infrastructure Construction Budget [Tib]
Employment Population Ratio [Jpr]	Salaries and Wages Lorenz Curve [Hsl]	Infrastructure Density [Tid]
Gender Gap in Employment [Jgg]	Salaries and Wages [Hsw]	Infrastructure Maintenance [Tim]
Government Employees [Jgv]	Social Benefits and Transfers [Hsb]	Infrastructure Use [Tiu]
Land Labor Ratio [Jlr]	Years of Schooling Lorenz Curve [Hys]	People Mobility [Tpm]
Youth Not in Education Employment or Training [Jne]	**Indicators [Z]**	Public Infrastructure Expenditure [Tie]
Energy [V]	Emissions Indicators [Zei]	Road Vehicles Park [Tvp]
Electricity Generation [Vgn]	Energy Indicators [Zvi]	Vehicles efficiency [Tve]
Electricity Generation Capacity [Vgc]	Government Accounts Indicators [Zgi]	Vehicles Fuel Consumption [Tvc]
Energy Bill [Vbl]	Human Development Index [Zhd]	Vehicles Use [Tvu]
Energy Productivity Impact [Vpi]	Land Use Indicators [Zli]	**Water [W]**
Final Energy Consumption by Sector [Vcs]	Material Consumption Indicators [Zmi]	Agriculture water withdrawal [Waw]
Final Energy Consumption by Vector [Vcv]	Planetary Boundaries [Zpb]	Efficient irrigation [Wei]
Final energy price [Vfp]	Poverty Indicators [Zpi]	Industry and domestic water withdrawal [Wiw]
Households Energy Saving [Vhs]	Production and Employment Indicators [Zyj]	Irrigated area [Wia]
Indicated Electricity Capacity [Vic]	SDG Indicators [Zsd]	Water acquisition probability [Wap]
Industry Energy Saving [Vis]	Statistics of Fit [Zsf]	Water supply [Wsp]
Levelized Cost of Electricity [Vic]	Unit Cost Indicators [Zuc]	
Primary Biomass Energy [Vpb]		
Primary Energy Import [Vpm]		
Primary Energy Production [Vpp]		
Primary Energy Supply [Vps]		
Public Electricity Capacity Construction [Vpc]		
Reference Energy Intensity [Vri]		

Appendix II: Model Disaggregation and Elements

Activity	**extractive industry**	**other infrastruture**
A01 - Agriculture	B05 - coal and lignite	power
A02 - Forestry	B06 - crude petroleum and natural gas	water
A03 - Fishing	B07 - metal ores	
B 05–09 Mining and quarrying	B08 - other mining and quarrying	**ownership**
C 10–33 Manufacturing		private
D 35 Electricity, gas, steam and air conditioning supply	**final energy**	public
E 36–39 Water supply; sewerage, waste management etc.	OIL	
F 41–43 Construction	GAS	**percentiles**
G 45–47 Wholesale and retail trade; repair of motor vehicles etc.	COAL	P1 - P100
H 49–53 Transportation and storage	BIO	
I 55–56 Accommodation and food service activities	ELE	**planetary boundaries**
J 58–63 Information and communication	HEAT	life satisfaction
K 64–66 Financial and insurance activities		life expectancy

L 68 Real estate activities	**final fuel**	nutrition
M 69–75 Professional, scientific and technical activities	OIL	sanitation
N 77–82 Administrative and support service activities	GAS	income poverty
O 84 Public administration and defence; compulsory social security	COAL	energy access
P 85 Education	BIO	secondary education
Q 86–88 Human health and social work activities		social support
R 90–93 Arts, entertainment and recreation	**fish**	democratic quality
S 94–96 Other service activities	fish 1	equality
T 97–98 Activities of households as employers etc.		employment
U 99 Activities of extraterritorial organizations and bodies	**generation**	co2 emissions
	OIL	phosphorus
adaptation	GAS	nitrogen
other	COAL	land change
government and social infrastructure	HYDRO	ecological footprint
business and tourism	WIND	material footprint
forests and ecosystems	SOLAR	fresh water
extreme weather and disaster risk	NUCLEAR	
human health	BIO	**policy year**
coastal and marine resources		2025- 2050
infrastructure energy and settlement	**governance**	
water and floods	RQ	**quintiles**
agriculture and fisheries	CC	qnt 1
	GE	qnt 2
adult age	VA	qnt 3
age 15 - age 100 & over	RL	qnt 4
	PS	qnt 5
age		
age 0 - age 100 & over	**industry (activity code)**	**renewable**
	B	HYDRO
age group	C	WIND
age group 0 to 4	D	SOLAR
age group 5 to 9	E	BIO
age group 10 to 14	F	
age group 15 to 19		**roads**
age group 20 to 24	**infrastructure**	roads a
age group 25 to 29	roads a	roads b
……..	roads b	
age group 100 and over	rail	**sdg**
	electricity	sdg 1 - sdg 17
agriculture land	water	
cropland		**sdg i**
pasture land	**intervention**	i 010101 - i 171902
	general education	
agriculture	general health	**sdg target**
A01 - Agriculture	family planning	t 0101 - t 1719
A02 - Forestry	general agriculture	
A03 - Fishing	fertilizer subsidies	**services (activity code)**
	water access	G - U
area	sanitation access	
rural	roads a	**sex**
urban	roads b	FEMALE
	railways	MALE
building	waste management	
residential	land protection	**SSP**
non residential	marine protection	SSP1 19
	reforestation	SSP1 26
centralization	small photovoltaic	SSP2 45
centralized	large photovoltaic	SSP3 70

decentralized	small hydropower	SSP5 85
	large hydropower	
childbearing age	large wind	**transport distance**
age 12 - age 54	large biomass	short
	vehicles efficiency	medium
consumption category	industry energy	long
conscat 1 - 12	households energy	
	water efficiency	**transport mode**
crop	general transfers	Air
crop 1	climate adaptation	Rail
crop 2	agriculture training	Public rubber
	Other A	Private rubber
education	Other B	Shared rubber
E0- no educational attainment	Other C	Active
E1- started primary education	Other D	Water
E2- completed primary education	Other E	
E3 - started secondary education		**vehicle**
E4- completed secondary education	**kpi**	passenger cars
E5- started tertiary education	kpi 1	freight and bus
E6- completed tertiary education	kpi 2	
	kpi 3	vehicle age
energy		age 0 - age 30
OIL	**land transport infra**	
GAS	roads a	**voters group**
COAL	roads b	vg 1
HYDRO	rail	vg 2
WIND		vg 3
SOLAR	**land transport mode**	vg 4
NUCLEAR	Rail	vg 5
BIO	Public rubber	vg 6
ELE	Private rubber	
HEAT	Shared rubber	**wood**
		wood 1
energy demand	**livestock**	
agr	animal 1	**working age**
ind		age 15 - age 70
ser	**mortality**	
res	aids	
tra	diarrhoeal	
oth	parasitic and vector	
	respiratory	
engine	maternal	
ic	neonatal	
ev	nutritional	
	neoplasms	
expenditure line	diabetes	
social benefits and transfers	cardiovascular	
administrative etc	road	
interest payment	violence	
health exp	other	
education exp		
transportation exp	**nutrient**	
energy exp	N	
agriculture exp	P	
water exp	K	
land protection exp		
marine protection exp		
adaptation exp		
waste exp		

grants		
other exp		
sanitation exp		