Start Clim 2021

iSDG_KlimAT

Ein SDG Modell für Österreich - Erfassung der Wechselwirkungen zw. SDG13 & anderen SDGs zur Simulation von Entwicklungspfaden & Kosten

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A-1 Kurzfassung

Das iSDG_KlimAT Projekt hat sich mit der Modellierung der Sustainable Development Goals (SDGs) befasst. Das übergeordnete Ziel des Projekts war die Etablierung eines nationalen SDG Modells für Österreich, um Synergien und Zielkonflikte zwischen den Klimazielen und anderen Nachhaltigkeitszielen und damit verbundene Kostenaspekte zu erfassen. Dafür kamen mehrere qualitative und quantitative Methoden aus der Systemdynamik zum Einsatz. Aus dem quantitativen Modellentwicklungsprozess konnten weitere notwendige Entwicklungsschritte abgeleitet werden, um das Modell für den österreichischen Kontext und konkrete Analyze von Klimawandelanpassungs- und Klimaschutzstrategien und damit verbundene Kosten vollständig nutzbar zu machen. Darüber hinaus fand ein Stakeholder*innen und Expert*innen Workshop statt, um ausgewählte Mitigationsstrategien (Verbot fossil betriebener Fahrzeuge, Gebäudestandards, Verbot fossiler Heizsysteme und CO2-Steuer) und deren ganzheitlichen (i.e. umwelt- und sozioökonomischen-) Auswirkungen zu erarbeiten Das Projekt hat die Grundlage für weitere Projekte (ACRP - SDGVisionPath & Horizon Europe - TANDEM), die sich mit der Modellierung von SDGs befassen, geschaffen. Auch der partizipative Ansatz wird in diesen beiden Projekten weiterverwendet werden. Außerdem eignen sich Elemente der partizipativen Modellierung auch um ganzheitliche regionale Klimaschutz- und -anpassungsstrategien zu erarbeiten.

A-2 Abstract

iSDG_KlimAT focused on modeling the Sustainable Development Goals (SDGs) to capture connections between SDG13 and other SDGs. The overarching goal of the project was to establish a national SDG model for Austria in order to capture synergies and trade-offs between the climate goals and other SDGs and the associated cost aspects. For this purpose, several qualitative and quantitative methods from system dynamics were used. On the one hand, the internationally established System Dynamics computer model iSDG of the Millennium Institute for Austria was developed. On the other hand, a stakeholder and expert workshop to capture systemic effects of various mitigation strategies was carried out. As a result of the project further development steps were derived from the quantitative model development process. This will make the model fully applicable in the Austrian context and enable more specific analyzes of climate change adaptation and mitigation strategies and the associated costs of those. At the national level, an improved integration of financial data would be needed. At the regional level a more detailed breakdown of individual sectors and the structural integration of more specific adaptation measures and their related structure into the iSDG model would also be beneficial. In addition to these quantitative aspects, we established the basis for further development of model structures, specifically climate change mitigation strategies, in a stakeholder and expert workshop. This was done by applying tools of participatory modelling, through which system structures of selected mitigation strategies (ban on fossil-fuelled vehicles, building standards, ban on fossil heating systems and CO_2 tax) were mapped out together with experts and stakeholders. From this initial synergies and conflicting goals were recorded. The method used (i.e. Causal Loop Diagrams) ensured a systemic comprehension of the participants' system knowledge and it allowed participants to gain new insights into climate protection measures and arising dynamics. For example, the positive effect on poverty through investment and training programs that would be necessary in connection with individual measures was recorded. However, it also became clear that this synergetic effect would only occur after a delay. The project has created the basis for further projects (ACRP - SDGVisionPath & Horizon Europe - TANDEM) dealing with the modeling of SDGs. The participatory approach will also continue to be used in these two projects. Furthermore, elements of participatory modeling were also identified as suitable for developing holistic regional climate protection and adaptation strategies as they enhance systemic understanding of the complex challenges related to climate change and can uncover important intervention points.

A-3 Introduction

In 2015, two important international agreements were adopted: (1) The 2030 Agenda and its 17 Sustainable Development Goals (SDGs) and (2) the Paris Agreement, aiming to keep global warming below 1.5°C compared to the pre-industrial era (UNFCCC 2015). A corresponding decision by the Council of Ministers to implement the 2030 Agenda was made in Austria in 2016 (Bundeskanzleramt 2017) and as part of the EU climate and energy package, Austria has committed to reducing its emissions not covered by the EU Emissions Trading Scheme (ETS) by 36% by 2030 compared to 2005. Ambitious climate targets are currently being set at EU and national level.

Despite significant efforts to combat climate change, biodiversity loss and inequality, these continue to increase (Alvaredo et al., 2018; Haberl et al., 2020; Otero et al., 2020; W. Steffen et al., 2018; Wiedenhofer et al., 2020). This can be attributed, among other things, to the complexity of the challenges. At the same time current crises, such as the Russian war in Ukraine and COVID-19, have functioned as a magnifying glass for many of the flaws of our current socio-economic system, which also opens up opportunities to induce a transformation towards a more sustainable socio-economic system (Bacevic, 2021; Hepburn et al., 2020; Klenert et al., 2020; Spash, 2020; B. Steffen et al., 2020). While the implementation of a climate and energy plan that meets the ambitious goals of the Paris Agreement is challenging but feasible, achieving the climate goals while taking into account the 2030 Agenda and its 16 other SDGs poses a particular challenge. This results, among other reasons, from the many positive and negative interactions between the SDG entities, i.e. targets, goals and indicators (see e.g. also the StartClim project CliPo_Interlink). To seize the opportunity and enable a transformation towards a more sustainable system, it is important to identify and implement measures and investments that enable synergies (i.e. simultaneous achievement of several goals) and avoid trade-offs. Scientists have made numerous efforts to identify effective solutions by depicting interactions between climate and other sustainability goals and thus support decision-makers in their choice of measures (Bennich et al., 2020; Foxon et al., 2013; Nilsson et al., 2016; Verburg et al., 2016). In addition, it is important for decision makers to understand how goals are achieved over time and how various measures affect individual goals and associated indicators. Computer-aided models represent a suitable approach to comprehend the interactions between different SDG entities and their development into the future, (Horvath et al., 2022). They make it possible to simulate planned measures and costs as well as their (reciprocal) effects (Allen et al., 2016; Pedercini et al., 2020).

A-3.1 Project goals and outcomes

Based on the presented background above, the aim of this project was to identify and model fundamental interactions between SDG13 "Climate Action" and other SDGs in Austria. For this purpose, the SDGs were modeled at the national level for Austria using the Integrated Sustainable Development Goals (iSDG) model (Allen et al., 2019; Collste et al., 2017; Pedercini et al., 2018), one of the few internationally established policy simulation tools which allow policy-makers and other stakeholders to explore the complex interconnections between the SDGs . The main goal was therefore to develop an iSDG model for Austria.

Other related goals and outcomes were:

1. Scientific:
   - 1.1. Analysis of potential synergies and trade-offs between SDG13 and other SDGs and associated costs for exemplary development paths;
   - 1.2. Contribution to the (further) development of systemic modeling of the SDGs at Austrian and European level;
   - 1.3. Identification of research and modeling needs in relation to the SDGs in Austria.
2. (Politically) practical:

2.1. An interactive SDG simulation tool (will be uploaded soon) that allows to explore potential synergies and trade-offs between SDG13 and other SDGs in the development scenarios for Austria;

2.2. Test System Dynamics tools for researching and policy making in the context of the SDGs in Austria.

A-3.2 Project outline

To achieve the goals stated above, the project was carried out following the steps outlined below:

1. Developing an iSDG model for Austria, including all steps of the modelling process from data collection to model calibration. During this part of the project, additional data and modeling needs were identified. (Project goals 1.1, 1.2, 2.1)
2. Carrying out a stakeholder workshop that applied Causal Loop Diagrams (CLDs), which can be used in participatory modelling settings, during which different climate change mitigation measures were investigated. (Project 1.2, 2.2)
3. Reflection of the findings in step 1 and 2, which led to the identification of further development needs, next steps and possible applications of the iSDG Austria model in future projects. (Project goal 1.3)
4. Comprehension of project results in this final report and installation of the interactive online tool. (All project goals)

The remaining part of the report will provide background information on the applied methodology, introduce the iSDG model and describe the modelling process, present and discuss modelling and workshop results and finally provide a conclusion and outlook on how the findings of this projects can and will be used in the future.

A-4 Methodology

Recent reviews of the SDG literature highlight a vast variety of methods to study SDG entity interactions (Allen et al., 2016; Bennich et al., 2020; Breuer et al., 2019; Horvath et al., 2022; Miola, A., Borchardt, S., Neher, F. and Buscaglia, 2019), ranging from qualitative methods such as literature reviews, causal-loop-diagrams, and keyword analysis to qualitative-quantitative methods such as expert elicitation methods (e.g. Nilsson scale, see Nilsson et al., 2016) and cross-impact matrix to quantitative methods such as statistical methods (e.g. correlations, regressions, factor analysis, etc.), network analysis and simulation models (e.g. integrated assessment models, CGEs, agent based models, system dynamic models). All methods have their strengths and weaknesses and may be combined. However, there seems to be a clear recommendation in the above-mentioned reviews to consider comprehensive and systematic approaches. Widely applied statistical methods, including network analysis, for example, can quite easily provide information on interactions between SDGs, but mostly fail to provide information on how and why these interactions take place, i.e. they cannot provide recommendations on concrete policy interventions or leverage points (Bennich et al., 2020).

Models are common tools applied to assess potential socio-economic pathways and to aid policy design and decision-making in order to meet specific (e.g. SDG) goals. However, when it comes to realising the SDGs many more components of social, economic and environmental processes need to be accounted for than is currently done in most models (Pedercini et al., 2019; Spittler, 2019). As simulations regarding sustainable development pathways aim to comprehend, explore systems and support decision-making they should integrate all three domains relevant to sustainable development and represent synergies and tradeoffs between attaining different goals (Pedercini et al., 2020; Verburg et al., 2016). World3 can be understood as the first simulation model that tried to capture the human-environment interactions in a holistic manner. It was developed almost 50 years ago and back then provided the basis for the report to the Club of Rome “Limits to Growth (Meadows et al., 1972). It remains influential and relevant until today (Turner, 2012). Even if since then, many economic, climate and integrated assessment models (IAMs) for different scales (local, national and global) have been developed to understand and evaluate the effects of various climate change mitigation and adaptation strategies within an SDG context (Doelman et al., 2019; Fujimori et al., 2019; Gao & Bryan, 2017; Hutton et al., 2018; Matsumoto et al., 2019; Rydzak et al., 2013). Many model reviews have assessed how well-suited models and modeling methods are for assessing complex issues related to sustainable development within certain sectors or domains (e.g. energy, climate, land use) and how well they can capture interactions of different domains, not only but in particular focusing on IAMs (Brouwer et al., 2018; Pfenninger et al., 2014; Spittler et al., 2019; Verburg et al., 2016). IAMs were originally developed to understand the links between energy, the economy, climate, and land. Due to their nature the models comprehend climate-related SDGs in great detail but socio-political aspects are mostly lacking (Allen et al., 2016; van Soest et al., 2019). The complexity of the social, economic and environmental domains and the interactions between different entities within them is not accounted for.

Based on the understanding that each of the SDGs is part of a system and together they represent important parts of our socio-economic and environmental systems, the methodology of this project was rooted in Systems Thinking, which provides a framework to comprehend all three domains of sustainability. More explicitly the project applied different tools of the System Dynamics method (Nations, 2015; Sterman, 2000). System Dynamics offers quantitative and qualitative methods for comprehending and investigating complex systems, often times uncovering so called counterintuitive behaviour. On the one hand the project relied on quantitative computational System Dynamics modelling and on the other hand it applied the qualitative tool of Causal Loop Diagrams in the context of a participatory modelling, both of which will be explained in the following.

A-4.1 System Dynamics Modelling

Computational System Dynamics (SD) modelling is a simulation-based modelling approach. The main characteristics and elements underlying this modelling approach make it suitable for comprehending complex relationships between variables in the long-term as well as for uncovering synergies and trade-offs (Sterman, 2000). Unlike other modelling approaches SD is a simulation and not an optimization approach. In optimization approaches usually a goal that is defined externally will be set in the model. The model then tries to identify the parameters necessary to reach that one goal within the given constraints. In SD the structure of the system is captured in the model and arising dynamics are modelled over time without optimizing towards a certain goal. This allows to model and explore "what-if" scenarios. This means that the effects of policies, which one wants to implement, and their effects on individual variables but also system-wide behaviours can be investigated. Due to the way relationships between variables are formulated, the four main elements of the SD method are feedback, accumulation, delay and non-linearity.

In SD feedbacks can be understood as relationships that link variables. This is especially relevant when looking at a problem from a system perspective, because one variable can affect several other variables and at the same time be affected by several other variables. If connections are circular rather than linear it is called a feedback loop. Feedback loops can create balancing (i.e. oscillating, goal seeking) or reinforcing (i.e. growth or decay) behaviour over time (Meadows, 2008). In fact, many reinforcing feedbacks within the climate system exist. For example, the warmer it gets, the more ice melts, which decreases the albedo effect and again leads to higher temperatures, which again leads to additional melting of ice shields etc. Feedbacks and loops also exist in social and economic systems and are an important element, when trying to understand system behaviour over time (Forrester, 1971; Moore et al., 2022). However, often those dynamics are not (fully) considered in many modelling practices. A by now well-known example would be the rebound effect, i.e. initial technical efficiency gains are offset by economy-wide cost and income effects that affect people's behaviours. In the case of car fuel efficiency increases, car use and size of cars was increased due to reduced cost per km, in total leading to lower or no fuel savings than originally envisioned due to efficiency gains. Considering such feedbacks enables researchers to analyze the implied system's dynamics more thoroughly also accounting for non-linear behaviour.

SD can be understood as a stock-flow-consistent modelling practice, in which stocks and flows are simultaneously mapped. Mathematically this means SD is differential equation-based. This is relevant as stocks can set limits to the system as well as cause delays in the system through the effect of accumulation, which again leads to non-linear behaviour (Meadows, 2008). The simulated effects of a decision or an action taken today could therefore impact distant future projections rather than having an immediate impact, like it is the case with infrastructural investments or educational interventions.

Hence, SD enables us to understand the structure of a system, which is necessary if we want to understand synergies and trade-offs between targets rather than just univariate effects of interventions from individual impact variables on one selected target variable. SD models are based on the principles of the four elements (feedback, accumulation, delay, non-linearity), which are arising from relationships between variables defined by equations in the computational models. It is important to point out that the structures of a system dynamic model are not developed to predict future developments of individual variables. (For example, to analyze the effects of introducing taxes on plastic products). Rather, applications of system dynamic models serve to depict the development dynamics of complex systems over time. In this sense, they serve in particular to exploratively depict the "further" effects of, for example, "broad" social developments or macroeconomic innovations.

The visual nature of SD modelling does not only make model structure transparent from a visual perspective, but also allows non-modelers without in-depth knowledge of mathematical formulation to more easily engage with and understand the model and the interlinkages between the different environmental, social and economic components.

A-4.2 Causal Loop Diagrams in the context of participatory modelling

Often models are developed and advanced by trained modelers behind their computers. This can also be the case in SD. However, SD does not only offer a set of tools to develop models or model structures for modelers and researchers by themselves, but the tools are well suited for and should ideally be used in a participatory setting. Hence, this enables expert as well as stakeholder engagement in the model development process. Different frameworks and methods for participatory modelling exist, for example group model building (Vennix, 1996) or community-based system dynamics (Hovmand, 2013). These two examples, among others, provide a framework on how to conduct participatory modelling processes that start with problem definition, cover computational model development and lead to scenario analysis, in which stakeholders are involved in each step of the process. Of course, more approaches and combinations of them can be found in practice (Gray et al., 2017; Meinherz & Videira, 2018; Tourais & Videira, 2021). Additionally, it is also possible to employ individual tools of SD in a participatory setting to support problem or system understanding and extract stakeholder knowledge without following each step of an entire group model building process.

One tool that is well suited for participatory expert and stakeholder engagement is that of Causal Loop Diagrams (CLDs) creating CLDs (Olivar-Tost et al., 2020). It is well suited for extracting knowledge on systems' dynamics from experts.

CLDs can be understood as “qualitative diagramming language for representing feedback-driven systems'' (Schaffernicht, 2010). This tool, which is used to develop a conceptual system model, enables the mapping of the relevant variables of the system and their causal relationships. Thereby, feedback processes are made explicit and the system’s dynamics can be portrayed, which serves as a conceptual model of the system that needs to be understood in more detail. Causal loops are made up of causal links. Causal links between individual variables are depicted by arrows. These links can have positive (+) or negative (-) polarity, which are referred to as link polarities, meaning they move in the same or opposite direction. The term positive or negative link does not say whether it is good or bad, but simply provides a description of the causal relationships between variables. A positive link is one in which the causing variable and affected variable change in the same direction (i.e. reinforcing). Hence, an increase in the cause leads to an increase in the effect, as well as a decrease in the cause leads to a decrease in the effect. For example, there is a positive link between the number of people and births, hence the two variables move in the same direction. The more people there are, the more births as well as the less people the less births (see Figure 1).

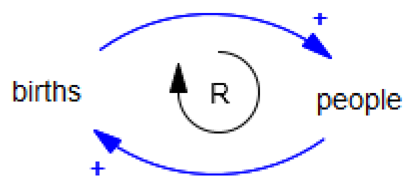

Figure 1: Reinforcing feedback loop

A negative link means the causing and affected variable move in the opposite direction. Thereby, an increase in the cause leads to a decrease in the effect and a decrease in the cause leads to an increase in the effect. In the example of Figure 2this translates into: more deaths lead to less people and less deaths lead to more people.

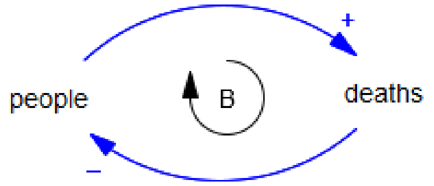

Figure 2: Balancing feedback loop

When causal links lead to circular connections they form causal loops. Causal loops, also called feedback loops, can either be reinforcing or balancing. Reinforcing behaviour is indicated by an R (see Figure 1) and leads to (exponential) growth or decay. This means that once the system is tipped into a certain direction this loop reinforces that behaviour. For example, the more births the more people, the more people the more births and so on and so forth. Balancing behaviour is indicated by a B and leads to goal seeking or oscillating behaviour over time as depicted in Figure 2. It means the more deaths, the less people, the less people, the less deaths, the more people the more deaths and so on and so forth. Hence, a balancing loop leads to a sort of equilibrium in the long run.

When several causal loops and links are combined, it is called a causal loop diagram (CLD). It is important to notice that causal links, causal loops and causal diagrams only represent the dynamic structure of a system, but not the direction of the system's behaviour. Thus, they explain what would happen if a given variable increases or what would happen if it decreases. In theory the system can behave in different directions but once one knows or assumes in which direction a certain variable moves, the effect on system behaviour and variables can be understood. When assigning polarities between two variables, other variables are assumed to be left aside, and only the causal relationship between those two variables is determined.

CLDs display the systems' dynamics and can therefore be used to investigate the main variables, their interlinkages and the resulting system behavior as well as related synergies and trade-offs in achieving different goals, such as the SDGs, can be uncovered. They should not be misunderstood for structural or mathematical representation of the system, which would imply more exact and detailed insights, such as the strengths of feedback loops, effects of accumulation and impacts of delays are beyond the scope of this method. As CLDs are a visual tool, they are highly communicable and are well suited for stakeholder engagement.

A-5 The iSDG model

Based on World3, the Millennium Institute built the Threshold21 (T21) model, to support integrated national planning efforts for the Millennium Development Goals (MDGs) in the Global South (Pedercini 2011). From this the iSDG was developed. This means the iSDG's structure relies on a SD model structure that has by now been improved over several decades. The model captures interactions among the SDGs and their sub-targets (Allen et al. 2019b, 2021). However, as the model originated from the T21 model, so far it was mostly applied in the context of countries in the Global South (Allen et al. 2020; Collste et al. 2017a; Pedercini et al. 2019) but is increasingly applied in high-income countries as well (Allen et al. 2019b).

As displayed in Figure 3, the model consists of a total of 30 sectors, integrating economic (blue), social (red), and environmental (green) aspects of sustainable planning, relevant in the SDG context.

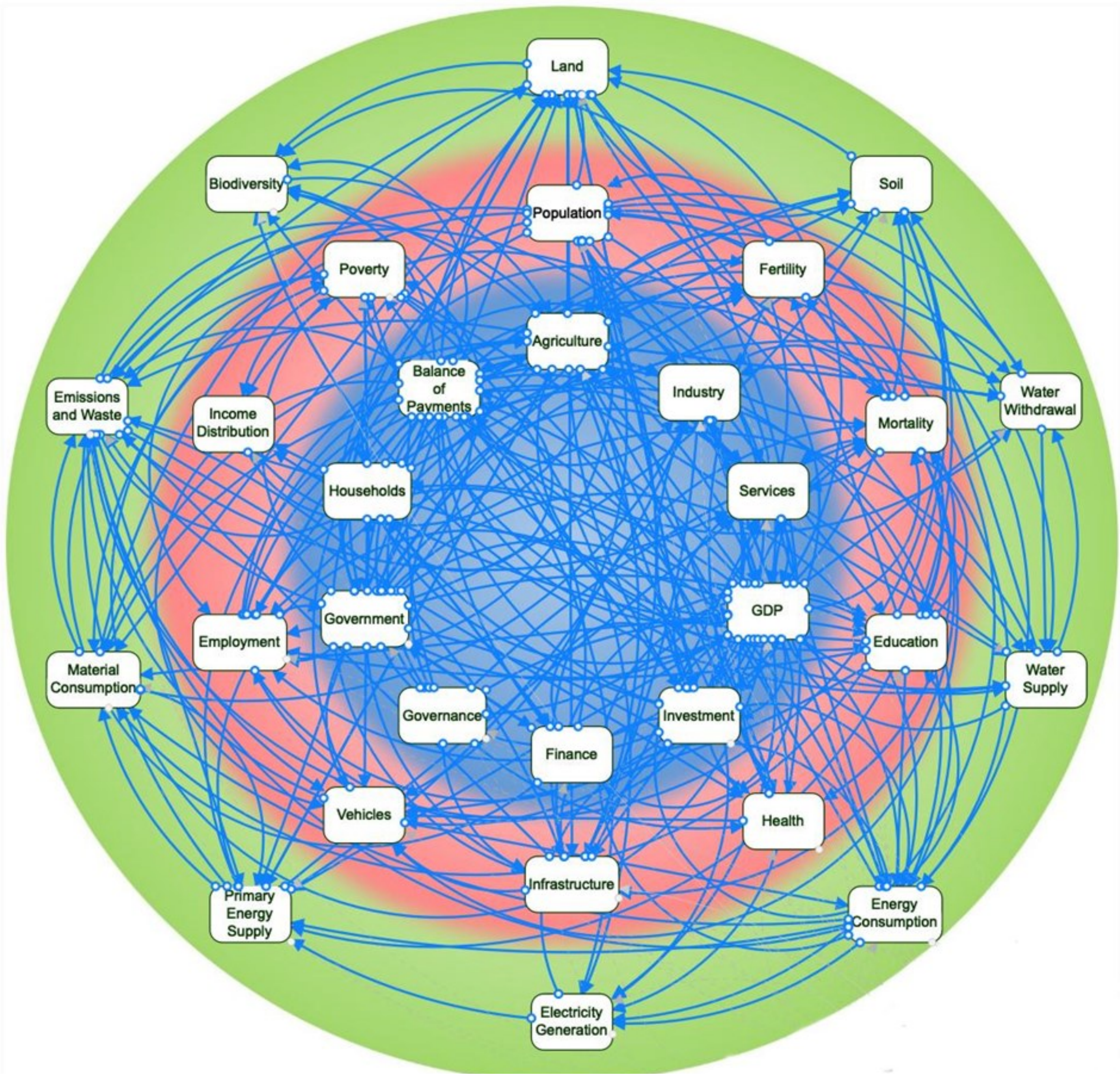

Figure 3: iSDG model sectors

As the model covers all SDGs, it supports a better understanding of the interconnections of the goals and targets to develop synergetic strategies to achieve them. The iSDG model simulates the fundamental trends for SDGs until 2030 under a business as usual scenario, and supports the analysis of relevant alternative scenarios. Running a business-as-usual (BAU) scenario shows how the country would progress towards each of the 17 SDGs if no additional measures were to be implemented. Such analysis provides an initial overview of the areas that require more attention from policy makers. Due to the high level of interconnectedness among goals in the model this step allows for building a shared understanding among stakeholders of how development in each area affects (and might be necessary for) developments in other areas. Additionally, the model supports the simulation of a variety of policies addressing each of the 17 Goals, in isolation and in combination with others, to understand their relevance as well as possible synergies and trade-offs. Finally, based on such analysis, a coherent SDG strategy can be developed, and the financial needs for its implementation can be assessed.

Due to the historic roots of the model, the original version does not have an elaborated climate change sector relevant in the context of the Global North, but rather includes a GHG emission sector connected to the technological, energy and production sectors and was more focused on the social and economic aspects of development (Spittler et al. 2019). However, historically countries in the Global South tended to be affected by climate change rather than affecting it, the effects of climate change are captured in several models. A detailed model description and documentation can be found online (https://isdgdoc.millennium-institute.org/en/). In the following the sector and policy structures of the model that are relevant in the context of climate change are discussed in more detail.

A-5.1 Climate change relevant sectors

The magnitude of climate change is externally determined as scenario parameters. This means the effects of climate change itself are not endogenously modeled even if GHG emissions and other underlying dynamics are. This is reasonable if the model simulations take place at national level, where changes in national GHG emissions will not impact climate change significantly (especially in small countries such as Austria). Although all sectors are interrelated, some sectors are more directly linked to the dynamics of climate change. Climate relevant sectors can be divided into those that are relevant to understand the causes of climate change and those that are affected by climate change.

A-5.1.1 *Sectors causing climate change and mitigation policies*

In the iSDG model sectors that are relevant for understanding the causes of climate change and potential mitigation policies are those that are directly related to GHG emissions. Those sectors include:

A-5.1.1.1*Emissions and waste*

In this sector emission and waste flows and stocks are accounted for. Emissions include fine particulate matter ($PM_{2.5}$) emissions and total GHG emissions as CO_2 equivalents. The calculations for $PM_{2.5}$ are based on final energy consumption and the number of vehicles (Klimont et al., 2002; Nussbaumer et al., 2008). Total GHG emissions in CO_2 equivalents (CO_2, N_2O, SOx and CH_4) include energy related emissions as well as other GHG emissions from energy supply and total motor vehicle consumption and non-energy related emissions from land use change (based on de- and reforestation), agriculture (based on level of activity) and cement (based on population size and income) (IPCC, 2000, 2006). While the emission part of this sector receives inputs from several other sectors within the iSDG (i.e. *Primary Energy Supply*, *Vehicles*, *Energy Consumption*, *Material Consumption*, *Agriculture*, *Land*), there are no exogenous inputs to this sector.

A-5.1.1.2 *Energy supply*

In the energy supply sector primary energy supply of gas, oil, coal, biomass, and electricity is calculated. Biomass energy supply calculations are based on crops production and forest products as outlined in Hoogwijk et al. (2003). The model follows a demand driven approach, which means the main drivers of primary energy supply are final energy consumption and electricity generation. Next to the main inputs to this sector coming from the *Energy Consumption, Electricity Generation and Vehicle* sectors, it also relies on exogenous inputs, such as electricity generation efficiency by source, other transformation losses factor, transmission loss factor and primary energy stock variant.

A-5.1.1.3 Energy Consumption

This sector represents drivers of final energy consumption, including consumption from production activities of the industry, service and agricultural sectors (GDP, population, electricity demand), households (based on population size and income), transport (vehicle fuel and electricity consumption) and residual uses (OECD/IEA, 2014). The model structure allows the introduction of energy related taxes, such as a CO_2 tax. Short-term price changes are not explicitly modelled but long-term price effects are embedded in the estimation of efficiency factors.

A-5.1.1.4 Vehicles

The Vehicles sector tracks the number of passenger and commercial road vehicles (internal combustion engines and electric). This represents the basis for calculating emissions produced by vehicles (fine particulate matter, $PM_{2.5}$). The model explicitly accounts for the replacement of old vehicles by new ones and the factors affecting decisions concerning the level of fuel efficiency of new vehicles, including public expenditure (subsidies). There are no exogenous model inputs to this sector, but it is linked to other iSDG internal sectors since income levels and road density affect purchases of vehicles (Greenspan et al. 1999; Litman 2015) and vehicles contribute to particulate emissions through fuel combustion and through tire, brake, and road dust (Klimont et al. 2002).

A-5.1.1.5 Agriculture

The agriculture sector includes crops production, fishery production (separating fish catch and harvest from aquaculture), livestock production and forestry production. Beyond the linkages to sectors that are relevant for the production factors (i.e. land, labor and capital) and influence factor productivity, such as investment, balance of payment, education, employment, government expenditure, governance, health, infrastructure, climate and energy prices, this sector is also linked to biodiversity, soil and water supply.

The production of each agricultural product is calculated slightly differently. Crop production is influenced by the harvested area, and soil nutrition (with the availability of macro-nutrients N, P and K represented), precipitation, irrigation, which along with total factor productivity affect the actual yield (Steduto et al., 2012; Tan et al., 2005). Production factors are combined in a Cobb-Douglas production function. More specifically, an increase in the production factors or their productivity reduces the difference between actual and attainable yield. Livestock production is affected by the same factors described above. However, in the case of livestock, production per unit of land does not strive towards maximum attainable yield, but is determined directly by growth in driving factors.

Similar to other economic sectors (i.e. industry and services) growth in production is driven by an increase in available production factors or by an increase in their respective productivities. This means that demand factors are not considered in the calculation of production and that the quantities produced are fully consumed.

In addition to prices, the following relevant parameters of this sector are exogenous to the model: crop intensity index, crop production value per ton, livestock value added per ton, forestry production, other agriculture input cost per ton of production and effect of change in type of crop yield.

A-5.1.1.6 Land

In this sector the land use for different purposes is calculated and tracked. It includes four classifications of land: agricultural land, settlement land, forest land and other land. Agriculture land is further divided into arable land and permanent crops, and pasture land. Other land accounts for all land that is not in any of the other categories and also functions as intermediate stage in the transformation between land uses.

The land sector ensures that total amount of land is always conserved. The approach used is based on the Food and Agriculture Organization's (FAO) international standard land classifications and includes an endogenous representation of the main factors that shift land from one category to another. Those factors include profitability of agriculture and livestock on demand of agricultural land, demographics and unemployment, capital intensity, unit cost for reforestation and unit cost for land protection. Exogenous model inputs in this sector are crop intensity index and share of cereal land (FAO, 1998, 2002; James et al., 2001; Kissinger et al., 2012; UNEP, 2012; Wolman, 1993).

A-5.1.1.7Soil

Due to their relevance to agricultural activities in the soil sector soil nutrient balances and their long-term impact are estimated particularly for nitrogen, phosphorus and potassium. Fertilization, biological fixation and deposition are accounted for as inflows and nutrient uptake from crops and crop residuals removed as well as leaching and gaseous losses are counted as outflows. The difference between in- and outflows is drawn from soil organic matter (Bot & Benites, 2005; Del Pino Machado, 2005; Roy et al., 2003). Exogenous inputs to this sector are fertilizer consumption, nutrient uptake proportion and fertilizer price per ton of nutrient.

A-5.1.1.8Mitigation policies

Although not explicitly categorized as mitigation measures, several interventions that affect CO_2 emissions and thereby, climate change, can be tested in the standard version of the iSDG, namely *Industry energy efficiency*, *Households energy efficiency*, *Vehicle efficiency*, *Small and Large scale hydro power*, *Small and Large scale photovoltaic* and *Reforestation*. In general, those interventions can be understood as investments. Hence, the available financial resources in a respective field increase to facilitate a shift towards a new technology or practice.

A-5.1.2 Sectors affected by climate change and adaptation policy

A-5.1.2.1 Infrastructure

The supply chain approach applied in the infrastructure sector allows to model the dynamics of transportation infrastructure, including construction, maintenance, and decay. This makes it possible to explicitly consider the effect of time lags in transportation infrastructure development, and on the rural access index. Currently the following infrastructure elements are considered: paved and unpaved roads, and railways. If necessary, others can be added. 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 et al. 2004; Rioja 2003). An important factor influencing construction quality and use of transport infrastructure, infrastructure life and maintenance cost is governance (Kenny 2012).

Additionally, intensity and frequency of natural disasters and their impacts on infrastructure, health and private capital are encompassed in this sector. Beyond this, transportation infrastructure influences many other sectors including education, agriculture, industry and services. This sector has no exogenous inputs.

Additional investment in infrastructure is one of the policy interventions possible in this sector. One of the assumptions in this sector is that natural disasters are increasing with climate change. Therefore, it is possible to invest in climate change adaptation to offset negative effects of those.

A-5.1.2.2 *(Industrial) production*

The industry and other economic sectors employ an extended Cobb-Douglas (CD) production function to represent industrial production (Cobb et al. 1928). Generally, the production factors include capital and labor. Capital can be subject to damage through extreme events (IPCC 2012). Factor productivity is influenced by drivers from other sectors, such as: education (average years of schooling used as proxy) (Barro 2001; Nelson et al. 1966; Romer 1990); health (life expectancy used as proxy) (Bloom et al. 2001; Howitt 2005; López-Casasnovas et al. 2005); infrastructure (including roads and irrigation infrastructure) (Calderón et al. 2004; Canning 1999); access to electricity (Calderón et al. 2004); level of governance (Kaufmann et al. 2002); macroeconomic stability (inflation rate used as proxy) (Bruno et al. 1998; Fischer 1993); climate change (Burke et al. 2015); energy prices (Arezki et al. 2014; Jiménez-Rodríguez et al. 2005; Peersman et al. 2012); female participation in the workforce (Cuberes et al. 2012; Loko et al. 2009) and openness to trade (Edwards 1998; Yanikkaya 2003). In the model climate change is assumed to negatively affect total factor productivity and thereby, economic activity.

Production growth is driven by an increase in available production factors or by an increase in respective productivities. This implies that demand factors are not considered in the calculation of production, that the quantities produced are fully consumed, and prices are exogenous to the model. This production-side determination of macroeconomic development pathways represents a standard approach to long-term growth modelling. In the model the production factors are used in unit-consistent form, using normalized values. A similar approach is used to normalize the drivers of productivity. The overall effects of variations in available production factors and drivers of productivity are combined in a multiplicative form, assuming Hicks-neutral technological change.

A-5.1.2.3 *Mortality*

To capture the effects of changes in the socio-economic sphere, mortality is represented endogenously in the model. Death rates are dependent on various factors, such as per capita income, access to basic health care, education, nutrition, access to electricity, access to drinking water and sanitation, exposure to air pollution, political stability and absence of violence, number of motor vehicles and climate change (Baker et al., 2011; Kunitz, 2007; Preston, 1975). As those factors influence age groups differently, death rates are age-specific. To accomplish this, initial gender specific life expectancies are determined at birth, which are then complemented by based on tabulated numeric relationships empirically estimated between life expectancy at-birth and the age- and gender-specific death rates in various regions.

Life expectancy is a key indicator for the Human Development Index as well as it influences important variables in other model sectors, for example productivity in agriculture, industry, and services sectors. The model has no exogenous input to the mortality sector.

A-5.1.2.4 *Adaptation policy*

The core iSDG model includes climate change adaptation as a standard policy intervention. Through investment in climate change adaptation the harmful effects of climate change on mortality, infrastructure and total factor productivity can be reduced.

A-5.2 Data

Data sets for mapping the historical developments in Austria for social, economic and environmental indicators must first be integrated into the model database. The data collection process for the iSDG relies on an established procedure by the Millennium Institute, which primarily record the corresponding data in internationally renowned databases, including World Health Organization-WHO, United Nations-UN, World Bank, International Monetary Fund-IMF, World Food Organization-FAO, International Energy Agency-IEA. Any data gaps or obvious data implausibility need to be supplemented or corrected with additional comparison of entries in regional or national databases, in Austria this meant supplementing data from Eurostat and Statistik Austria.

A-5.3 Modelling process

As the iSDG model is often used for government consultation in countries in the Global South, the country model development process includes interaction with stakeholders and local experts in all stages mainly to ensure that the model meets the needs of the client (e.g. ministry or agency) who will be using the results, data is made available if not available by international sources and the client understands the model and receives sufficient training, so it can be used independently in the future.

The scope of this project was much smaller and there was no governmental client. Hence, the process was adapted to the scope and needs of the project and it was intended to cover the following steps:

1. *Data collection*

   In order to adapt the current structures of the iSDG model for an analysis of Austria causal relationships, data sets (see information above) for mapping the historical development in Austria needed to be collected.

2. *Calibration of the iSDG model for Austria*

   After a successful model data collection and adaptation process, the iSDG was calibrated against the historical development. For this the model, meaning the numerical values of and relationships between variables, were calibrated based on the data collected in the previous step. The basic model is validated by systematically assessing the development of the endogenous indicators represented by the model with the historical developments (i.e. from 2000 to 2020). For these technical quality assurance tests, the MI team relies on so-called structural and behavioral tests.

3. *Implement the business as usual (BAU) scenario for Austria*

   An application of the calibrated and validated iSDG base model without additional scenario assumptions generates the results of the BAU scenario. In the BAU scenario most variables (apart from those explicitly defined as exogenous in the model description) are calculated endogenously, meaning they depend on the development of other variables. Once the model has been successfully calibrated also the dynamics from the year 2000 to 2020 are calculated endogenously. Unlike in other, iSDG calculates population endogenously. The calibrated model should serve as a reference for assessing the achievement of the SDG goals.

4. *Assessment of climate change scenarios*

   Due to the scope of the project, it was not possible to make any structural adjustments to the model but already existing policies in relation to climate change have been (or were) explored.

A-6 Participatory modelling workshop

As outlined in section A-4 Methodology, participatory elements can be used to support the SD modelling process or simply enhance systemic understanding of a problem as well as proposed solutions through the involvement of stakeholders and experts. Due to the limited scope of the project, no full group model building process could be carried out. The fact that this project relied on an already tested and validated model meant there was no urgent need to do a group model building process to develop an initial SDG model for Austria. Nonetheless, the development process of the iSDG for a specific country usually relies on stakeholder and expert involvement. Hence, a workshop that included participatory elements to capture dynamics of climate change mitigation policies, currently not captured by the iSDG, was conducted for the Austrian case. The goals of the workshop were: i) create a systemic understanding of the dynamics influenced by and arising from different proposed climate change mitigation strategies, their effects on other SDGs and related cost aspects in Austria among the project team as well as experts and stakeholders; ii) introduce and discuss the iSDG, its potential use cases and limitations, with Austrian SDG experts and stakeholders; iii) test and explore participatory modelling tools, explicitly CLDs, with Austrian SDG experts.

Hence, experts and stakeholders in the field of climate change and related SDGs were invited to BOKU to participate in a 4h in-person workshop. To ensure the workshop time could be used in the most productive way, a pre-workshop survey was sent out to participants. The workshop followed the structure outlined below and detailed in the Workshop presentation:

1. Introduction to the iSDG, especially focusing on model aspects relevant to SDG13 and climate change.
2. Interactive group work, for which the participants were split into four groups. Each group built a CLD for one of the climate change mitigation measures that were selected from the pre-workshop survey (i.e. CO2 tax, fossil fuel ban in buildings, fossil fuel ban for cars, building standards).
3. Wrap up in which the participants shared their CLDs with others and provided feedback.

A-7 Results & Discussion

In this section the project results related to developing an iSDG model for Austria will be discussed. Results regarding the modelling with the iSDG will especially focusing on the scientific project goals 1.2. “Contribution to the (further) development of systemic modeling of the SDGs at Austrian and European level” and 1.3. “Identification of research and modeling needs in relation to the SDGs in Austria”. Due to calibration issues with the model, results related to project goal 1.1. “Analysis of potential synergies and trade-offs between SDG13 and other SDGs and associated costs for exemplary development paths” cannot fully presented at this stage. However, results concerning goal 1.1. will partly be addressed in the modelling results and discussion section and it will also be discussed in the workshop results. Workshop results also contribute to project goal 1.3.

A-7.1 iSDG model

As a general finding it can be mentioned that the iSDG is based on a model that was developed for national planning and policy analysis in the Global South. Hence, in some parts the underlying data and structure of the model mainly applies to this context. Since countries in the Global South have rather been affected by climate change than causing it, the SDG13 related model structure allows for exploring the different degrees of climate change and its impacts on other SDGs. This also is the reason why investment into climate change adaptation is seen as the main SDG13 policy intervention covered in the iSDG core model. Thereby, the model can capture the trade-off that occurs from climate change adaptation investments, which increases productivity, and climate change mitigation. Although no other SDG13 policy is available in the model, policies that contribute to climate change mitigation, such as investment in renewables (SDG7) efficiency (SDG8) and vehicle (SDG11) policies, are encompassed within the model structure. Despite the core model structure being more focused on issues prevalent in the Global South, much of it is still applicable to assess the SDGs and especially synergies and trade-offs between them in the context of the Global North (compare (Allen et al., 2019)). As most of the measures are related to investments, it can also be used to assess the cost of different climate change mitigation and adaptation measures. Therefore, the iSDG provides a solid basis for further development for assessing SDG13 in connection to the other SDGs in Austria.

Due to the calibration issues it was only possible to carry out the first two steps of the adapted modelling process for Austria (i.e. 1. Data collection & 2. Calibration of the iSDG model for Austria). This means the remaining part of the iSDG model results will mostly discuss findings related to issues that led to complications for the calibration of the model.

A-7.1.1 Data findings

While data was available for most sectors, in some cases international data sources needed to be replaced or supplemented with EuroStat or Statistik Austria data, as the international data was inaccurate or missing. This was especially true for government budget and finance data. Government data was replaced by Statistik Austria and Eurostat data. For finance, it was a bit more complicated as the source usually used for collecting this type of data for the iSDG is the IMF. This source proved to have some significant gaps when it came to Austria. Not all of the required finance data could be validated and/or supplemented by national sources within the scope of this project, which turned out to be one of the main issues for calibration and running a BAU scenario. Beyond this, also data in the agricultural, land and soil sectors had to be replaced. Other data that is more relevant to the Global South, for example health (e.g. malnutrition) and poverty (e.g. international poverty index), was scattered and in some instances incorrect but could only sometimes be replaced by national sources. However, this only represents a minor issue as it does not affect SDG attainment in Austria to a large extent.

A-7.1.2 Calibration findings

Some of the above-mentioned data issues led to issues that only became apparent in the model calibration process. In the end, all sectors could be calibrated successfully. Some discrepancies between historic and modelled developments in the soil and energy sectors remained. However, these do not significantly affect model performance. Another issue occurred in the household sector, which caused a delay in model calibration. Unfortunately, in the household sector calibration of private saving was more difficult than expected. Initial problems with calibrating this variable led to an immense overestimation of GDP. Further research on the initial data and going through several calibration routines made it possible to render reasonable results for private saving and GDP growth. Nonetheless, it is recommended to improve this part of the model in the future.

A-7.2 BAU scenario results

As already explained above, most variables are endogenized in the model. Hence, only few assumptions about exogenous inputs were made. One of the main assumptions was that average temperature increases by 1.5°C (this is in line with the default settings of the iSDG).

While it was possible to run a BAU scenario until 2040, it was not possible to generate reasonable SDG attainment results for all SDGs. This was mainly because some indicators did not proof to be adequate for the Austrian context rather than issues regarding the model itself. Hence, the following discussion of the BAU scenario will only cover some aspects related to the SDGs and particularly SDG13. This scenario has not been aligned with the commonly used WEM (With Existing Measures) scenarios also used by the Umweltbundesamt in Austria. Hence, the first result presented of the BAU scenario is that of population as this is one of the main exogenous drivers of the WEM scenarios. The population grows from just over 8 million in 2000 to almost 9 million (8992382) in 2024. After this it starts to slightly decline again to around 8.45 million in 2040. Another variable endogenously calculated by the iSDG, which is used as exogenous input in some other models, is GDP. The BAU run of the model does not capture the effects of COVID-19. Therefore, the GDP growth rate (SDG8) steadily increases to 1.84% in 2030 from 1.55% in 2020 and decreases to 1.8% in 2040. Total GHG emissions in CO_2 equivalents have grown by 10.8% in 2040 (SDG13), as well as domestic material consumption and the material footprint also keeps increasing (SDG12). This means that despite growing emissions they grow slower than GDP, due to declining energy intensities of primary energies and growing renewable shares in total final energy consumption (SDG7). In the BAU scenario the population below the poverty line (SDG1), measured in euro, would steadily decrease to less than 10% in the year 2030. The GINI coefficient (SDG10) peaks in 2024 at 0.313 and declines to 0.26 in 2040. Performance for SDG4 (measured by secondary school completion rate) improves steadily. In some of the SDGs, particularly SDG2,3,6 and 15 performance is good from the beginning and does not decline. However, this is due to the indicators chosen (e.g. access to basic health care, access to safely managed water resource, protected territorial waters), rather than due to the great performance in all these aspects in Austria. The indicators in the model refer to the international SDG indicators that are often more relevant in the Global South than in the Global North.

A-7.3 Climate change scenario

Although an advanced analysis of different scenarios is not possible at this stage a simple comparison of the already existing measures in the iSDG was conducted. To test which of the investment measures would yield most effects, all climate relevant investments were tested individually by assuming an additional expenditure of 10% of GDP into the respective investment options outlined under climate mitigation relevant options above, from the year 2023 to 2030. Independent of how realistic the assumption of the 10% is, insights into how different strategies compare to each other can be generated through this testing strategy. None of the tested strategies individually renders promising results, with their effects only becoming apparent close to or after 2030. This is due to the delays that occur when investing in efficiency increases of different sectors or in renewable energy. Despite there not being large differences, the "best" strategy would be to invest in vehicle efficiency, because the delay is shorter than for efficiency increases that relate to larger infrastructural changes. Delays related to all technological solutions cause the currently captured policy options alone to be insufficient to reach goals until 2030. However, due to rebound, this should not be overestimated. It could be argued that instead of investing in more efficient vehicles, investment should be geared towards electric vehicles. This is currently not a policy option covered by the model but some aspects related to this are discussed below in section 7.1.4 Vehicle fossil fuel ban.

A-7.4 Participatory modeling workshop

Based on the insights gained through working with the iSDG model and the understanding that measures already captured by the model will not be enough to achieve climate change mitigation targets, it was decided to focus on climate change mitigation measures in the participatory modelling workshop. This could help to identify and support new structural developments of the model. Therefore, the main question of the workshop was: How do climate change mitigation measures and associated costs affect (sustainable) system dynamics?

A-7.4.1 Results and discussion regarding workshop content

The main results from the workshop are the CLDs developed by the four groups, which will be discussed in this section. Before introducing the findings of the individual groups some general points regarding the CLDs and how to read them as well as general insights that are relevant to more than one group's CLD will be discussed.

It is important to notice that the CLDs below (Figure 4 to Figure 8) represent the participants' collective understanding of the systems' dynamics, which is influenced by their respective field of expertise. Additionally, the time constraint did not allow participants to go into depth in all aspects they identified as relevant for their system. Nonetheless, several important dynamics and cost aspects related to the suggested climate change mitigation strategies could be determined. Although the variables were not changed, some visual adaptations were made to highlight identified loops (in colour). Variables connected by grey are either variables that exogenously influence/push/drive the systems' dynamics or are influenced/pushed/driven by it but are not part of the wider endogenous system's dynamics. In general, the description of the loops is not carried out variable by variable but focuses on the dynamics arising from it and how this dynamic is created. However, the CLDs can, of course, be read variable by variable following the rules outlined in the methodology section.

As explained above, CLDs are a powerful tool to comprehensively depict the underlying dynamics of a system but they are not differentiating between different structural elements (i.e. stocks, flows and auxiliary variables) or provide a mathematical representation of the system. Hence, insights with regards to system dynamics and overall behavior can be drawn from them, which allows for example to understand reinforcing and balancing behaviors, identification of some leverage points[1] (i.e. places to Intervene in a system) and to gain a first understanding about synergies and trade-offs. It should be noted that more exact and detailed (quantitative) insights, such as the strengths of feedback loops, effects of accumulation and impacts of delays cannot be understood from CLDs and quantifying them is beyond the scope of this project. However, this comprehension of the system can aid future system analysis, for example by laying the foundation for future modelling exercises.

Regarding the resulting CLDs of the workshop what can be noted is that all mitigation policy options are connected to investment dynamics, as the intervention forces investment in new technologies

[1] Donella Meadow's (2008) defined leverage points as places to intervene in a system.

and/or infrastructure. This includes development as well as installation of new technologies and infrastructure. While investments are an important aspect, their effects can occur with a delay, due to the time needed to adapt infrastructure and develop and implement new technologies. Additionally, investment often was related to government budget, which means another delay related to the socio-political structure might occur.

Similarly, skilled labor, which is connected to training and education, is seen as an important aspect for the implementation of almost all interventions except that of the fossil fuel ban for vehicles. While the dynamics of skilled labor and education and training can drive the system's behavior into the desired direction and have a synergistic effect on poverty risk reduction, a delay until the dynamics of this gain traction needs to be considered.

Beyond the delays, the relative strength of loops cannot be exactly determined. Hence, the dynamics can show potential development paths of the system but further parametrisation and model development would be necessary to analyze different potential future scenarios. A description of the dynamics of each intervention will be presented in the following:

A-7.4.1.1Fossil fuel ban for buildings

In Figure 4 one can see the dynamics that the group identified as relevant for assessing the effects a fossil fuel ban in buildings. It was assumed that a fossil fuel ban would directly affect the number of heating system exchanges, which relates to a number of other relevant dynamics. According to this group's CLD heating system exchanges are directly driven by one reinforcing loop (R1) and two balancing loops (B1 & B2) as well as a another indirectly connected balancing loop (B3). While a fossil fuel ban for buildings pushes the dynamic of heating system exchanges to steadily increase due to a reinforcing dynamic caused by education and skilled labor supply (see Figure 4 R1), the dynamics of investment cost and financing instruments are balancing out heating system exchanges over time (Figure 4 B1-3). Despite not being represented in this diagram, the delay related to education needs to be considered when analysing this dynamic further. This means driving the reinforcing feedback loop R1 in the desired direction by for example investing in education, can be identified as an intervention point in this diagram. Similarly, interventions for reducing the balancing effect of cost, investment and financing of heating system exchanges, could be explored.

Another insight that can be drawn from this CLD is that although heating system exchanges are mostly driven by the above-mentioned loops, heating system exchanges influences other dynamics in the system, such as those related to alternative and biomass boilers, which again affects biomass use and electricity, which relate to further dynamics (of sustainable development) that are partly covered by the iSDG already.

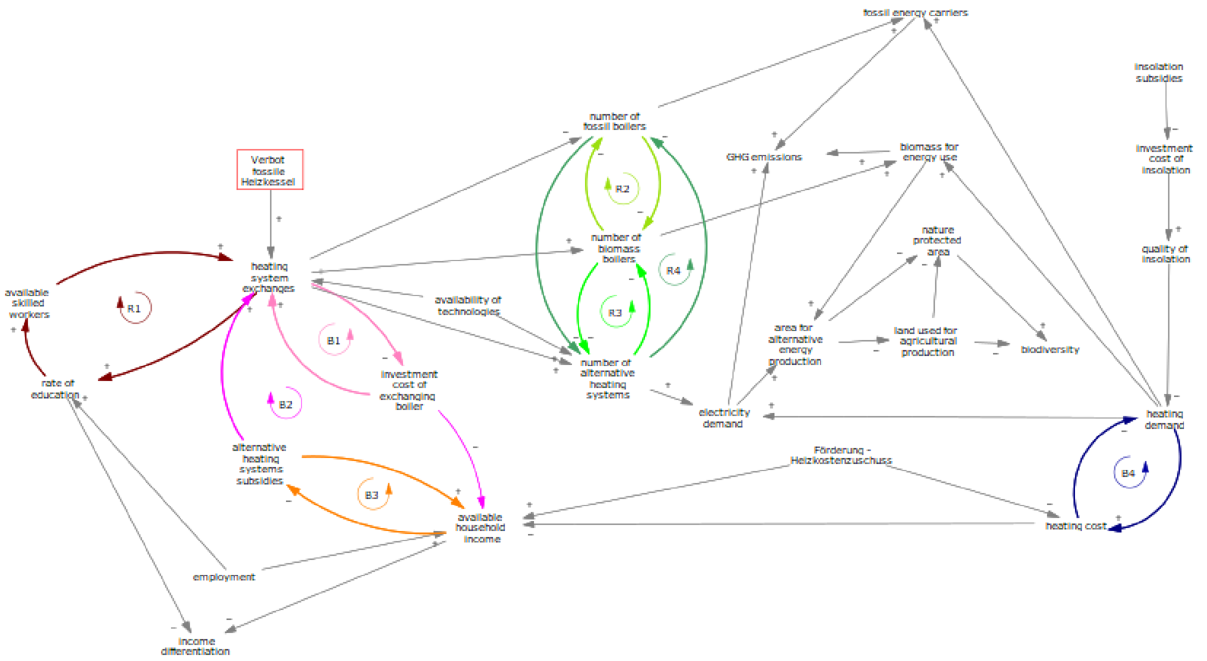

Figure 4: Fossil fuel ban for buildings CLD

A-7.4.1.2 Building standards

In this CLD the main dynamics connected to building standards (i.e. insulation), as identified by the group, are captured. One reinforcing (Figure 5 R1) and five balancing (Figure 5 B1-5) dynamics were identified in relation to building standards. For B1 & B2 in Figure 5this means the balancing behaviours arise from the dynamics of regulation, technological advancement and skilled labor. In Figure 5 B3-5 the balancing effect of cost and renovation investment is added. Both balancing behaviours mean that the number of renovated houses is not growing continuously but rather follows a pattern of increase and decrease over time (i.e. oscillation). Only one reinforcing (Figure 5 R1) dynamic occurs in this CLD, which is related to cost of renovation and affordability. This reinforcing loop could either steadily drive the number of renovated houses down or up, depending on which direction it is pushed into. In connection with the balancing loops, the reinforcing loop could have the potential to increase the magnitude of oscillation in the number of renovated houses, as it iteratively gets pushed into different directions (i.e. more/less skilled labor) through the balancing dynamics of the remaining loops (Figure 5 B1-5). Through driving the one reinforcing loop (Figure 5 R1) of skilled labour and affordability towards more skilled labour the dynamic can lead to an overall trend of growing number of renovated houses. Such an intervention would also reduce the risk of poverty. Additionally, in order to driving the reinforcing loop into the desired direction, a possible intervention could also address the balancing effects, to reduce oscillations. In the chart, two balancing loops (Figure 5 B4 & B5) that impact the building standard dynamics are depicted but the influence from the latter on the former was not considered.

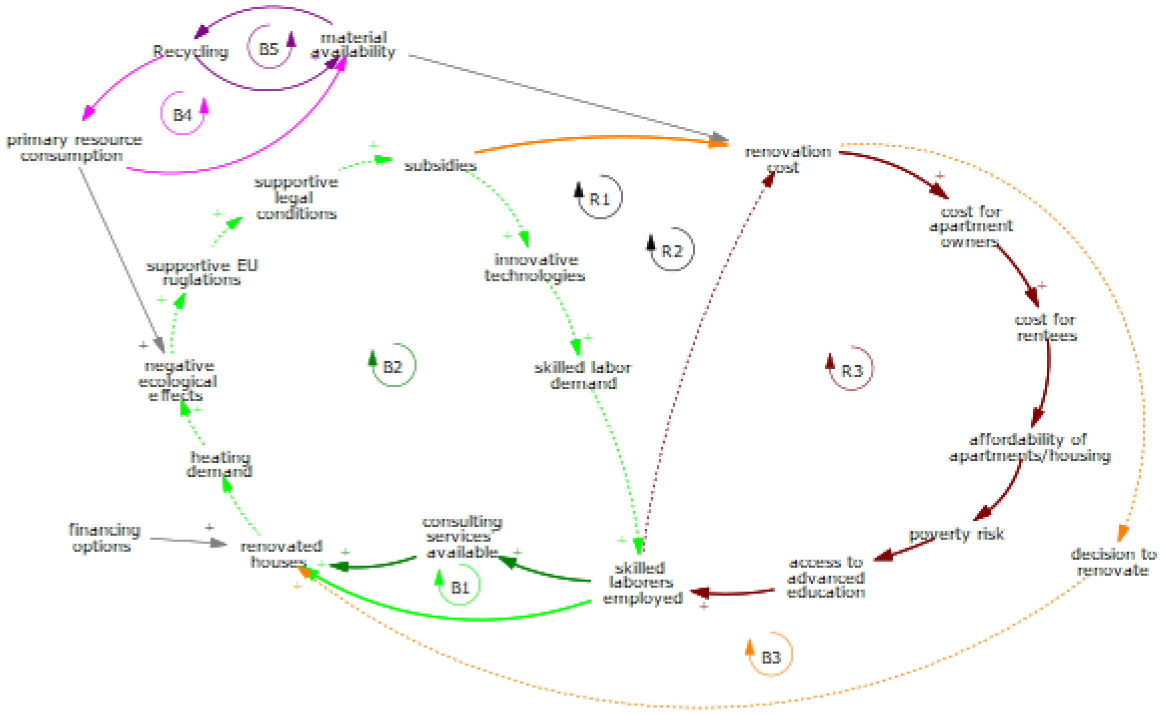

Figure 5: Building standards CLD

A-7.4.1.3 CO_2 tax

Figure 6 shows how a CO_2 tax directly affects the price of fossil energy and government revenue and through this several other dynamics as depicted. While the former (i.e. price of fossil energy) only influences variables related to the dynamics of the CO_2 tax but is not influenced through those dynamics itself, the latter is part of the dynamics itself. This means that government revenue is part of the identified balancing and reinforcing feedback loops. Thereby, it affects and is affected by the dynamics of the loops. The first two loops government revenue is part of are reinforcing (Figure 6 R1 & R2). Hence, pushing government revenue to increase through implementing a CO_2 tax would lead to ever growing government revenue through the dynamics connected to skilled employment and income level as well as the growing consumption due to state transfers. As displayed in Figure 6 all of the factors in R1 & R2 are set to continuously grow once they are pushed into the direction. However, other factors can affect those variables, also changing their behavior over time, such as the two balancing loops or the price of fossil energy (see Figure 6). The two balancing loops (Figure 6 B1 & B2) represent how technological innovation and fossil energy consumption influence government revenue iteratively. B1 in Figure 6 displays how when government revenue increases due to the CO_2 tax, more R&D in low carbon technologies occurs and more low carbon technologies get employed, this leads to a decreased use of fossil-based energy technologies, which reduces employment, which again leads to lower income level and consumption and thereby, lower government revenue. However, this decreased government revenue, causes lower investment in R&D in low carbon technologies, which would increase the use of fossils, which in the end leads to higher government revenues again. The same balancing dynamic is evident in B2, however it acts through the additional factor of fossil energy consumption. Technological developments are not only creating and acting through the two balancing loops but also two reinforcing loops (Figure 6 R3 & R4), meaning they drive the system further into the direction it gets pushed as a result of the (oscillating) dynamics in the balancing loops or through external factors, such as the CO_2 tax. As described above the CO_2 tax pushes the reinforcing dynamics connected to government revenue into a direction that is beneficial for government revenue but also low carbon technologies. Higher prices due to the CO_2 tax on the other hand are contradicting this as they push private consumption down, which could lead to lower government revenues and variables in the other reinforcing loops would also follow a decreasing trend.

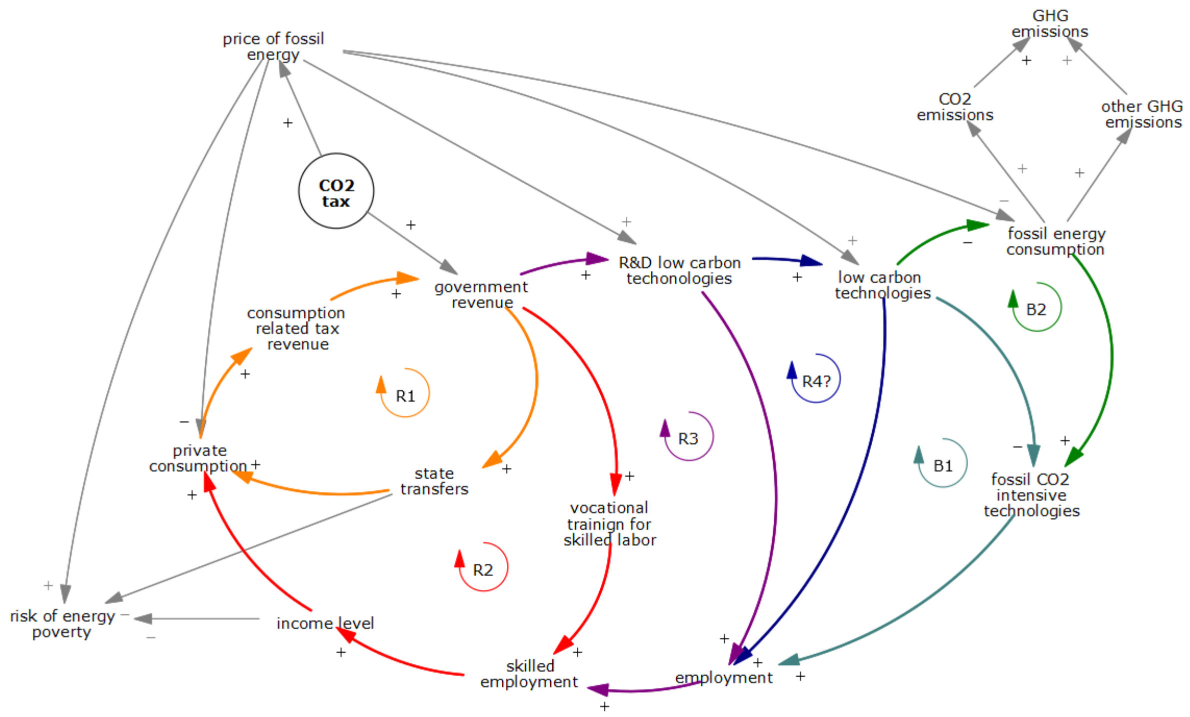

Figure 6: CO_2 tax CLD

A-7.4.1.4Vehicle fossil fuel ban

This group determined several dynamics that are relevant to understanding the impacts of a ban on fossil-fueled vehicles. All of the dynamics identified except one were of reinforcing nature. Several variables of the transport system that are directly influenced by a fossil fuel ban for vehicles were identified. Those variables are highlighted in blue if they are positively (+) and red if they are negatively (-) affected in terms of link polarity (see Figure 7).

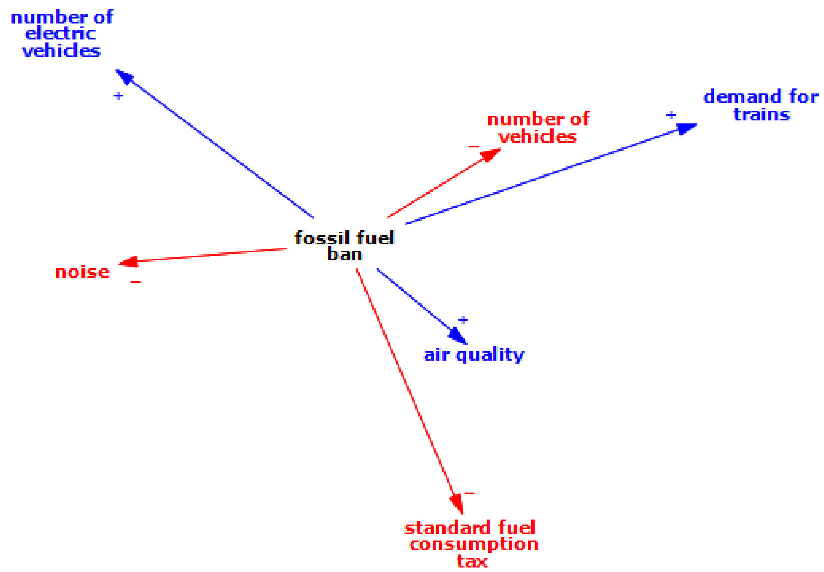

Figure 7: Variables affected by vehicle fossil fuel ban

Not all variables that were identified to be affected are embedded into the system's dynamics. Air quality and standard fuel consumption tax affect the system as they can push it into a certain direction but are not affected by its dynamics. On the one hand, a fossil fuel ban would increase air quality through which health and satisfaction of citizens improves. On the other hand, by implementing a fossil fuel ban, the standard fuel consumption tax would fall, which means the available public budget as well as the acquisition cost of new vehicles decrease. The acquisition cost of electric vehicles drives a reinforcing dynamic (Figure 8 R1) as it increases the number of vehicles, which again decreases the production cost of vehicles, which reduces the acquisition cost of electric vehicles. This again leads to a higher number of electric vehicles etc., hence an ever-growing number of electric vehicles. The other three variables that are directly affected by the fossil fuel ban are embedded into the system's dynamics. One of them is the number of electric vehicles, which is part of the dynamics described before.

The introduction of the fossil fuel ban enhances the reinforcing dynamic causing a rising number of electric vehicles (Figure 8 R1). At the same time the number of electric vehicles also positively influences the number of vehicles, which means in the case of a fossil fuel ban introduction it would increase the number of vehicles. However, the number of vehicles is also negatively influenced by the introduction of a fossil fuel ban for vehicles as fossil fuel vehicles are removed. Additionally, the number of vehicles is directly connected to three reinforcing loops (Figure 8 R2, R3, R6). It is important to note that those reinforcing dynamics can accelerate the effect of an increasing or decreasing number of vehicles, depending on which direction (i.e. increasing/decreasing) this variable initially moves. One way this initial behavior would be enhanced is through the development of parking and public spaces, which impacts on demand for walking and biking (Figure 8 R2). Another way would be through public transport infrastructure and access to trains (Figure 8 R3). Last but not least the number of vehicles is part of a wider system dynamic (Figure 8 R6) that reinforces initial behavior through driving the dynamic of parking spaces, public spaces, citizen satisfaction and health, the cost of health and thereby, the public budget and investment in alternative infrastructure and access to public transport, which again influences the number of vehicles.

Also demand for trains, which is positively affected by a fossil fuel ban, is connected to two reinforcing dynamics (Figure 8 R3 & 4). This means introducing a fossil fuel ban would lead to a growing demand for trains and public transport, which would lead to a lower number of vehicles and more infrastructure again increasing the demand for public transport. However, the variable is connected to further dynamics and variables, which can cause the reinforcing affect to potentially shift into the other direction over time.

Infrastructure and investment create a reinforcing dynamic (see Figure 8 R5). Investment and available public budget, however, create the only balancing loop in this representation of the system, which can lead to a shift in the direction (i.e. increasing/decreasing) of reinforcing behaviors.

Another insight that can be drawn from this is CLD is how other variables related to the SDGs, such as employment are driven through the depicted dynamics.

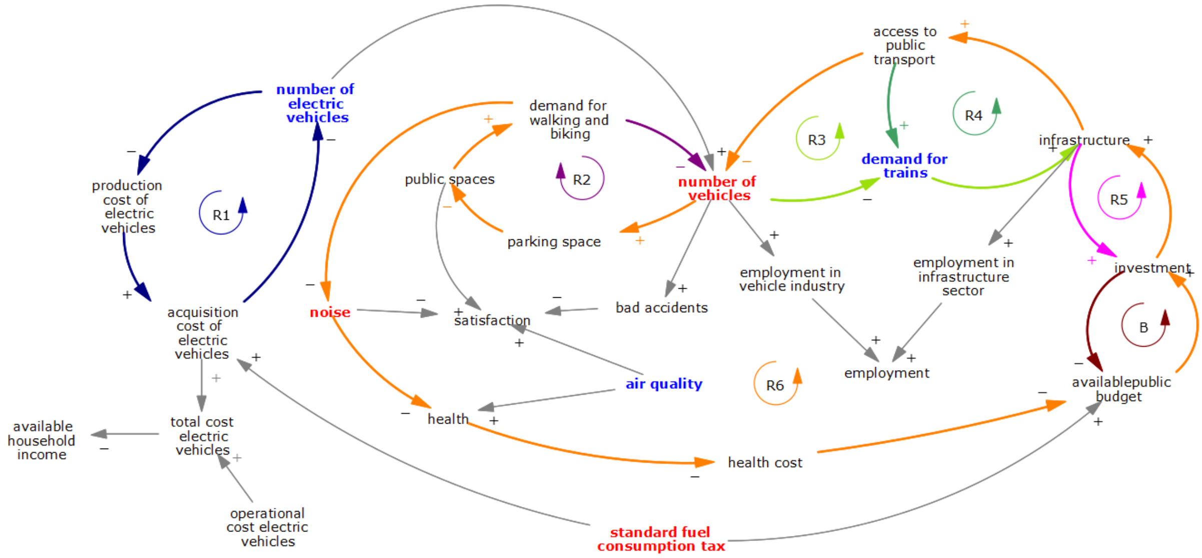

Figure 8: Vehicle fossil fuel ban CLD

A-7.4.2 *Results and discussion regarding workshop method*

Despite not carrying out the steps of a full group model building process, holding the workshop still made sure some of the benefits of participatory modelling could be gained in this project as for example described in (Antunes et al., 2006; Videira et al., 2010). It enabled participants of the workshop to combine their knowledge and expertise relevant to the mitigation policies. This fostered the participants' learning as they could explore connections between individual system components. This enhances their understanding of synergies and trade-offs occurring in relation to different mitigation policies. Additionally, the workshop provided the project team with a basis for potential future project and model structure developments.

A-7.5 Further development needs and next steps

Based on the above several development needs to proceed with modelling the SDGs and particularly interventions related to SDG13 should be taken. Those steps can be divided into more concrete and short-term ones that relate to finalizing the iSDG model for the Austrian context and more long-term ones that.

Short-term model development needs and next steps:

- Resolving the major calibration issue around private saving to run a business as usual scenario for Austria. For this additional finance data will be required and investigating related model structures will be necessary.
- Resolve minor issues related to current energy and land and soil sectors.
- Integration of further SDG indicators relevant to the Austrian context.

Long-term model development needs and next steps:

- Integrate additional model structures (based on stakeholder and expert engagement) for climate change mitigation and adaptation strategies and their effects on national level.
- Investigate how to down-scale/disaggregate the national model structure to make it applicable for assessing climate change mitigation and adaptation strategies and their effects on regional/local level.

Other development needs and next steps:

- Carry out stakeholder and expert workshops that apply elements of participatory modelling to enhance insights into climate change mitigation and adaptation measures and their system wide effects among experts and stakeholders.

A-8 Conclusion & Outlook

iSDG_KlimAT focused on modeling the Sustainable Development Goals (SDGs) to capture connections between SDG13 and others. As a result of the project further development steps could be derived from the quantitative model development process. This will make the model fully applicable in the Austrian context and enable more specific analysis of climate change adaptation and mitigation strategies and the associated costs of those. At the national level, an improved integration of financial data would be needed. At the regional level a more detailed breakdown of individual sectors and the structural integration of more specific adaptation measures and their related structure into the iSDG model would also be beneficial. In addition to those more general findings related to the quantitative model assessment, in a stakeholder and expert workshop, the basis for further development of model structures climate change mitigation strategies was created. This was done by applying tools of participatory modelling, through which system structures of selected mitigation strategies (ban on fossil-fuelled vehicles, building standards, ban on fossil heating systems and CO_2 tax) were mapped out together with experts and stakeholders. From this initial synergies and conflicting goals were recorded. The method used (i.e. Causal Loop Diagrams) ensured a systemic comprehension of participants system knowledge of workshop participants as well as it allowed participants to gain new insights into climate protection measures and arising dynamics. For example, the positive effect on poverty through investment and training programs that would be necessary in connection with individual measures was recorded. However, it also became clear that this synergetic effect would only occur after a delay. While it was not possible to run a full analysis concerning synergies and trade-offs and related costs, the project laid the foundation for modelling and analyzing those in the future. The project has created a good basis for further projects (ACRP - SDGVisionPath & Horizon Europe - TANDEM) dealing with the modeling of SDGs. The participatory approach tested in iSDG_KlimAT will also be used in these two projects. Furthermore, elements of participatory modeling were also identified as suitable for developing holistic regional climate protection and adaptation strategies as they enhance systemic understanding of the complex challenges related to climate change and can uncover important intervention points.

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