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SYSTEMS ANALYSIS FOR SUSTAINABLE WELLBEING

50 years of IIASA research, 40 years after the Brundtland Commission, contributing to the post-2030 Global Agenda

CONTENTS

CHAPTER 05. GLOBAL SYSTEMS ANALYSIS FOR UNDERSTANDING THE DRIVERS OF SUSTAINABLE WELLBEING

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5.1 A short history of global systems modeling (at IIASA)

The golden days of global systems modeling

At the same time as systems theory was being developed in the 1950s and 1960s,[1] Jay Forrester embarked on the endeavor of modeling the dynamics of management, industrial, and urban systems, culminating in the development of the World1 and World2 Earth systems models.[2] These formed the basis of the World3 model, developed by Dennis Meadows, Donella Meadows, Jorgen Randers, and William Behrens III, which underpins the Club of Rome's influential study on *Limits to Growth*[3] and, in updated and extended versions, the follow-up studies *Beyond the Limits*[4] and *Limits to Growth—The 30 Year Update*.[5] The original World3 model includes five modules: i) population and ii) capital, as stocks, which exhibit potentially exponential growth subject to feedback from the other sectors—iii) agriculture, iv) pollution, and v) non-renewable resources—which are subject to limited, or in the case of non-renewables, negative growth. One core conclusion was that the then current trends in population growth and capital accumulation were unsustainable in the light of limited resources but that these trajectories could be changed to sustainable ones, if an early enough policy change were to be instigated. This conclusion was subsequently criticized for wrongly "predicting" resource exhaustion (although prediction was never the intention) at much too early a date. Many of these issues were addressed in updated versions of the model to incorporate emerging environmental, economic, and social trends.[4,5]

Many other systems models of increasing degrees of realism and complexity have been developed since these early days of global systems modeling.[6] At IIASA, the Wonderland model, the PEDA model (see Boxes 5.2 and 5.3), and the FeliX model (discussed in detail in Section 5.3) are just a few examples.

Box 5.1. World systems models

By Brian Fath

A model is a tool, a simplification of reality, to describe key aspects that are deemed relevant to addressing the question at hand. While models can be exploratory, having a clear identification of their purpose will help guide the model development. The first challenge is to pull out those interesting features within a requisite system boundary, leaving other parts of the environment as exogenous: in other words, to determine what is endogenous to the model and what is exogenous. The model will continue interacting and exchanging with its environment through connections carrying inflow and outflow across the system boundary. One consideration for the model is to include enough of the original system to capture the feedback and self-organizing processes inherent in all complex, adaptive systems, typically in terms of production, consumption, and reuse, as seen in an ecological food web model, industrial metabolism, or a socioeconomic system. In that context, a model utilized in systems analysis should not be too narrow in scope.

Any model must carefully consider the dimensions of space and time. The spatial extent is largely informed by the question at hand. Clearly, a global model would include processes and feedbacks spanning the planet's socioeconomic–ecological systems. For example, the first world models, such as World3, included the following subsystems: i) food, ii) industrial, iii) population, iv) non-renewable resources, and v) pollution.

An updated version of such a world model might include additional emphasis on biodiversity and ecosystem services, urban systems and metabolism, governance, and equity. Regarding the temporal dimension, a system dynamics model can simulate into the future, but the time horizon is always constrained by the clarity with which the system processes are known and modeled, and the largely unknown probability that the system switches into a new regime, therefore making the past an unreliable predictor of the future. It is thus more reasonable and appropriate not to see the model simulation outcome as a prediction per se, but as a set of possible scenarios. Or conversely, one can begin with a desirable outcome and back-cast the inputs and decisions likely to reach it, which is a common approach in models involving climate targets.

IIASA has carved out a space dealing with problems that are universal or global, and developing and applying models accordingly. Universal issues are ones that lie within national boundaries, but with which each nation has to deal, for example, education, health care, biodiversity, water supply, housing, etc. Global issues are ones that cross international borders and require global collaboration, for example, energy, climate, food supply, satellite technologies, management of the commons, regulating ecosystem services, etc. In such areas, international cooperation is an important tool for easing tensions by promoting and enhancing science diplomacy.

Finally, a hallmark of systems thinking and system dynamicss models is the goal of capturing causal processes and feedbacks that can lead to better anticipation and possibly avoid or lessen unintended consequences. History is littered with good intentions that went awry due to having too narrow a scope and too myopic a vision—it is not a stretch to say that all current environmental problems are the result of yesterday's solutions, from climate change to ozone depletion to eutrophication. Systems models are the one tool that provides insight, training, and some heuristics to balance and counter this reductionism and promote better decision-making.

Box 5.2. The Wonderland model

By Warren C. Sanderson

The Wonderland model is a global model of the interactions among population, economic development, the environment, and environmental policy. I created this model at IIASA in 1994 to study the processes through which the Earth's environment could collapse, resulting in the loss of a substantial number of human lives.[7]

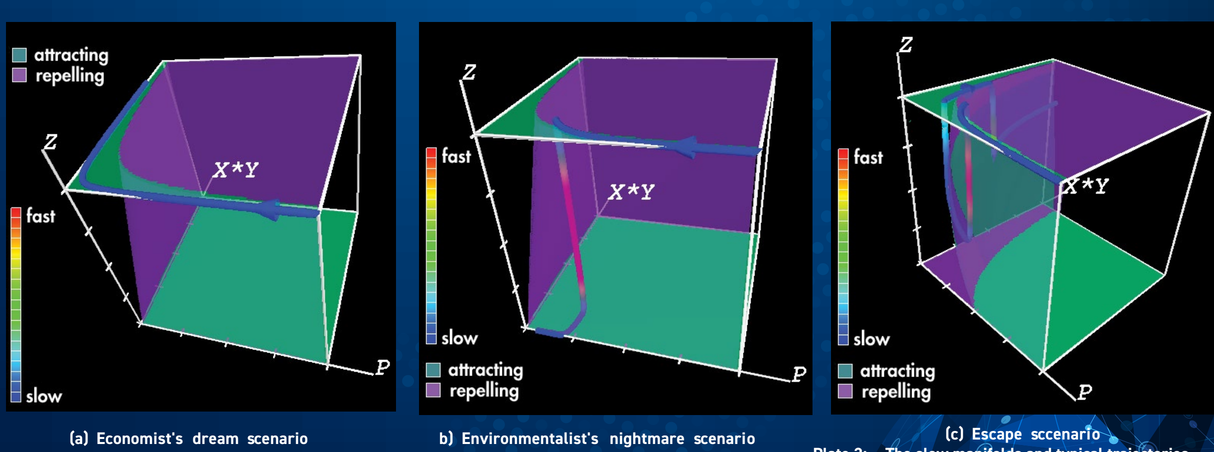
The Wonderland model is extremely simple by design, concentrating on the structure of processes that could lead to an environmental collapse. It is not meant to be predictive. It has only eight equations: two describing an economy affected by environmental conditions, three describing population dynamics and how they are related to environmental conditions, two related to the flow of pollution and how the environment reacts to it, and one related to the costs of policies designed to improve the environment.

Studies of the Wonderland model have elucidated some of its most important analytic features.[8,9] Environmental collapse in Wonderland seemed unpredictable, and two papers investigated that unpredictability. They found analytic expressions for the level of pollution at which environmental stability was lost and the environment would begin to deteriorate, for the time between the loss of environmental stability and the onset of an environmental collapse, and for the level of pollution at the onset of the environmental collapse. These analytic expressions have important implications for understanding environmental collapse. First, when the level of pollution becomes high enough, the environment changes from being stable to unstable. Second, there can be a very long lag between the loss of environmental stability and the onset of an environmental collapse. This period makes the management of environmental problems difficult because during this period, pollution flows can continue to increase with only minor changes in the environment. Third, the level of pollution at the onset of an environmental collapse could be considerably higher than the level of pollution at which the environment first becomes unstable. Reducing pollution at the onset of an environmental collapse to a level consistent with stability may be physically or economically impossible.

An expanded version of the Wonderland model has been used in policy analysis.[10] This version parameterizes it for two regions, OECD and non-OECD countries, adds policymakers with utility functions incorporating environmental quality and economic growth, and parameters relevant for policymaking. Using uncertain model parameters, static and dynamic strategies are developed, which are tested over scenarios similar to the current Shared Socioeconomic Pathways. Three short-run strategies, labeled "Stay the Course," "Slight Increase," and "Crash Effort," have been evaluated. None of these did very well. A dynamic strategy labeled "Safety Valve," which is a two-period strategy where the initial strategy is evaluated at a fixed time in the future and a second strategy is then employed making use of what was learned, did the best. Even using the "Safety Valve" strategy, there are situations where an environmental collapse would still occur.

The Wonderland model supports the application of the precautionary principle in environmental policy. The model shows that rapid degradation in the environment can occur after many years of benign-seeming changes. Policies to avoid environmental collapses must be taken prior to the observation of a strong signal that the speed of environmental deterioration is increasing.

Figure 5.1. **Visualization of the Wonderland model: The slow manifolds and typical trajectories**



Note. Source: Gröller et al. (1995).[11]

Box 5.3. The PEDA model, quantifying "vicious circle" dynamics

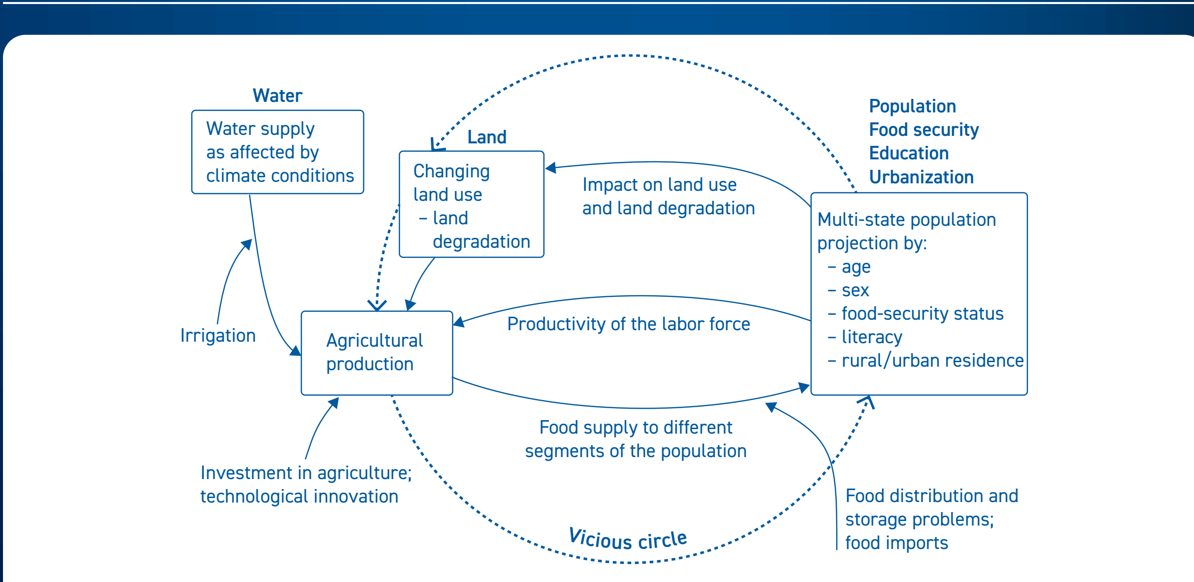
By Wolfgang Lutz

PEDA stands for Population–Environment–Development–Agriculture and is a model developed at IIASA in collaboration with the UN Economic Commission for Africa (UN ECA) to illustrate for governments and stakeholder groups the critical systemic interactions among these factors that are typically addressed independently by different sectors of government. It was developed by Wolfgang Lutz and Sergei Scherbov around the year 2000 and applied to Burkina Faso, Cameroon, Ethiopia, Madagascar, Mali, Uganda, and Zambia.

The PEDA model is based on "vicious circle" reasoning,[12,13] which assumes a dynamic relationship between resource degradation, poverty (food insecurity), and population growth (fertility)—see Figure 5.2. It also includes literacy as a factor affecting both fertility and agricultural productivity. In contrast to other models being used at the time, it also includes two truly innovative features in the form of a fully multi-dimensional population module (differentiating by age, sex, literacy, food-security status and urban/rural place of residence) and by introducing a food distribution function based on a Lorenz curve the shape of which can also be influenced as a policy variable.[14,15]

This model with its country-specific applications for Africa came in the form of user-friendly software that was used in many training workshops and policy exercises for government officials, NGOs, and interested scientists. In addition to the predefined scenarios, users were also able to modify some of the key parameters of the model—corresponding to alternative policy options—and immediately see the long-term consequences of their policy choices.

Figure 5.2. **Basic structure of the PEDA model linking population, food security, and the environment in Africa**



Note. In a vicious circle, high population growth of the rural food-insecure population contributes to degradation of marginal lands. This decreases agricultural production, which in turn increases the number of food-insecure persons. Source: Lutz at al. (2002).[14]

Trials and tribulations

In due course, global systems modeling ran into several challenges of a practical nature, mostly relating to a shortfall of computational power, and also of a conceptual nature. To some extent, these led to deadlock and even abandonment of some of the most ambitious efforts. Richardson[16] discusses eight domains which are crucial for the progress of system dynamics modeling, mostly relating to the advancement of knowledge and practice. In terms of tackling more direct challenges to the modeling, he discusses i) the need for better tools to understand model mechanisms, ii) procedures and standards for confidence and validation, and iii) ways of making models accessible to a wide audience.

Richardson[16] relates his call for a better understanding of model mechanisms to the choice between simple model structures with easy-to-interpret behaviors and more complex structures which, though adding realism, may turn into black boxes. Lutz et al.[14] make a similar point when studying whether key dynamics and insights of the PEDA model can be expressed in a reduced-form way. Indeed, due to their high level of aggregation, many of the global systems models can be read as reduced-form representations of much more complex bio-physical models of Earth systems, and micro-founded agent-based models of the economy, its underlying networks, and its key sectors. While Lutz et al.[14] demonstrate that the reduced-form representation can replicate the dynamics of the more complex PEDA model and thus allows users to "see the forest for the trees," they caution "that there is no forest without trees"; that is, the macro patterns are ultimately generated by individual behaviors. And for effective policymaking, it is important to understand the incentives underlying these behaviors. Ultimately, the choice of model structure and detail should depend on its purpose.[6,17] If the objective is to project the evolution of a global system accounting for the nexus of feedbacks across its subsystems, a global model may well be appropriate. When it comes to an analysis of policymaking, however, where policies have a bearing on behaviors, at least some of the black boxes need to be opened.

Such an approach can easily generate excessive complexity. Considering this, one of the approaches also exercised by IIASA researchers is the soft- or hard linkage of models. Examples of soft linkages include the linkage between IIASA's Model for Energy Supply Strategy Alternatives and General Environmental Impact (MESSAGE) with the Greenhouse Gas–Air Pollution Interactions and Synergies (GAINS) model to account for air pollution impacts, and the Global Biosphere Management Model (GLOBIOM) to account for emissions from land use.[18] Strikingly, such approaches may also benefit from global systems models that are employed as emulators of the more complex modeling framework and thereby allow for a means of cross-checking outcomes at an aggregate level.

The development of tools and frameworks that facilitate the understanding and validation of models belongs to the domain of modeling methodology as opposed to implementation methodology.[19] As regards the latter, soft system–analytic approaches toward stakeholder involvement, co-creation and nexus modeling have recently been developed and are increasingly deployed, with some pioneering work carried out at IIASA.[20] Here, reduced-form global systems models have the potential to foster systems thinking among stakeholders and structure the development of joint scenarios that keeps sight of both the forest and the trees, metaphorically speaking.

Finally, global systems models, which are both comprehensive in capturing inter-systems linkages and reduced in terms of intra-systems mechanisms, can be excellent sandboxes for the exploration of the macro-level ramifications of new concepts, research questions, and policy scenarios.

A way forward

In summary, we can identify four roles for global systems models: i) as macroscopic tools to identify emergent patterns of systems that are difficult to trace from detailed close-up models; ii) as emulators of clusters of close-up models, which allow us to step back from sectoral models and have a look at the total to check for plausibility and coherency; iii) as illustrators of key systemic processes in stakeholder processes; and iv) as exploratory tools for new approaches and computational analyses in systems modeling within comparatively simple yet comprehensive settings.

The exploratory function of a global systems model is what we will be drawing on in the remainder of this chapter. Specifically, we aim to incorporate into a system dynamics model the notion of human wellbeing as the outcome of demographic, social, economic, and environmental development, measuring its evolution within the model in a comprehensive and rigorous way, and assessing how it varies across the population and over time alongside different scenarios.

5.2 The case for including wellbeing measures in global systems models of sustainable development

In the last five decades, numerous institutions and researchers worldwide have participated in the advancement of human wellbeing indices. The explicit aim of these efforts is to assist governments in formulating effective policy interventions for enhancing quality of life across diverse national and cultural settings.[21] Up to the present, by far the most prominent and widely used wellbeing indicator continues to be GDP per capita. Yet, after heavy criticism of the concept, the majority of modern wellbeing indices look beyond the measurement of national income and attach greater attention to social and ecological dimensions of human development, including social capital, governance, civil liberties, and environmental quality.[22–24] Many of these recently proposed indicators aim at one composite metric, which incorporates a multitude of these different dimensions, with prominent examples being the Human Development Index,[25] the OECD Better Life Index,[26,27] the Decent Living Standard,[28] and the Social Progress Index.[29] While also being multi-dimensional in nature, the Years of Good Life (YoGL) indicator, as described in greater detail in Section 5.4, differs from the previously mentioned indices, as it is a fully integrated measure that can stand alone, has substantive meaning in its own right, and can easily be broken down for different population groups without being constrained by national accounting frameworks. A detailed derivation and application of YoGL, as well as a comparison between YoGL and other existing wellbeing indicators can be found in Lutz et al.[30]

Ever since the 1987 Brundtland report *Our common future,* sustainable development, defined as "meeting present needs without compromising future generations' ability to meet their needs," is linked to the wellbeing of distinct present-day and future generations.[31,32] Against this backdrop, it is striking that, while several global systems models generate the Human Development Index as an outcome (e.g., FeliX, IMAGE, IFs), the broader wellbeing implications of sustainable development pathways at the population level have rarely been assessed in a rigorous way. One notable recent exception is the Earth4All model,[33] which has been developed as a much enriched and updated successor of the *Limits to Growth* models and explicitly includes an Average Wellbeing Index (AWI). The AWI is a weighted mean of five components: worker disposable income; public spending per capita; the ratio of owner-to-worker income as a measure of inequality; observed global warming as a measure of environmental-related wellbeing; and the rate of growth in the AWI over the past five years as a measure of perceived progress. While this index captures many important dimensions of wellbeing, it is nevertheless highly aggregative and somewhat arbitrary in its composition. In particular, it is only indirectly linked to the population as the ultimate subject of wellbeing, and for that reason does not allow the detailed analysis of the emergence of wellbeing across the subgroups of a population that would be at the heart of an analysis of sustainable and fairly distributed wellbeing for the human population.

Modeling objective, approach, and findings

For a demonstration of how the evolution of wellbeing *across and within cohorts of a population* can be incorporated into a global systems model, we amend in the remainder of this chapter the Full of Economic-Environment Linkages and Integration dX/dt (FeliX) system dynamics model, which was developed at IIASA, as follows. We begin by modifying the model to take proper stock of the evolution of educational attainment across the cohorts of the population and across genders as a driver of fertility, longevity, and economic productivity (Section 5.3). We subsequently introduce the YoGL indicator of wellbeing into the FeliX model to map consistently the impact of development pathways on wellbeing, as channeled through changes in longevity and the shares of the population who are out of poverty and meeting basic standards in terms of health and cognition (Section 5.4). Based on these model enrichments to capture major aspects of demography and wellbeing, we call the resulting framework the DEMOFeliX model. The model extension is followed by the characterization of three baseline development scenarios (reference, optimistic, and pessimistic) and the description of a female empowerment policy scenario in Section 5.6. Results on policy impacts across the three baseline scenarios on human wellbeing are then presented in Section 5.7, and conclusions are drawn in Section 5.8.

5.3 Modeling education, poverty, and health in the DEMOFeliX model*

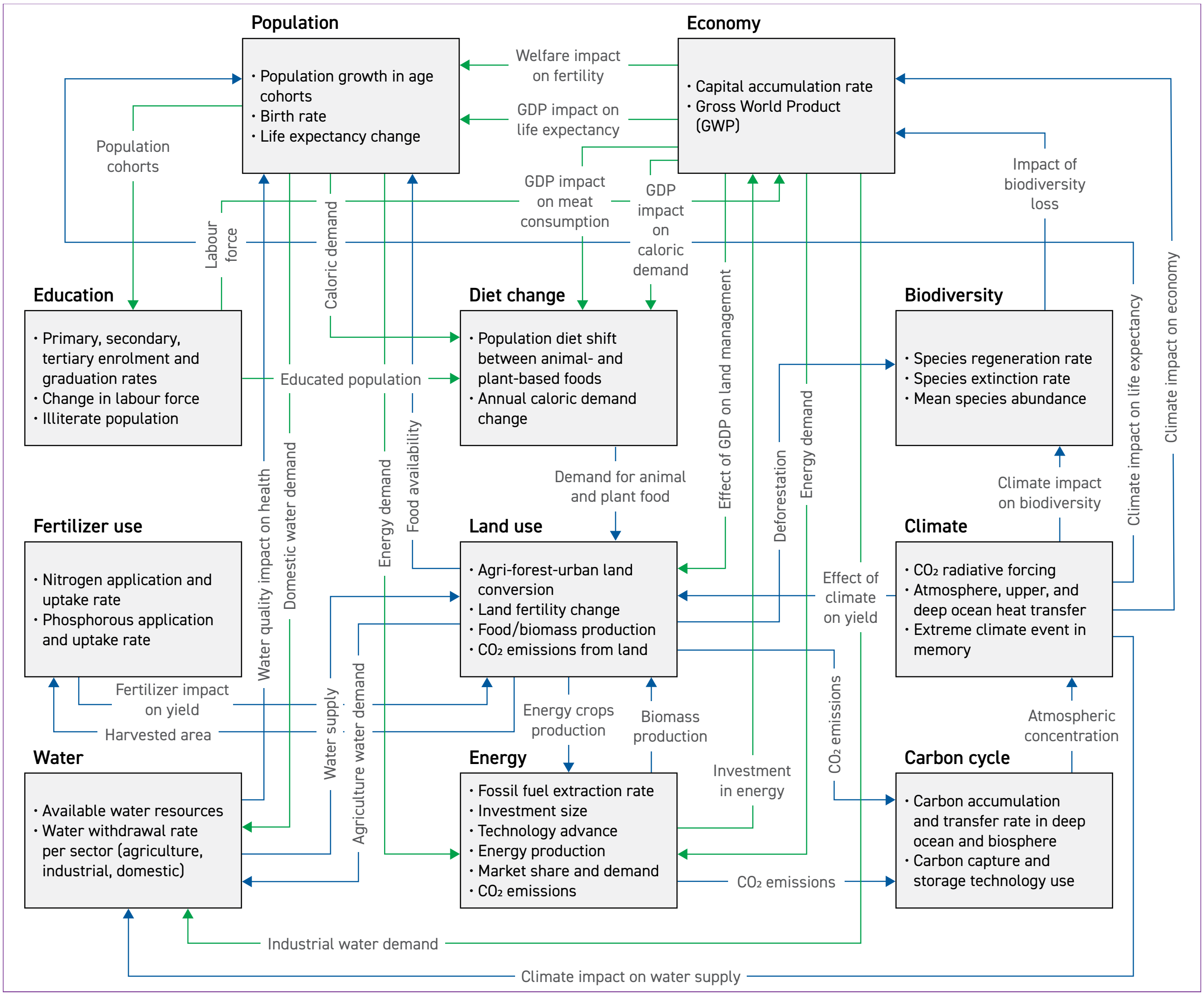
Brief introduction to the original FeliX model

The FeliX model is a globally aggregated, feedback-rich simulation model of climate, economy, environment, and society. It captures the core physical and anthropogenic mechanisms of global environmental and economic change within and between economies, energy, carbon cycle, climate, biodiversity, water, population, and land use. The development of FeliX started during 2006–2009 at IIASA in the European Union–funded GEO-BENE project to support global Earth observations. Since then, the model has been used to assess the socioeconomic and environmental impacts of Earth observation improvement,[35,36] carbon cycle impacts of global emission pathways,[37,38] and the population dynamics of shifts to sustainable diets.[39] In recent years, the need to analyze synergies and trade-offs among sustainable development goals (SDGs) has attracted attention to feedback-rich models that can capture the broad scope and interactions of the SDGs. In line with such research gaps, FeliX has also been used to investigate the sustainable development pathways based on an endogenous analysis of SDG synergies and trade-offs,[40] and specifically to analyze the trade-offs between environmental pressures and eradication of global poverty.[41]

FeliX is an empirically grounded, easily traceable system dynamics model that has low computational requirements and can hence be used in large uncertainty analyses and interactive stakeholder engagement. Instead of techno-economic detail at a high level of resolution, FeliX is geared toward running what-if analyses of cross-sectoral feedbacks, which are depicted in Figure 5.3. Those cross-sectoral feedbacks include the major human-Earth system interactions, such as the climate impacts of energy and land use, the environmental impacts of water and fertilizer use, and the feedback of climate damage and environmental degradation on economic growth, crop yields, and human mortality. More detailed information on the modules can be found in the model documentation[34] and on the FeliX model description page (https://iiasa.ac.at/models-tools-data/felix).

* Technical Note: The DEMOFeliX model is fully documented in a IIASA Working Paper.[34] The paper also describes the considerable potential of the model for further development in terms of alternative policy scenarios, regionalization, and more in-depth analysis of the channels through which policies have a bearing on long-term wellbeing.

Figure 5.3. **Overview of the FeliX model**



Note. Boxes show the main modules and summarize their components, and links refer to the interconnections between them. Source: Moallemi et al. (2022).[40] Adapted under the terms of the Creative Commons Attribution 4.0 International License.

Accounting for the role of education and human capital in the DEMOFelix model

As discussed in Chapter 2, and as will be further highlighted in Section 6.2, extensive research shows that education is an essential prerequisite for humanity's most important aspirations, including health and avoidance of premature death,[42–48] ending poverty and hunger,[49–52] improving institutions and participation in society,[53,54] fostering economic growth,[51,55,56] and enhancing adaptive capacity to already unavoidable climate change.[57,58] To account for the key role of education for global sustainable development, important adjustments have been made to the population, education, and economy modules of FeliX.

While a detailed description of the population module is given in the model documentation,[34] here we will provide only a brief overview of the major adjustments to the population, education, and economy modules of FeliX implemented within this project. In line with previous findings showing that educational attainment should be routinely added to age and sex as a third demographic dimension,[59–61] in DEMOFelix both fertility and mortality in the endogenous population module are determined by level of education, thus reflecting empirical evidence. Total fertility is formulated as a multiplicative function of Gross World Product (GWP) per capita and *mean years of schooling*, hence preventing a strong assumption of the monotonic dependence of fertility solely on economic growth or education. Furthermore, to provide a more accurate and nuanced understanding of fertility, the current FeliX model incorporates age-specific fertility rates, moving away from relying solely on overall birth rates. As regards mortality, life expectancy at birth is now additionally determined by mean years of schooling and by temperature increase (to account for climate change) in addition to GWP per capita and total food supply per capita.

The resulting population size at different age cohorts feeds back into the education module to compute the population of primary, secondary, and tertiary education graduates through enrollment rates and graduation rates. This module represents the size of population with each educational attainment level as a stock chain to account for the aging of people who graduate from each level and the transitions between the education levels. Therefore, primary, secondary, and tertiary education graduates are represented by a stock variable for each gender and 5-year age group corresponding to the education level. Mean years of schooling are then formulated as the population-weighted average of the duration of each education level. Enrollment rates are formulated as endogenous variables dependent on economic growth.

Production of GWP and labor force composition

Gross world production (GWP) is calculated by total reference economic output (REO), adjusted for the impact of climate change and biodiversity. The total REO is the sum of the REO generated by the skilled and unskilled labor force and determined according to a Cobb-Douglas production function, depending on the technology and capital allocated to the skilled/unskilled labor force and the size of this labor force. Technology and capital follow exogenous trends, determined by the model calibration. We assume that the size of the skilled labor force is the sum of the total population aged 15–64 with tertiary education, and half of the population aged 15–64 with secondary education, multiplied by the labor force participation rates of the respective groups. The size of the unskilled labor force is determined by the remaining population aged 15–64 and the corresponding labor force participation rates.

Conceptualization of poverty

The global poverty rate is defined as the proportion of the population aged 15+ living below the international extreme poverty line ($2.15 per capita per day in 2017 PPP). In the calculation of poverty rates, we follow Fosu,[62] Lakner et al.,[63] and Liu et al.[41] and assume that income follows a log-normal distribution as characterized by the mean and standard deviation of income. Here, the mean income can be calculated from the per capita income and the Gini coefficient within each population group, while the standard deviation of income can be calculated from the Gini coefficient. Finally, we obtain the per capita income within each age and gender group as a function of global warming potential and the respective Gini coefficients based on the relative income of the skilled as opposed to the unskilled. Further details on the modeling of GWP and poverty can be found in the model documentation.[34]

5.4 Wellbeing in the DEMOFeliX model

To consistently account for the evolution of wellbeing, we extend the FeliX model to implement the Years of Good Life (YoGL) indicator as a wellbeing measure. YoGL was developed by Lutz et al.[30] and aims to estimate the remaining years of life an individual can expect to live in a "good" state. By considering the changing characteristics of human populations that reflect the overall wellbeing of society, YoGL is specifically designed to assess the sustainability of long-term development trajectories.[64]

YoGL is built on the fundamental assumption that individuals experience any quality of life only if they are alive. Recognizing that mere survival alone is insufficient to capture wellbeing, however, YoGL is contingent upon meeting minimum standards of both objectively observable conditions (capable longevity) and subjective life satisfaction. Drawing on earlier works by Desai, Sen, and Boltvinik,[65] the objective conditions measuring "capable longevity" are further divided into three dimensions: i) being out of poverty, ii) being cognitively enabled, and iii) being physically healthy. To be considered as "good" years in the YoGL calculation, individuals must surpass critical thresholds in all three objective dimensions and report a minimum level of overall life satisfaction, thus bridging the divide between those who only accept subjective indicators versus those pointing to the need for objective criteria. In YoGL, years of life are only considered as "good" if people are above critical thresholds on both objective and subjective grounds.

In previous empirical applications of YoGL,[30,66,67] the population share above critical thresholds in all YoGL dimensions is derived from individual characteristics, as measured in representative cross-sectional surveys. In a global macro model such as FeliX, however, a different approach is required to capture the YoGL components and project the future prevalence rates. The three objective YoGL dimensions are therefore assumed to be endogenous variables, generated by direct and indirect impacts and feedbacks within the different FeliX modules (see model documentation[34] for more details). Subjective life satisfaction is not considered in the current version of DEMOFeliX due to lack of data at the global level.

Human Development Index as an alternative welfare measure

To provide a contrast, we also report the temporal dynamics of the HDI, based exclusively on objective indicators. The HDI is a capabilities-oriented index consisting of life expectancy at birth as a measure of health; the average of expected and mean years of schooling[68] as a measure of education; and GWP per capita as a measure of resources.[25]

5.5 Baseline scenarios

To take the uncertainties of environmental change and human responses into account and to explore the implications of these varying futures for the evolution of wellbeing, we consider three baseline scenarios. These come from the Shared Socioeconomic Pathways (SSPs) scenarios, as described in Chapters 2 and 4:

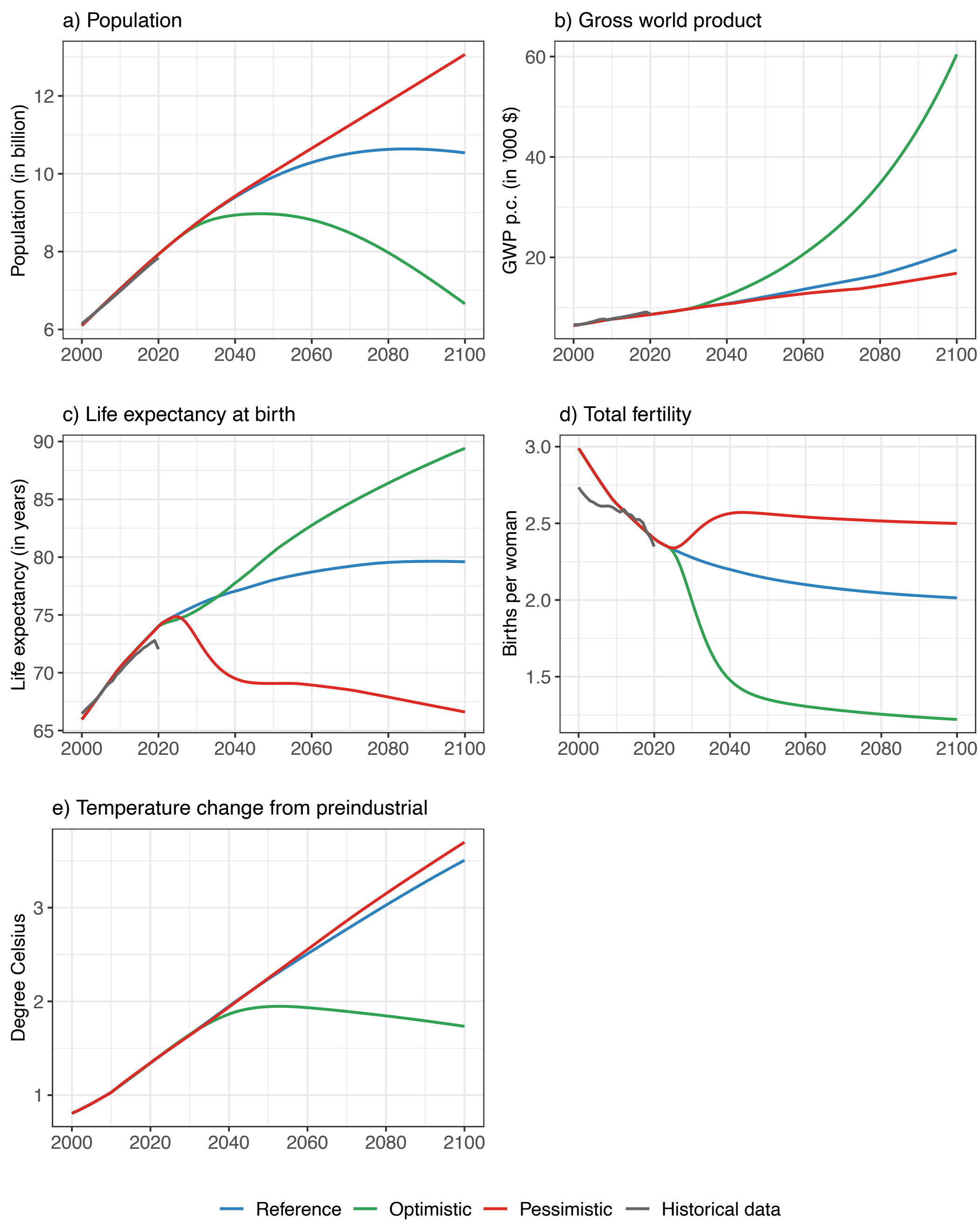
- **Reference scenario:** follows the **SSP2** (middle of the road) narrative for energy, land use, food, and climate policy,[69] as calibrated in Moallemi et al.[40] Demographic indicators follow the SSP2 projections, too, except for the climate impact on mortality which leads to lower life expectancy projections than does the SSP2 narrative. Climate impacts on mortality rates are incorporated into the model using the temperature- and education-dependent estimates of Bressler et al.[70] In contrast to the original SSP2 projections, GWP per capita is also endogenously projected based on labor force, technological progress, and capital investments. It takes the climate damage to economic output into account based on the empirical damage function estimated by Burke et al.[71] for long-term impacts of a given temperature increase across all regions and income levels pooled.

- **Optimistic scenario:** follows the **SSP1** narrative (green road with low challenges to mitigation and adaptation) for energy, land use, food, climate policy. The narrative for population and education follows SSP1, with the exception of climate mortality and climate damage function on economic output, as described for the reference scenario. The eventual climate impact on economy and mortality depends on the temperature projection created by this narrative. In addition, this scenario assumes that technological progress in the non-energy sector will be 50% higher in 2100 as compared to the reference scenario, reflecting possible spillovers from rapid technological change toward a greener economy.
- **Pessimistic scenario:** follows the **SSP3** narrative (regional rivalry with high challenges to mitigation and adaptation) for energy, land use, food, climate policy. The eventual climate impact on economy and mortality depends on the temperature projection created by this narrative. This scenario assumes that technological progress in the non-energy sector will be 50% lower in 2100 compared to the reference scenario, reflecting possible negative impacts on technological progress in a world that remains heavily reliant on fossil-related technologies and is subjected to stronger climate damage.[72]

Figure 5.4 depicts the outcomes in terms of global population and GWP per capita across the three scenarios for the hundred-year time span 2000–2100 (a comparison of the baseline scenarios to the SSP projections can be found in the model documentation[34]). Population reaches 10 billion around mid-century in both the reference and pessimistic scenario, whereas it peaks at 8.9 billion at the same time in the optimistic scenario. GWP growth is positive in all scenarios, but the strong climate damage and loss of biodiversity in the reference and pessimistic scenarios impose a sizable drag on growth and leave the global average GWP per capita at around US$20,000, as opposed to $60,000 in the optimistic scenario. The stabilizing population in the reference scenario is attributed to the stabilizing values of global life expectancy and total fertility rates, whereas the low fertility, induced by increasing educational attainment and economic growth, outperforms the high life expectancy and leads to low population in the optimistic scenario. Notably, life expectancy can keep increasing only in the optimistic scenario, where the climate impacts on mortality are significantly reduced by strong climate action and increasing education levels.

Economic growth is accompanied by an educational expansion, as depicted by the global total number of tertiary graduates and mean years of schooling. Here, the optimistic scenario features a higher growth of tertiary graduations, which reaches 3.65 billion people by 2100 and can be traced to an earlier and stronger shift in the educational distribution from primary toward tertiary education. In the pessimistic scenario though, educational expansion is halted. As discussed in more detail in the model documentation,[34] global poverty is curbed in all scenarios, with the pessimistic scenario still resulting in a global poverty rate of 7% by 2030.

Figure 5.4. **Projections of global population**



Note. (a), Gross World Product (GWP) per capita (b), life expectancy at birth (c) and total fertility rate (d), global mean temperature change from preindustrial times (e), in the three baseline scenarios. Historical data (black line) is obtained from the Wittgenstein Centre Data Explorer[73] for all demographic variables and from the World Bank[74] statistics for GWP (GDP) per capita.

5.6 Female empowerment as policy scenario

There is an increasing recognition that female empowerment is a strong driver of sustainable development.[19,75] This includes direct effects of female empowerment for economic development;[76–79] the impact of female health on (female) education and economic development;[80,81] the impact of female employment opportunities on female empowerment;[82] the impact of female empowerment[83] on democracy; and the impact of female political representation on maternal mortality and education.[84,85]

To capture key dimensions of female empowerment in terms of education and labor market participation, we additionally define a policy scenario based on the assumption that implemented policies will have the following effects by 2030: (a) Female enrollment in primary and secondary education doubles; (b) Female labor force participation increases, reaching 94% in 2030 for women aged 25–54, and 67.5% for women aged 55–64; (c) Quality of secondary education increases, with "skilled" secondary graduates increasing to 60%. This policy scenario is superimposed on all three baseline scenarios, allowing us to study the impact and leverage of such an empowerment policy package.

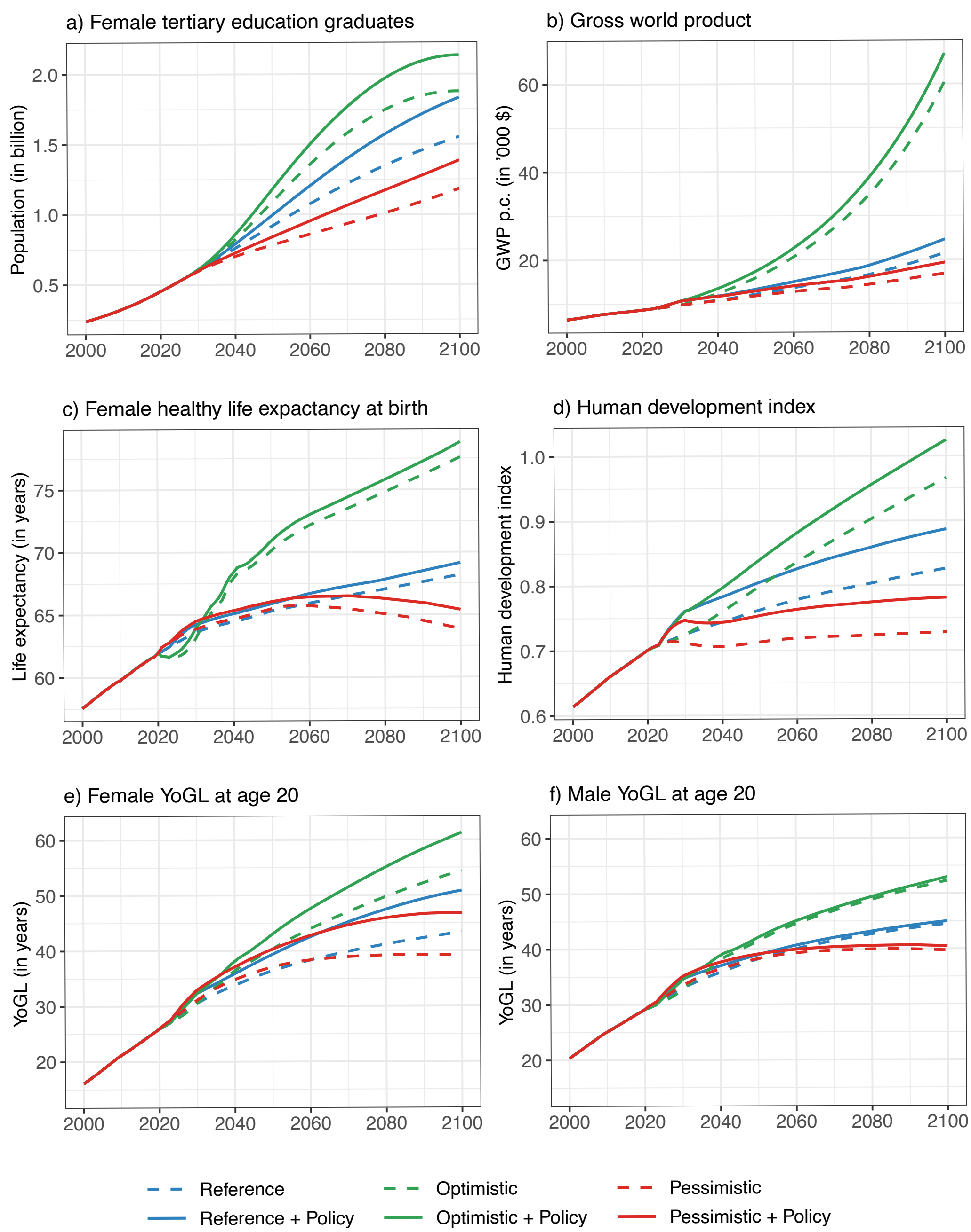
5.7 Main findings and policy implications

Figure 5.5 summarizes key results when the impact of the empowerment policy package across the three scenarios is considered. Adding the policy package results in a sizable increase in the mean years of schooling across all baseline scenarios. Combined with the expansion of the female labor force participation, the educational expansion leads to a sizable increase in GWP growth across all scenarios. While the absolute gain is largest in the optimistic scenario, the policy package has the strongest impact in the pessimistic scenario in relative terms, raising GWP by about 15% despite the high climate damage. Notably, the strengthening of education and labor market opportunities for women comes with a significant advancement in the reduction in global poverty. This is by directly eradicating poverty among unskilled women, with additional GWP growth only playing a secondary role. Female empowerment also results in a visible increase in healthy life expectancy across all scenarios.

Global wellbeing as measured by YoGL increases under all baseline scenarios, albeit at different rates. The increase is more marked for the optimistic scenario, while the pessimistic scenario shows stagnation and even a minor decline in YoGL from 2060 onwards. Under all baseline scenarios, YoGL is on average lower for women than for men, tending toward a male wellbeing advantage. The difference is largest in the pessimistic scenario, while it dissipates and eventually reverses in the optimistic and the female empowerment policy scenario. Compared to the HDI, YoGL increases by on average about twice the rate, indicating important differences in the measurement of wellbeing progress across the two indicators.

Both the HDI and YoGL increase with policies toward female empowerment. While the policy raises the HDI by about 6–7% by 2100, it boosts female YoGL at age 20 by some 7 years to between 61 years in the optimistic scenario and 50 years in the pessimistic scenario, amounting to a 12% and 19% increase, respectively. Here, it is notable that female empowerment yields substantial gains in all scenarios alike, implying that female empowerment is a "robust" policy approach toward welfare improvements, regardless of the underlying development of the world. Moreover, given that the relative gains are somewhat larger in the pessimistic scenario, female empowerment can be viewed as a strategy that enhances resilience. This finding is consistent with earlier work which has shown that increasing educational attainment can have substantial benefits for wellbeing, as measured by the HDI, and reducing vulnerability to climate impacts.[87] Finally, we note that with gains to male YoGL being much more modest, the female empowerment package also leads to a reversal of the gender gap in YoGL by 2100, essentially reflecting the male disadvantage in life expectancy.

Figure 5.5. **Overview of policy impacts across the baseline scenarios for selected indicators**



Note. (a) Women with tertiary education; (b) Gross World Product; (c) Female healthy life expectancy at birth; (d) Human Development Index; (e) Female YoGL at age 20; (f) Male Years of Good Life at age 20. The data and projections for the demographic indicators are from the Wittgenstein Centre's updated SSP2 projections.[86] Data for GWP per capita and the global poverty rate is from the World Bank.[74]

5.8 Toward a sustainable wellbeing agenda

Global systems modeling has a 50-year history at IIASA, with Jay Forrester's World Model having been published just one year before the founding of IIASA in 1972 and substantial parts of the model's further development having taken place within the IIASA network. While global systems modeling has met several conceptual and pragmatic challenges along the way, it continues to play a role in an emulator/model-linking function; an illustrator function; and an exploratory function. This chapter draws on the latter two in further developing a global systems model to study the evolution of sustainable wellbeing. This constitutes an innovation for systems modeling, which so far has been insufficiently applied to sustainable development from a wellbeing perspective.

When searching for an impactful policy trigger, our results indicate that female empowerment, in particular through the expansion of female education and labor force participation, has multiple benefits, including enhancing economic growth, longevity, and physical and cognitive health. By shifting women who are particularly at risk of poverty out of the low-skilled group, global poverty can be curbed much earlier than in the baseline scenarios. All these mechanisms substantially enhance welfare as measured by YoGL, a finding that holds regardless of whether the baseline development trajectory is "optimistic" or "pessimistic." We thus find strong confirmation from a system dynamicss perspective that female empowerment should, indeed, be a key component of any sustainable development agenda.

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This report chronicles the half-century-long history of the International Institute for Applied Systems Analysis (IIASA), established in 1972 in Laxenburg, Austria, to address common social, economic, and environmental challenges at a time when the world was politically dominated by the Cold War.

The report reveals IIASA's transition from its original raison d'être as a cooperative scientific venture between East and West to its position today as a global institute engaged in exploring solutions to some of the world's most intractable problems—the interconnected problems of population, climate change, biodiversity loss, land, energy, and water use, among others.

It provides a concise overview of IIASA's key contributions to science over the last 50 years and of the advances it has made not only in analyzing existing and emerging trends but also in developing enhanced scientific tools to address them. The report also shows how IIASA is currently working with distinguished partners worldwide to establish the scientific basis for a successful transition to sustainable development.

At this critical mid-term review point of the 2030 Agenda for Sustainable Development, the report focuses on the big picture and clarifies why, after years of scientific endeavor, the ultimate goal of this difficult global mandate should be sustainable wellbeing for all.

The report is in six parts that summarize past and current IIASA research highlights and points toward future challenges and solutions: i) Systems analysis for a challenged world; ii) Population and human capital; iii) Food security, ecosystems, and biodiversity; iv) Energy, technology, and climate change; v) Global systems analysis for understanding the drivers of sustainable wellbeing; and vi) Moving into the future: Three critical policy messages.

The three critical policy messages, necessary to trigger discussions about a post-2030 Agenda for Sustainable Development are: (1) Suboptimization is suboptimal: Mainstream a systems-analysis approach into policymaking at all levels. (2) Enhance individual agency: Prioritize women's empowerment through universal female education; and (3) Strengthen collective action and governance: Global cooperation and representation for the global commons.

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