

Exploring Degrowth Pathways Using System Dynamics

Key words:

Degrowth, Limits to growth, degrowth pathways, World3, planetary boundaries

Abstract

During the 40 years that have passed since the publication of The Limits to Growth, the concept of degrowth and system dynamics have sometimes developed separately. There is now increasing evidence supporting the conclusions of The Limits to Growth and degrowth is a concept being discussed both in the academic and public debate. There is a need to look at potential ways to adapt to the limits of our world system. In this study degrowth pathways are explored by the use of causal loop diagrams and system dynamics simulation models. Departing from a study of degrowth pathways and the Limits to Growth's World3 model, the potential effectiveness of degrowth pathways are explored. The conclusions are that degrowth proposals have a large potential impact when looking at the feedbacks and relations in the causal loop diagrams, but that this does not show in the simulated behavior of our modified World3 model. It is possible that this depends more on the structure of the World3 model than on the effectiveness of the proposals introduced. Hence, we believe that there is a need for new system dynamics world models to fully explore the potential of degrowth and the transformation to a sustainable society.

Therese Bennich, Tom Bongers & David Collste
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Introduction

“There is too much bad news to justify complacency. There is too much good news to justify despair.”

– Donella H. Meadows¹

It is now more than 40 years since *The Limits to Growth* (Meadows, Meadows, Randers, & Behrens III, 1972) was published. The study departed from four potential behavior patterns of the future world population. The objective was to see which development pattern was most likely to occur, given the structure of the world (Meadows, Richardson, & Bruckmann, *Groping in the Dark*, 1982).

One of the conclusions of the study was that physical growth constraints would be “*an important aspect of the global policy arena in the twenty-first century*” (Meadows et al., 2004, p. xvii). Now, 40 years later, there is increasing evidence supporting the conclusions of the study, e.g. the thinning of the ozone layer, climate change, biodiversity loss, and the decrease of phosphorus and nitrogen (Rockström, et al., 2009; Steffen, et al., 2015). We have so far been unable to create the change needed to reach a sustainable development as we are not sufficiently acknowledging the physical boundaries of the planet (Meadows, Randers, & Meadows, 2004).

One discourse questioning unrestricted growth, in line with the conclusions of the Club of Rome study, is *degrowth*. Degrowth has its roots, beside the work presented by the *Club of Rome*, in the fields of economic ecology, social ecology, economic anthropology and in environmental and social activist groups. Degrowth is now on the agenda, discussed both in academic circles and environmental movements (Videira, Schneider, Sekulova, & Kallis, 2014). In this paper we explore different *degrowth pathways* and their potential effectiveness. We depart from the article *Improving understanding on degrowth pathways: An exploratory study using collaborative causal models* (Videira, Schneider, Sekulova, & Kallis, 2014), in which degrowth proposals are presented and evaluated in terms of compatibility. We also depart from *The Limits to Growth’s World3 model* as presented by Meadows et al. (1972).

The main objectives of our study are:

- To examine, refine and improve the model drafts (Causal Loop Diagrams) of degrowth proposal as presented by Videira et al. (2014).
- To translate these degrowth proposals into the World3 model in order to examine their potential effectiveness.

The first part of the paper explains the methodology used and states our starting points for the modelling exercise. After that, we present the theoretical background of the study. The following section shows the refined versions of the Causal Loop Diagrams, and thereafter the stock and flow structure is presented. This is followed by an analysis, a presentation of the simulation results and the different scenarios. We end with a discussion of the results before a final conclusion.

¹ (Meadows D. , The state of the planet is grim. Should we give up hope? | Grist, 2001)

Methodology

Both causal loop diagrams (CLDs) and system dynamics simulation models are used. The World3 model and the degrowth pathways proposed in Videira et al. (2014) serve as starting points for our examinations of the effectiveness of degrowth pathways. We refine and improve the three CLDs presented by Videira et al. (2014), and link the sectors together in one CLD that shows how the sectors are interrelated. In the refinement process we have embedded systemized knowledge based on degrowth literature and the World3 model.

Based on the refined CLDs we have chosen two proposals - resource sanctuaries and work sharing for integration into the World3 model. The basis for our choice of these two proposals is our interest in testing these policies on an aggregated, global level, and their applicability to the World3 model. We translated these proposals into stock and flow structures for integration into the World3 model (Meadows, Randers, & Meadows, 2004). This is the simulation part of the modeling exercise. In order to evaluate the potential effectiveness of the proposals we used two reference modes - industrial output and the ecological footprint. The proposals are examined based on their impact on the reference modes.

Background

This section gives an introduction to degrowth, the paper by Videira et al. (2014) and the World3 model.

Degrowth

Theories challenging the market economy, industrialized capitalism and growth in productivity and output go back to the 19th century (Exner, 2014). However, degrowth as a concept was more formally introduced in the 1970s and the publication of *The Limits to Growth* (Meadows, Meadows, Randers, & Behrens III, 1972). The purpose of this study was “*to gain insights into the limits of our world system and the constraints it puts on human numbers and activity (...) [and] to help identify and study the dominant elements, and their interactions that influence the long-term behavior of world systems.*” (Meadows, Richardson, & Bruckmann, 1982, s. 24). As a consequence of the problem formulation, the book focuses on the pattern and mode of overshoot and future decline. The authors were criticizing the hegemonic growth paradigm. Criticism against the book was massive and the developed world model, World3 (Meadows, Richardson, & Bruckmann, 1982). For example, economist F.A Hayek wrote: “*far-reaching claims are made on behalf of a more scientific direction of all human activities and the desirability of replacing spontaneous processes by "conscious human control".*” (von Hayek, 1975, s. 439). Nevertheless, the World3 model is probably also the most acclaimed world model. Today there is a growing appraisal of the book and a recent comparison between the scenarios presented by Meadows et al. (1972) where the real world development shows that the world is developing in a pattern that is close to what the authors initially called the ‘standard run’ (Turner, 2008; Rockström, et al., 2009).

Besides Meadows et al. (1972), degrowth has its roots in the fields of economic ecology, social ecology, economic anthropology and in environmental and social activist groups. The anthropologists are questioning whether western models of development should be imposed on the so called developing countries – and challenge the current growth paradigm and GDP as an indicator for human progress. Another source of degrowth theories comes from the request for decentralization and the strengthening of democratic institutions. Economic interests are considered as having too much influence on politics and the education system. Yet another part of the degrowth debate

relates to a more spiritual dimension, raising questions about the *meaning of life* and promoting non-violence, art, and a simplistic lifestyle (Schneider, Kallis, & Martinez-Alier, 2010). Some argue that degrowth best serves as a visioning tool which could help redefining well-being and welfare. Degrowth would then enable the development of an alternative vision for the future, a future where *better* is promoted instead of the current *more* (Martinez-Alier, Pascual, Vivien, & Zaccai, 2010). Also, degrowth aims to display the unsustainability in growing just for the sake of growth. As stated by Serge Latouche (quoted in Matinez-Alier et al. (2010)), a degrowth society should be a “*society built on quality rather than on quantity, on cooperation rather than on competition*” (p. 1742) . Further, in a degrowth society “*humanity [is] liberated from economism for which social justice is the objective*”(p. 1742). Latouche also writes that “*The motto of de-growth aims primarily at pointing the insane objective of growth for growth*” (Martinez-Alier, Pascual, Vivien, & Zaccai, 2010, p. 1742). From an environmental perspective unlimited physical growth is unsustainable for different reasons, primarily because it threatens the biophysical limits of planet earth. The ecological field emphasizes the need for ecosystem protection and the lack of respect for other living beings. A slightly different approach is provided by the field of ecological economics, which points out that the planetary boundaries and the depletion of resources will eventually counteract economic growth. Herman Daly refers to the current economic growth of developed countries as *uneconomic growth* (Daly H. , 1999). The ultimate goal of degrowth is not negative GDP growth (Kallis G. , 2011). Many of the people in favor for degrowth do however argue that economic growth, even if it is labelled as a *green growth* or *sustainable growth*, will eventually lead to the collapse of the socio-ecological system as we know it today. This would inevitably also show in a decrease of GDP (Kallis G. , 2011).

There are many definitions of degrowth, since it is argued to be a *multi-dimensional* framework rather than one single indicator or policy. This opens up for different interpretations and various proposals for implementation. One definition of degrowth from an economic-ecological perspective is a sustainable, democratic and equitable reduction of throughput in society (Daly E. H., 1997). This definition refers to a process where the energy and materials extracted, consumed, used and finally returned to the environment as waste are reduced. A more elaborate definition is one stated by Schneider, Kallis & Martinez Alier (2010). This definition includes increased human well-being as an objective for degrowth. It also emphasizes a long term perspective. Degrowth is however not meant to be sustained indefinitely, but rather serve as a transition towards a more sustainable state of the environment and social system (Kallis, Kerschner, & Martinez-Alier, 2012).

Introducing degrowth as a solution to environmental problems has met opposition. Primarily, many mainstream economists do not agree that there are limits to economic growth (Litan, Baumol, & Schramm, 2008). Another point of criticism is that the concept is vague and the debate unfocused. The lack of a clear definition of what it means to *degrow*, and what exactly it is that needs to degrow could be problematic. No agreed definition could cause a lack of clear policy suggestions, and furthermore difficulties in measuring the outcomes of degrowth proposals. It could also generate low support from decision makers and the public (van den Bergh, 2010).

Improving understanding of degrowth pathways

In the article *Improving understanding on degrowth pathways: An exploratory study using collaborative causal models* (Videira, Schneider, Sekulova, & Kallis, 2014) the authors recognize the lack of clear goals and metrics in the degrowth debate. Departing from this, their aim is to clarify certain aspects of degrowth by exploring how different proposals relate to each other. The degrowth pathways are explored through involvement of researchers and activists in a collaborative setting. The method used was *Causal Loop Diagramming*. The process started with the identification of a ‘problem variable’ that was placed at the centre of each diagram, “*after which causes and consequences were added*” (Videira, Schneider, Sekulova, & Kallis, 2014, p. 62). Feedback processes

in the three sectors were recognized and after that different degrowth pathways were identified as leverage points. Furthermore, the compatibility of the proposals was presented in a matrix, identifying synergies. A toolkit was developed, in order to enable additional examination of future pathways. Examples of the pathways discussed in the article are house sharing, work sharing, resource sanctuaries, restriction on advertising, and moratoriums on large infrastructure projects. We have chosen two of the proposals presented in the article: resource sanctuaries and work sharing. These are further explored in the stocks and flows section below.

The World3 model

The simulation model we use for our examination of degrowth proposals is the World3 - first presented in *Limits to Growth* (Meadows, Meadows, Randers, & Behrens III, 1972) . A slightly modified version was presented in *Limits to Growth: The 30-Year Update* (Meadows, Randers, & Meadows, *Limits to Growth: The 30-Year Update*, 2004). We use the modified version. It is a highly aggregated system dynamics model that is divided into different subsystems; e.g. population, industry, agriculture, food production, non-renewable resources and pollution. The subsystems or sectors interact with each other and the behavior of the system arises from these interactions. The model can be used to evaluate different scenarios and to see how a change in one or more elements changes the behavior. This is useful for our case since we want to see how suggested degrowth pathways affects the behavior of the global system. Further, the model is useful for this study because our reference modes industrial output and ecological footprint are included.

We have identified two reference modes – the ecological footprint and industrial production – that are used to explore the potential effectiveness of the chosen degrowth pathways. As we depart from an environmental understanding of degrowth we are particularly focusing on the behavior in terms of industrial production and environmental impacts. Indexed data of industrial production is here displayed together with the industrial output as modeled in the World3 model. As an indicator for environmental impact we have chosen the Ecological Footprint, also displayed together with modeled values from the World3 model (in the model as ‘Human Ecological Footprint’). Our objective with the modelling exercise is to see what effect the chosen degrowth pathways are likely to have on these reference modes.

Reference modes

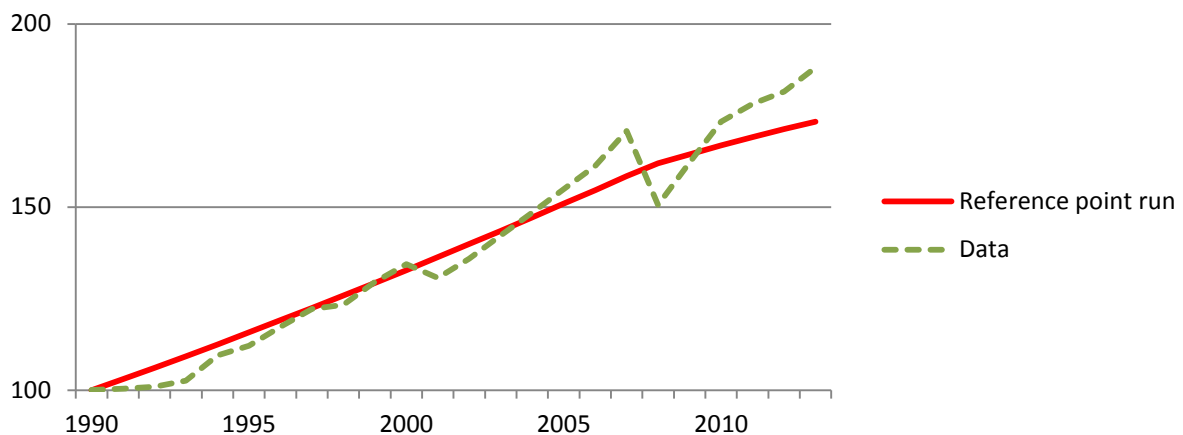


Figure 1: Relative development of industrial output since 1991, for World3 'reference point run' and data. Index: 1991. Source of data: CPB Netherlands Bureau for Economic Policy Analysis. For further comparison between world development and World3 runs, see Turner's *A comparison of The Limits to Growth with 30 years of reality* (2008).

The global industrial production is value added in mining, manufacturing, and utilities (CPB Netherlands Bureau for Economic Policy Analysis, 2013). This industry value makes up a large part of GDP. Historically the global industrial production has grown significantly. The increase in industrial output is problematic from an environmental perspective because it increases environmental impacts for instance pollution, unless it is coped with continuous extensive greening of the technologies used - which has so far not been the case (Meadows, Randers, & Meadows, 2004).

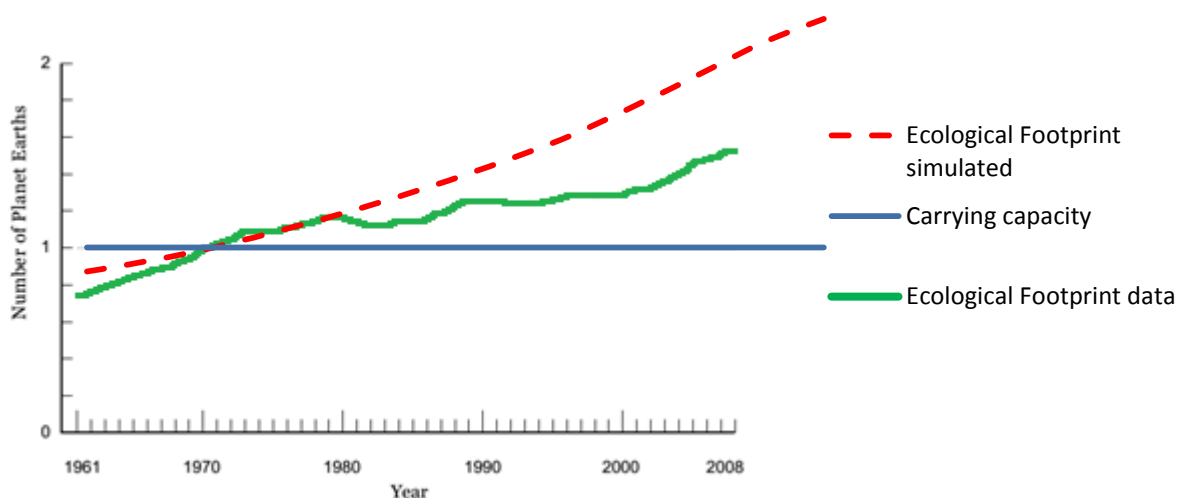


Figure 2: Development of the global Ecological Footprint according to data and the values simulated by the 'reference point run' in World3. Both are compared to the carrying capacity. Sources: WWF International (2012), and the World3 model (Meadows, Randers, & Meadows, 2004).

The environmental impacts in our study are measured in terms of the global Ecological Footprint (EF). The EF estimates the demand humans place on the earth's ecosystems. It is defined as "the area of productive land and water ecosystems required to produce the resources that the population consumes and assimilate the wastes that the population produces, wherever on Earth the land and water is located" (Wackernagel & Rees, 1996). Figure 2 presents the footprint for the global population together with the simulated Ecological Footprint from the World3 model's reference point run. Both are compared to the earth's carrying capacity. From this graph we can derive that the EF is growing and that human's demand has been exceeding nature's supply from around 1970. This

unsustainable condition is also referred to as 'overshoot'. A minimum condition for ecological sustainability is that footprints must be smaller than ecological capacity (Wackernagel & Silverstein, 2000). The sustainable level for Ecological Footprint in Meadows et al. (2004) is presented as 1.1, a level that was passed around 1980. In the graph presented, the simulated values are higher than the data suggests. This might have to do with the fact that World3 only approximates the ecological footprint *"to the extent this is possible within the confines of the limited number of variables in the World3 model"* (Meadows, Randers, & Meadows, Limits to Growth: The 30-Year Update, 2004, s. 292).

Modelling degrowth pathways

In this section we present Causal Loop Diagrams (CLDs) that capture and refine the important aspects of the three CLDs developed by Videira et al. (2014). This is followed by a presentation of the stock and flow diagrams (SFDs) that build on these CLDs.

Refined and improved Causal Loop Diagrams

In our refinements of the CLDs presented by Videira et al. (2014) we have included some variables from the World3 model. The refinements are based on our reasoning of the loops, in more detail presented in Table 1 in the Appendix. We have chosen to color some of the loops to make them easier to distinguish. Further, the degrowth pathways and their potential impacts are marked with thick lines. Each loop has got a number and a name. There are three sectors: one economic, one ecological and one social. We firstly present the original CLD and then the refined version for each sector. Lastly, we integrate all refined CLDs into one diagram.

Social sector

The social sector CLD as presented by Videira et. al (2014) is shown in Figure 3. The main variable is social inequality and from this CLD we can identify the main drivers of this variable (reinforcing loops R1, R2, R3, R9 and R10 in Figure 3). For example, the utilitarian view drives the will of accumulation and thereby increases social inequality. The impacts of social inequality are also shown in the CLD (reinforcing loops R4, R5, R6, R7 and R8). Several degrowth proposals are presented in the figure, marked with blue arrows. They address both the causes and effects of social inequality. One example is education, that is proposed to increase the recognition and promotion of the commons which could increase the support for other ethics.

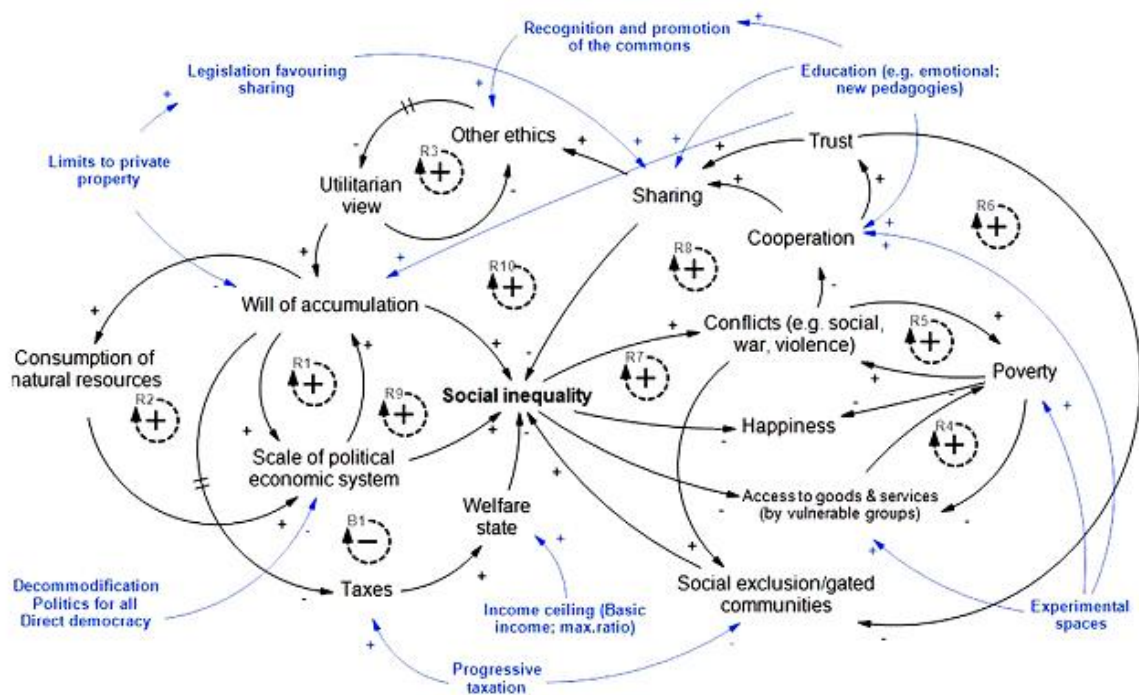


Figure 3: Feedback loops and degrowth proposals in the 'social sector' (Videira, Schneider, Sekulova, & Kallis, 2014).

Our refined social sector CLD is presented in Figure 4 and includes most of the loops presented by Videira et al. (2014). The utilitarian view and its effects on the will of accumulation are found in the upper left of Figure 4. Other core variables are size of the public sector, poverty, conflict and social inequality. The degrowth pathway of 'Education for sustainable development' is believed to increase the presence of other ethics and thereby impede the hegemonic position of the utilitarian view ('Education' in the CLD presented in Figure 3). All loops found in Figure 3 except R1, R4, R10 and B1 are also found in Figure 4— some are however slightly altered (see the Appendix for details on the refinements).

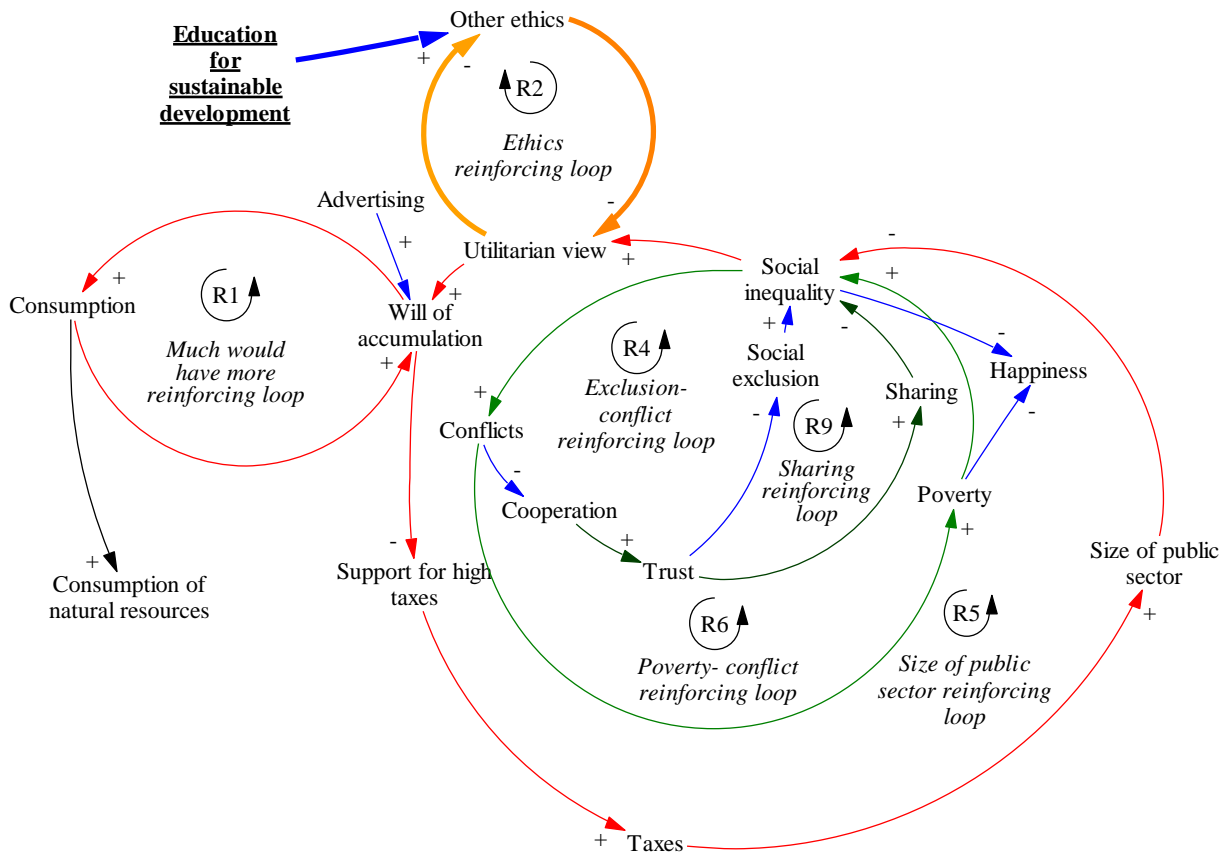


Figure 4: Feedback loops and the degrowth proposal 'Education for sustainable development' (in Videira, Schneider, Sekulova, & Kallis (2014)'Education' (e.g. emotional; new pedagogies)' in the 'social sector' part of our refined CLD.

Economic sector

In the original CLD showing the economic sector, here presented in Figure 5, the will of accumulation is also a driving factor. In the economic sector it increases consumption of natural resources. This increases private debt which can lead to increased financial market speculation and a financial market crisis. Growing debt can also lead to increased unemployment and social inequality through austerity policies. Different degrowth policies that can alleviate these negative consequences are included as leverage points, e.g. work sharing and basic income (blue arrows).

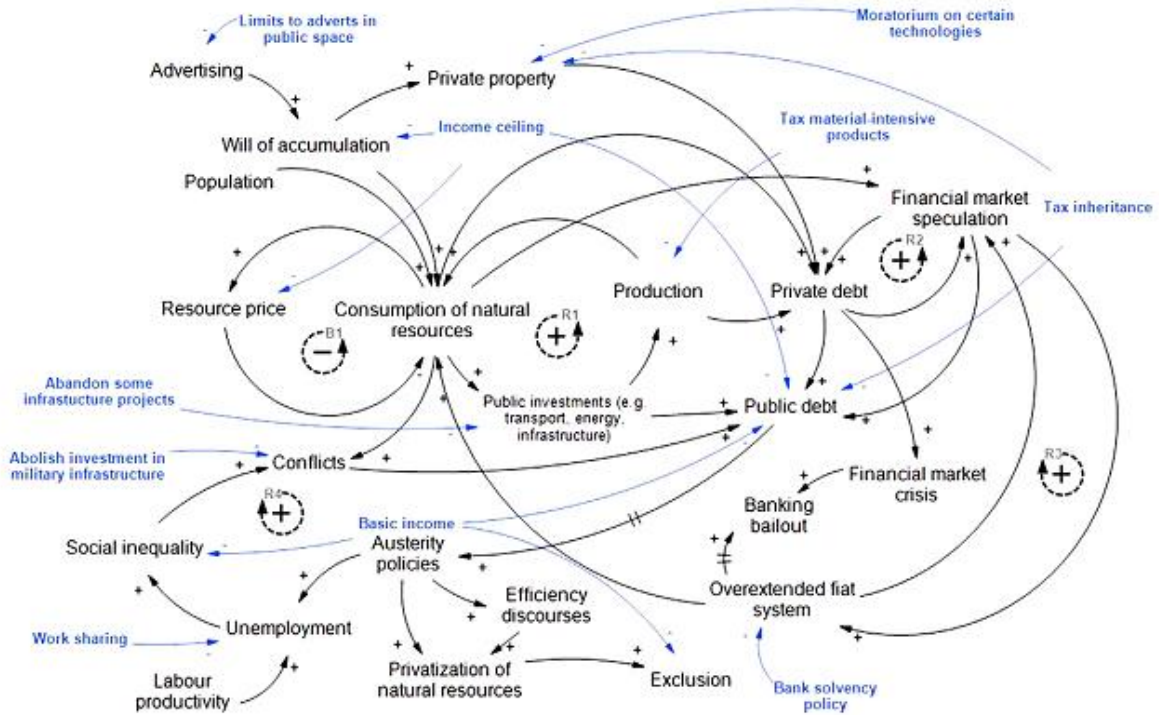


Figure 5: Feedback loops and degrowth proposals in the 'economic sector' (Videira, Schneider, Sekulova, & Kallis, 2014).

Our focus is not as much on the financial sector as it is on the production and consumption. Two reinforcing loops of production and consumption are put at the core (R1 and R3) of our CLD, presented in Figure 6. Except from loop R2 and R3 all loops found in Figure 5 are also found in Figure 6 – even though some are slightly altered (see the Appendix for details). Our CLD also includes the degrowth pathway 'Nonrenewable resource sanctuaries' which is included in the 'ecological sector' in Videira et al. (2014) as well as the proposal 'Work sharing'.

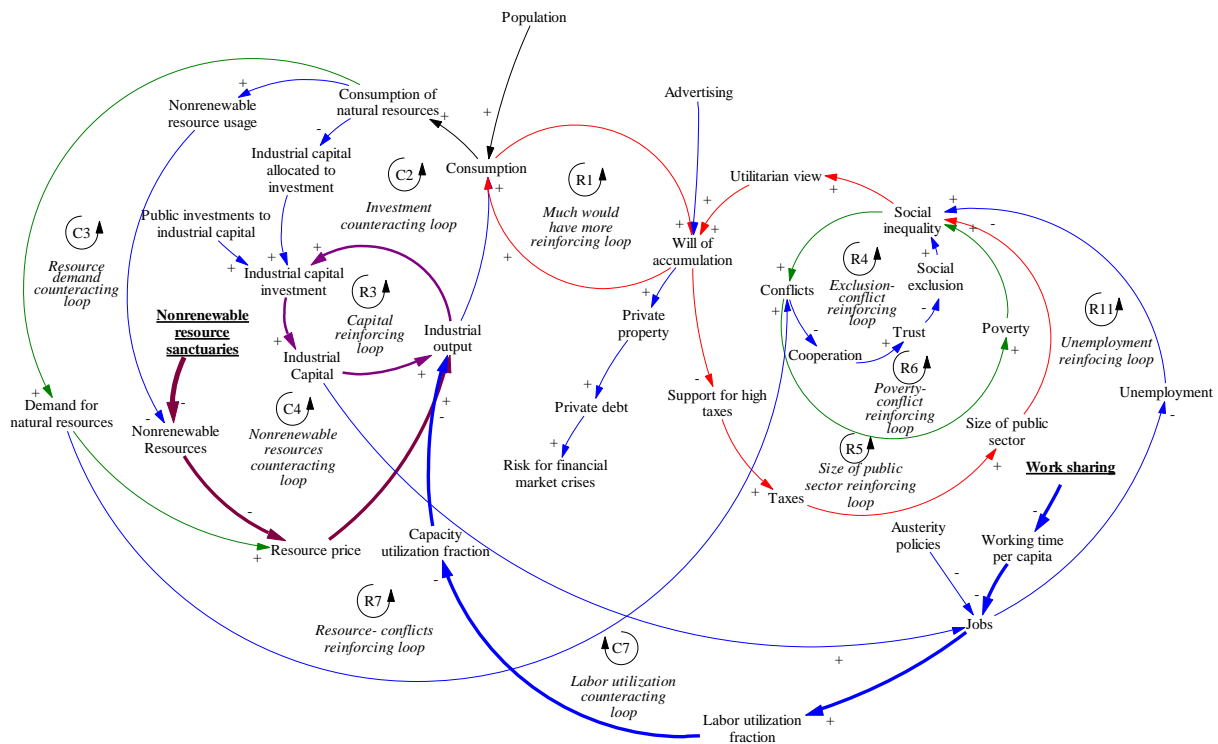


Figure 6: Feedback loops and the degrowth proposals 'Nonrenewable resource sanctuaries' and 'Work sharing' in the 'economic sector' part of our refined CLD.

Ecological sector

The original CLD presenting the ecological sector (Figure 7) is mainly focusing on the pressures on the state of biodiversity. It represents concerns related to overexploitation of natural resources and changes in natural land cover. One degrowth proposal is to introduce resource sanctuaries which would decrease the consumption of natural resources, increase the natural land cover and increase the state of biodiversity.

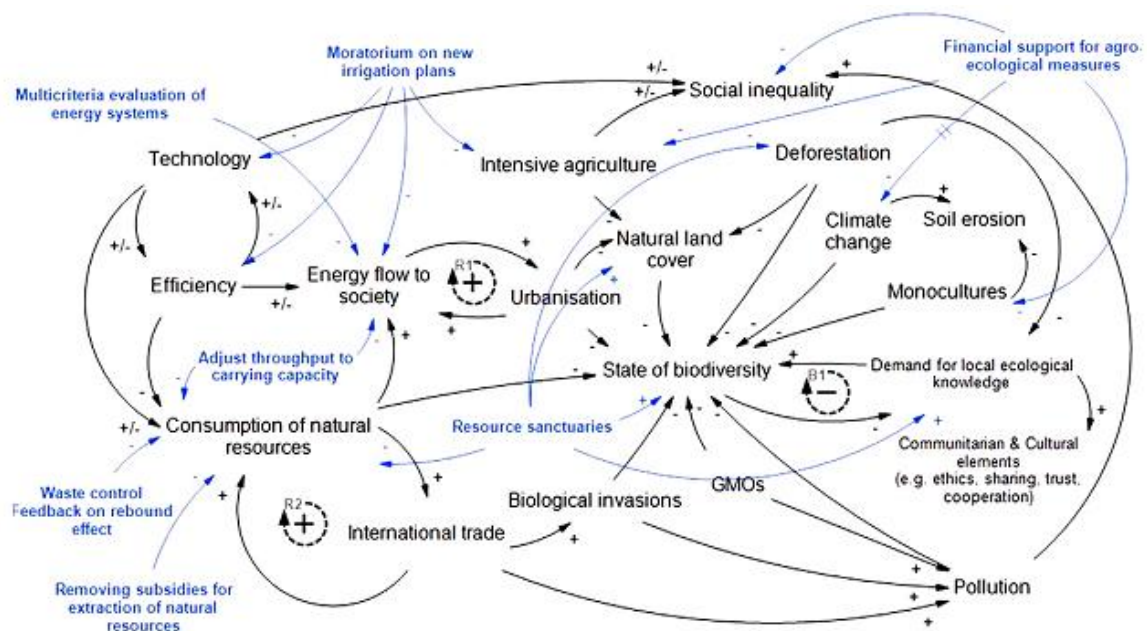


Figure 7: Feedback loops and degrowth proposals in the 'ecological sector' (Videira, Schneider, Sekulova, & Kallis, 2014).

Similar to the ecological sector CLD of Videira et al. (2014), state of biodiversity is put at the core of our CLD shown in Figure 8. While Videira et al. (2014) put the resource sanctuaries policy within the ecological sector, we included it in the economic sector, Figure 6..Note: Loop R8 is only a loop when the sectors are put together as in

Figure 9.

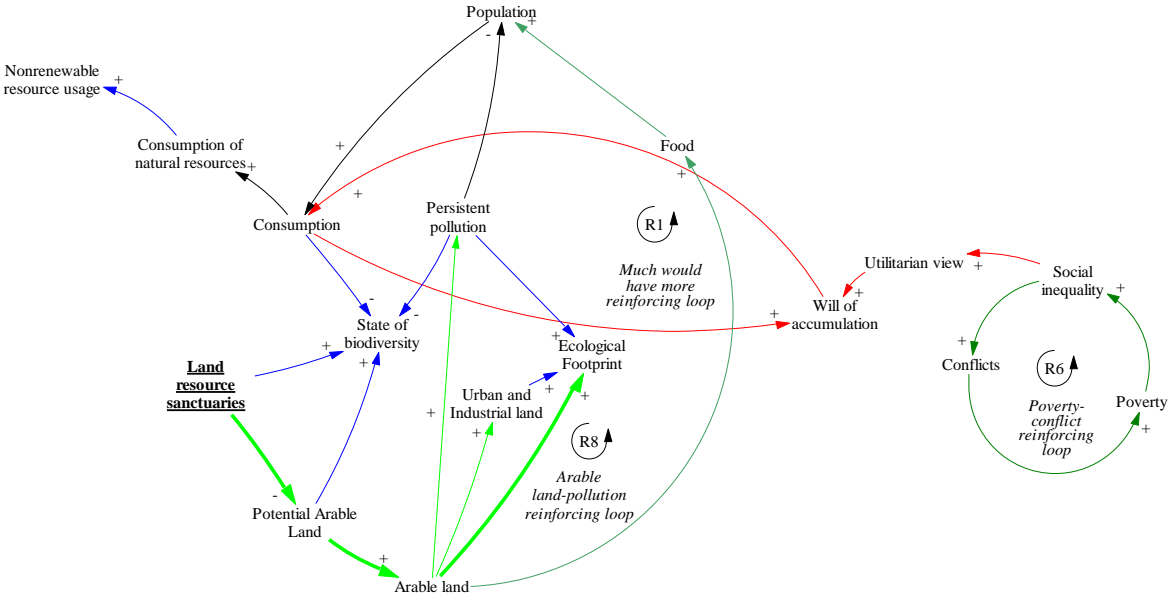


Figure 8: Feedback loops and the degrowth proposal 'Land resource sanctuaries' in the 'ecological sector' part of our refined CLD.

Causal loop diagram including all sectors

Figure 9 presents a CLD including all the sectors and the links between them. Also some important links from the World3 model are included. A more elaborate description of the CLD is included in the Appendix.

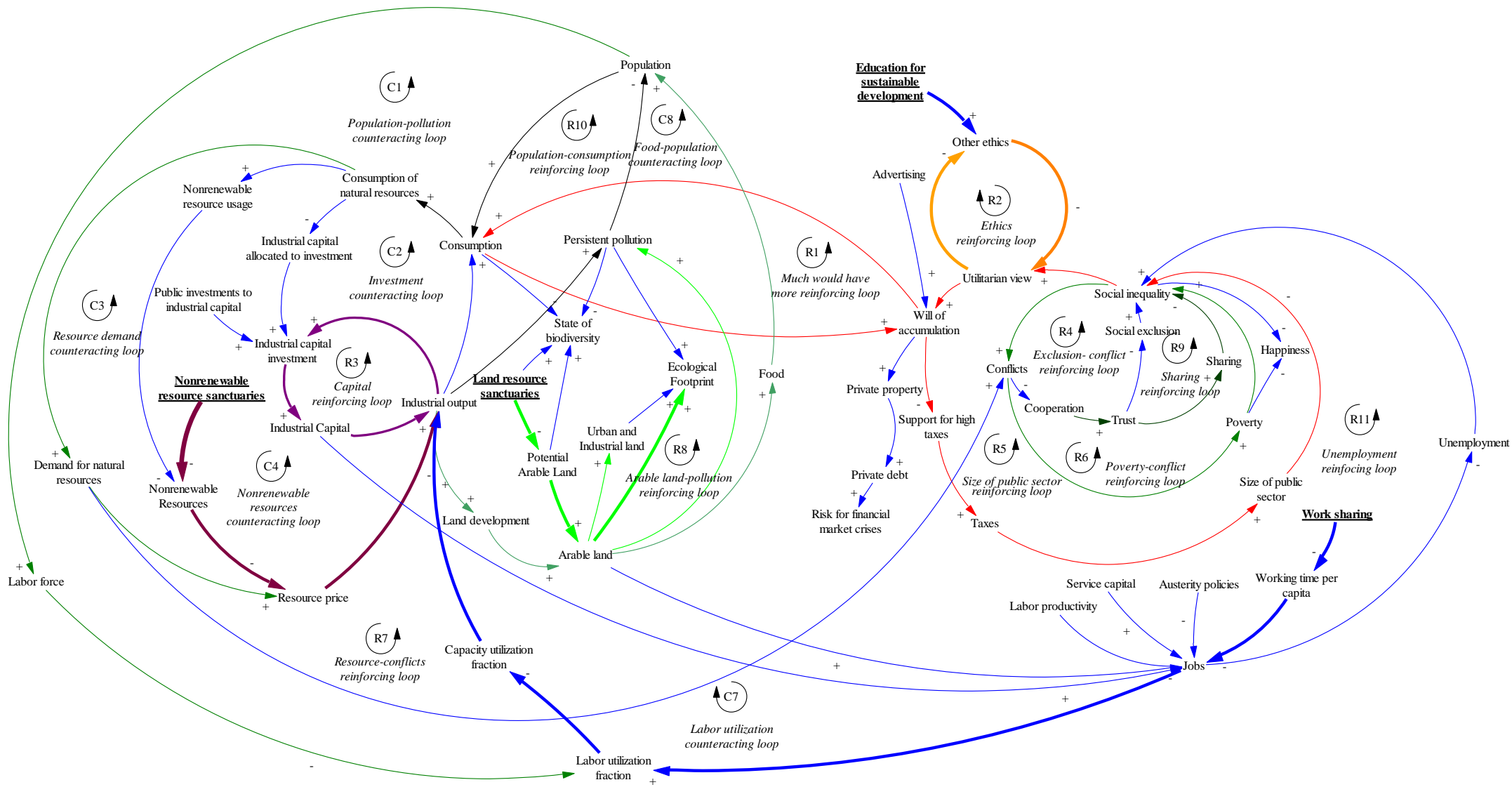


Figure 9: Major CLD showing the loops presented above and other loops we believe are relevant. Explained in further detail in Appendix A.

Stock and flow diagrams

To explore the effects of the degrowth proposals, we added structure in the World3 model and then simulated and analyzed the behavior. In this section we present and explain the modifications.

Resource sanctuaries

The first proposal introduces resource sanctuaries and this is represented by structure added within two sectors of the model. Within the nonrenewable resources sector of the World3 model (Figure 10) the main stock is *nonrenewable resources*. When nonrenewable resources are used resources remaining will decrease. One assumption made is that a lower fraction of resources remaining leads to a higher fraction of industrial capital allocated to obtaining resources (this follows the assumption that the resources that are left are more difficult to extract). The fraction of capital allocated to obtaining resources serves as an input to the industrial output sector of the model (the more capital allocated to obtain resources, the less industrial output). This feeds back to the resource usage rate (the less industrial output, the less resource usage). The resource conservation technology part represents the efficiency improvements in technology which, ceteris paribus, decrease the resource usage rate.

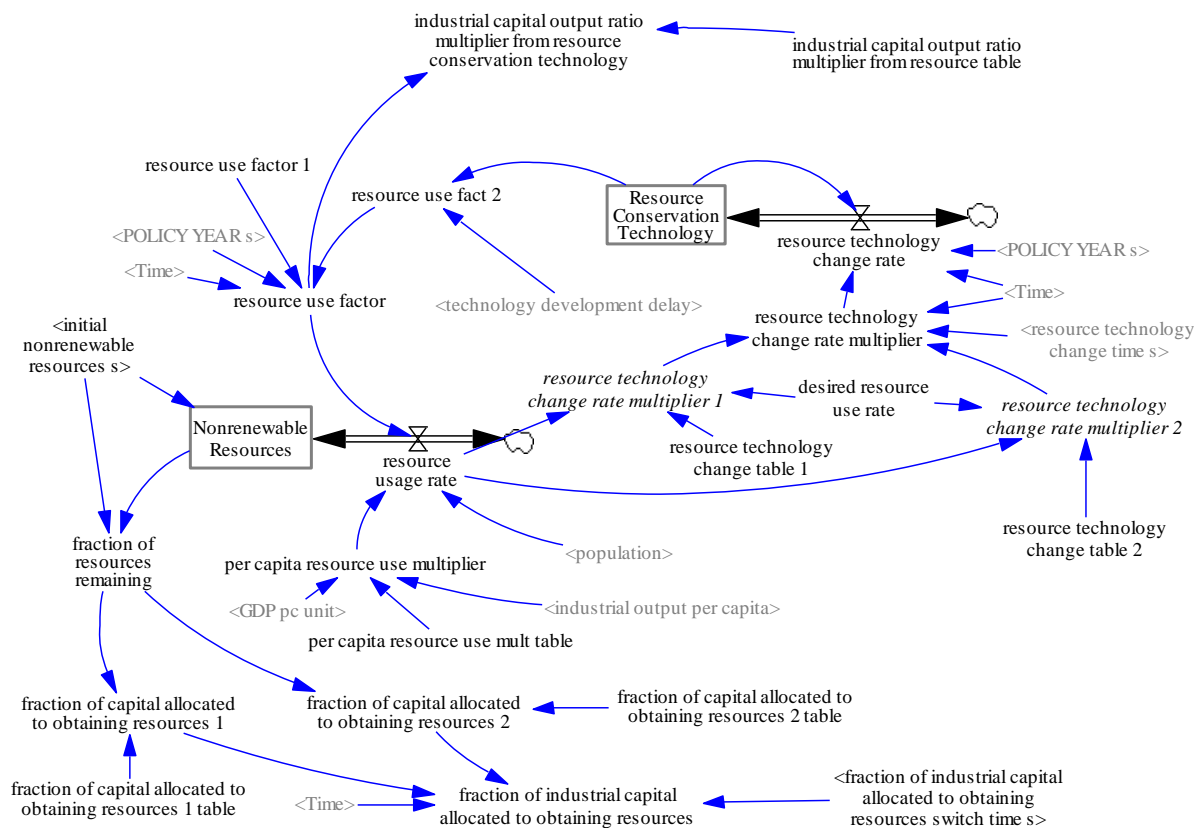


Figure 10: Nonrenewable Resources sector of the World3 model.

Figure 11 presents the added stock and flow structure in which we have introduced the nonrenewable resource sanctuaries. One of the degrowth proposals is to put a cap on the resource usage rate, in other words, expand the area of protected nonrenewable resource sanctuaries (Kallis, Kerschner, & Martinez-Alier, 2012). The proposal calls for a “desired” quantity of nonrenewable resource sanctuaries. In our structure this desired number is based on a fraction of the level of nonrenewable resources at the moment of policy implementation in the year 2014. This fraction is initially set to 15% and is based on the Yasuní-ITT proposal (Nysingh, 2012). In the proposal the Ecuadorian government planned to keep approximately 20% of the country’s proven oil reserve in the ground, located in the Yasuní National Park (Nysingh, 2012). The aim of this proposal was to conserve biodiversity, to protect the indigenous groups still living in voluntary isolation in the park

and to avoid release of pollutant emissions. We have added a desired level of nonrenewable resources sanctuaries of 15%. The time to create the sanctuaries is set to 5 years. Although it is a possible time frame in line with the urgent need to act for sustainability, one might argue that it is an overly optimistic assumption given the high level, and extent, of decision making needed for such a change. Nevertheless, it is a useful and applicable number when using the World3 model to investigate the potential outcomes of this degrowth pathway.

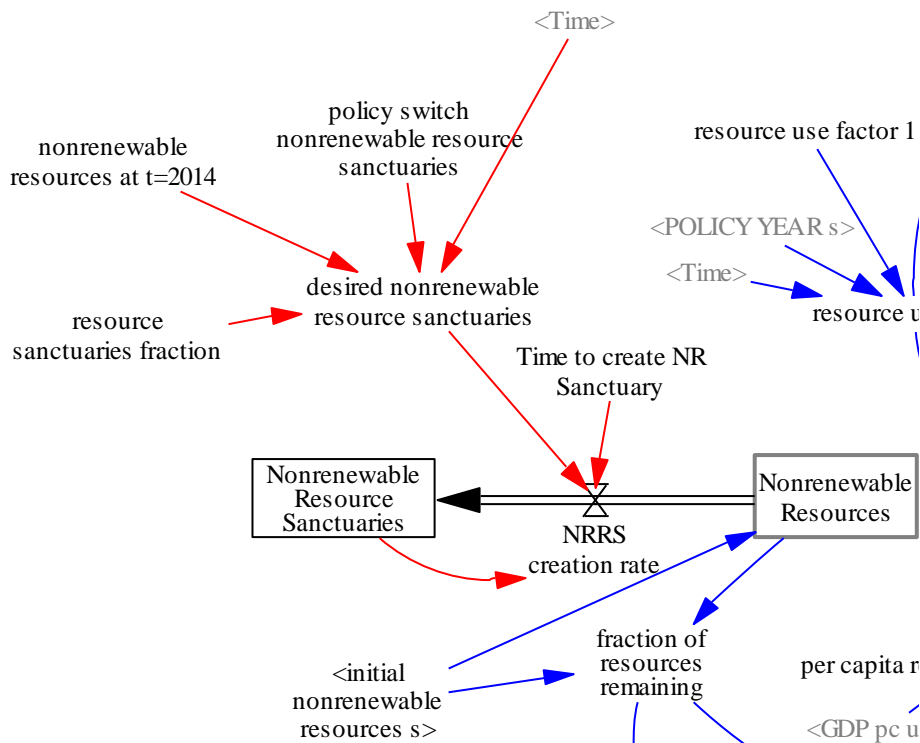


Figure 11: Model extension of nonrenewable resource sanctuaries.

The land development, land loss and land fertility sector of the World3 model (Figure 12) represents how potentially arable land may change into arable land and urban and industrial land. The rate in which the potentially arable land develops into arable land depends on investments. Arable land can then be used for urban and industrial purposes, and the rate depends on the land required per capita. Land required per capita uses input from the industrial sector (the higher the industrial output, the more land required) and the demographics sector (the bigger the population, the more land required) of the model.

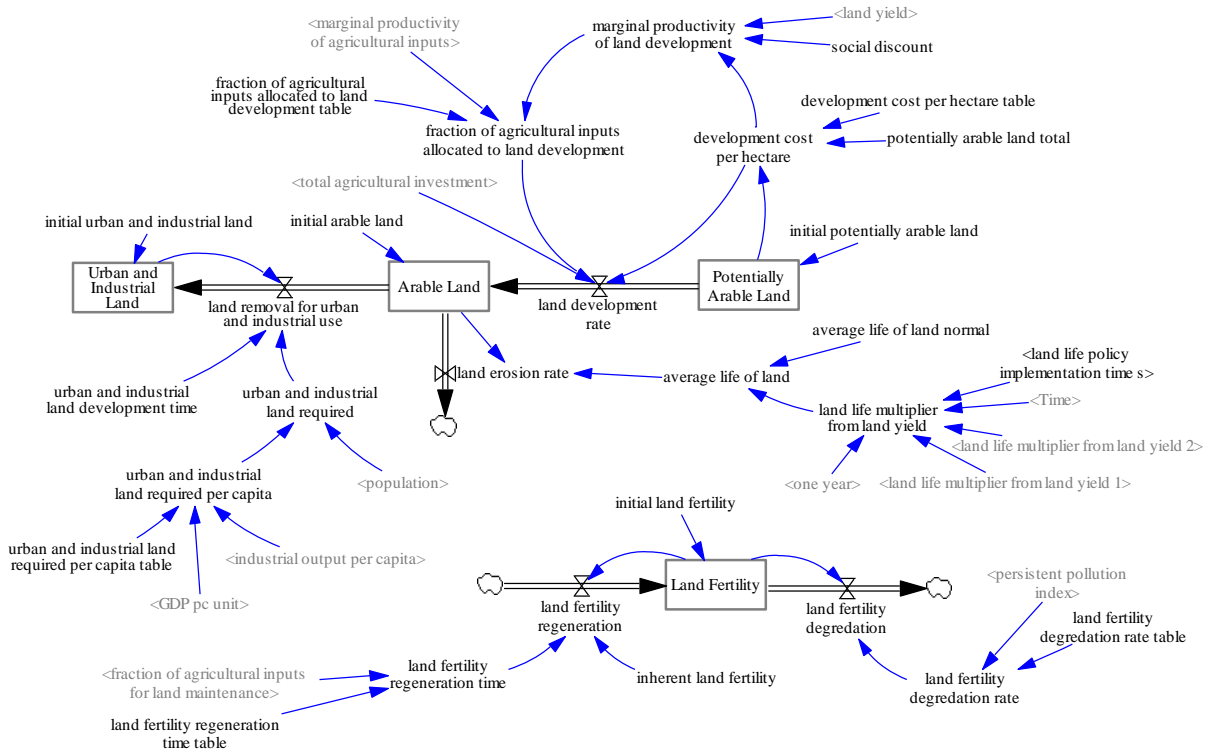


Figure 12: Land development, Loss, Fertility sector of the World3 model.

We added stock and flow structure to this sector to represent the land resource sanctuaries, as presented in Figure 13. It is modelled in a similar way as the nonrenewable resource sanctuaries, and has the same underlying assumptions and reasoning. When land resource sanctuaries are created, the potentially arable land decreases since it becomes protected land and can then not be developed into arable land. Lower levels of arable land decreases the ecological footprint but also the food production. Moreover, less urban land decreases the ecological footprint as well. Just as the nonrenewable resource sanctuaries and with similar reasoning, the desired land resource sanctuaries is set to 15% and the creation time to 5 years.

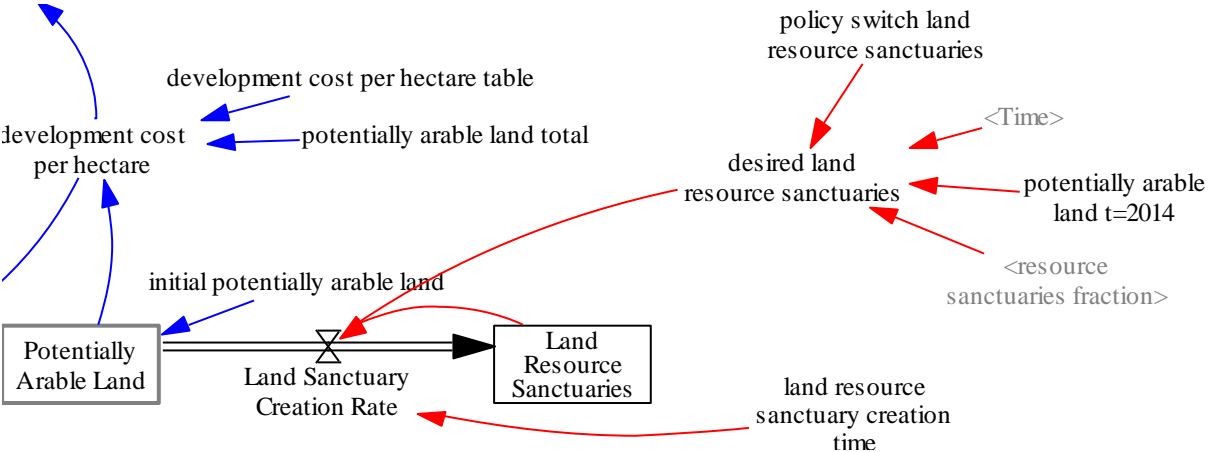


Figure 13 Model extension of land resource sanctuaries.

Work sharing

The work sharing proposal is represented with added and modified structure in the job sector of the model. The original job sector of the model mainly includes the jobs that are created (in terms of people), presented in Figure 14. The amount of jobs depends on the potential jobs in the different sectors, which in turn is determined by the level of capital and the jobs per capital unit. Labor utilization fraction is then calculated by dividing the amount of jobs by the labor force and this fraction serves an input to the industrial- and services output. A higher labor utilization fraction means a lower capacity utilization fraction that leads to a lower output.

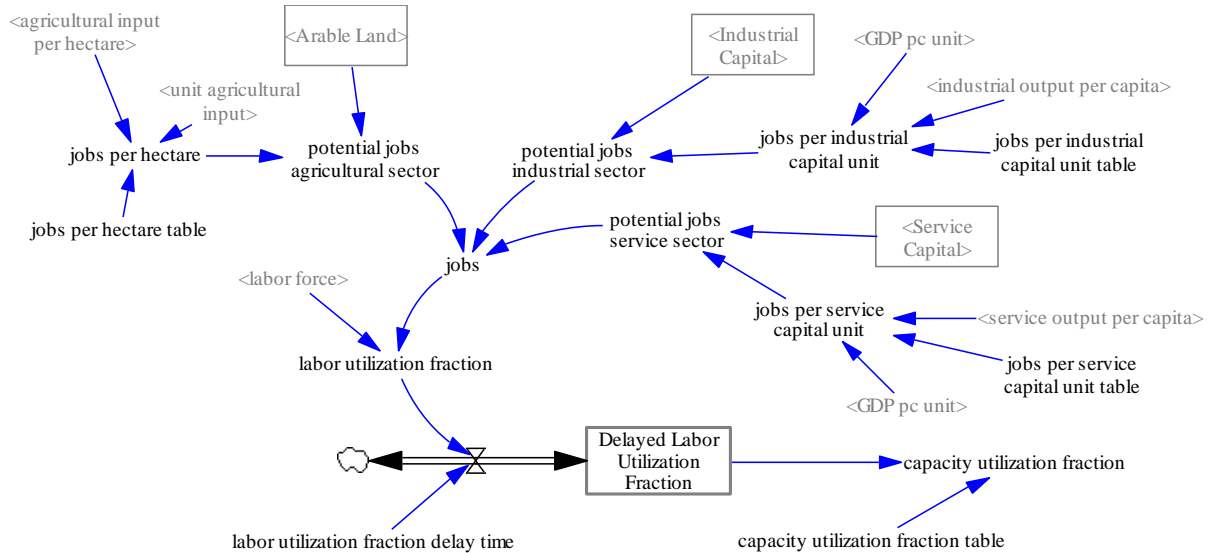


Figure 14: Jobs sector of the World3 model.

The work sharing proposal is represented by the added and modified structure shown in Figure 15. In the debate lowering working hours has been introduced as a proposal to “address a range of urgent, interlinked problems: overwork, unemployment, over-consumption, high carbon emissions, low well-being, entrenched inequalities, and the lack of time to live sustainably, to care for each other, and simply to enjoy life.” (Coote, Franklin, & Simms, 2010). We have nevertheless limited the modelling of work sharing to only include lowering the average working hours per person. We base our policy on the suggestions made by New Economics Foundation to halve the working week of developed countries from 40 hours to 21 hours (Coote, Franklin, & Simms, 2010). In our model, we lower the average working hours per person from 8 to 4 hours. As with resource sanctuaries, we model 5 year of average implementation. The proposal would in the model decrease unemployment and increase the labor utilization fraction. By increasing this fraction the proposal would affect the industrial and service output. We have chosen not to model an increase or decrease in productivity as an effect of the policy because the causal effect of a decrease in working hours has been dubious (Lanoie, Raymond, & Shearer, 2001) (Kallis, Kalush, Flynn, Rossiter, & Ashford, 2013).

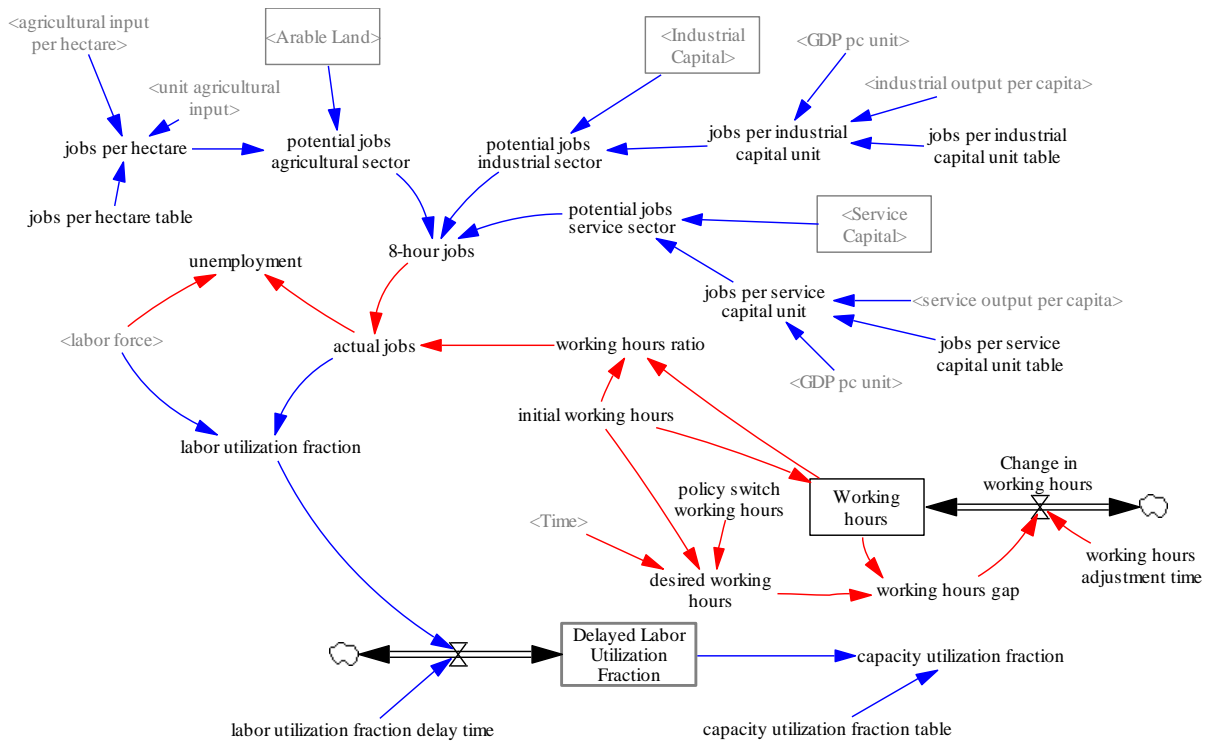


Figure 15: Model extension of work sharing proposal.

Results and analysis

In this section we present the simulation results. We also present validation tests conducted through assigning extreme values to certain parameters. Every simulation run is compared against the *reference point run*. The reference point run is the *Scenario 1* of the World3 model, in the 1972 edition called *standard run*. The reference point run is presented together with data shown in in the background section. It is more or less a business as usual (BAU) simulation without major policy changes. Population and production levels increase until growth is no longer possible because of the depletion of nonrenewable resources and other constraints i.e. limits to growth. The reference point run presents continuous growth until 2014, but at that time industrial output and other variables increase decreasingly, and industrial output reaches its peak in 2016.

In Figure 16 the runs for the different degrowth proposals are compared against the reference point run for the Ecological Footprint. Note that the precise values at each point are neither meaningful nor possible to read and that is why we have chosen to display them on a highly aggregated level.

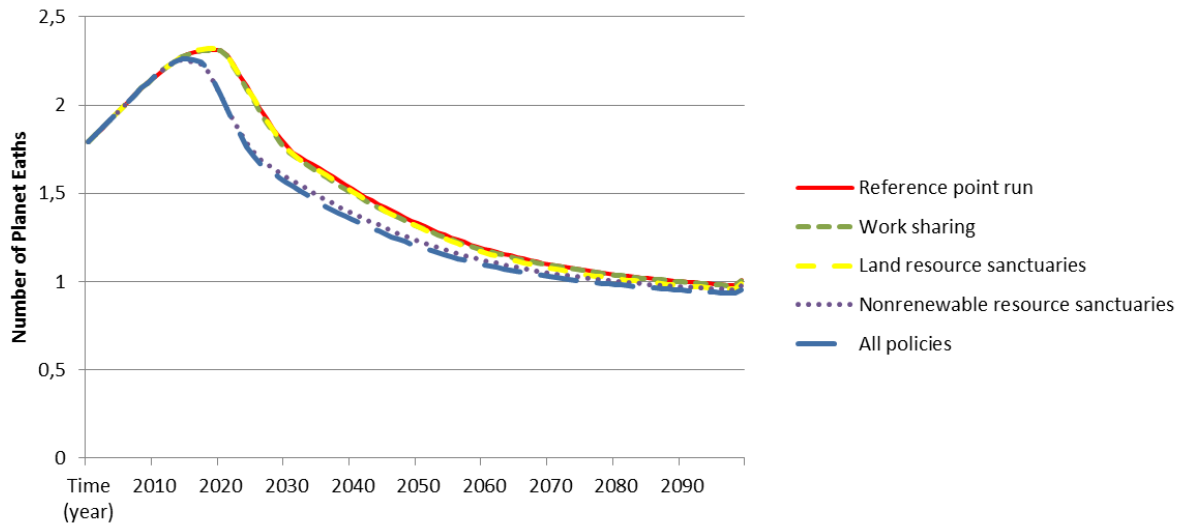


Figure 16: Ecological Footprint with initial degrowth proposals.

Figure 16 shows that the work sharing proposal and the land resource sanctuaries, as we have modelled them, have little impact on the Ecological Footprint. The nonrenewable resource sanctuaries proposal has more impact as the ecological footprint decreases significantly. When all the proposals are introduced simultaneously, the most impact can be seen. Note that all the runs end up at a Human Ecological Footprint of one planet earth in the long-run, which is reasonable given the balancing feedbacks at play with a higher footprint.

Figure 17 presents the runs for the different degrowth proposals when compared against the reference point run for the Industrial Output variable. The pattern is similar to the Ecological Footprint development presented above, which makes sense given their high correlation. Again, the work sharing and the land resource sanctuaries have less impact while the nonrenewable resource sanctuaries proposal affects the development significantly. When all proposals are implemented simultaneously we see the largest impact.

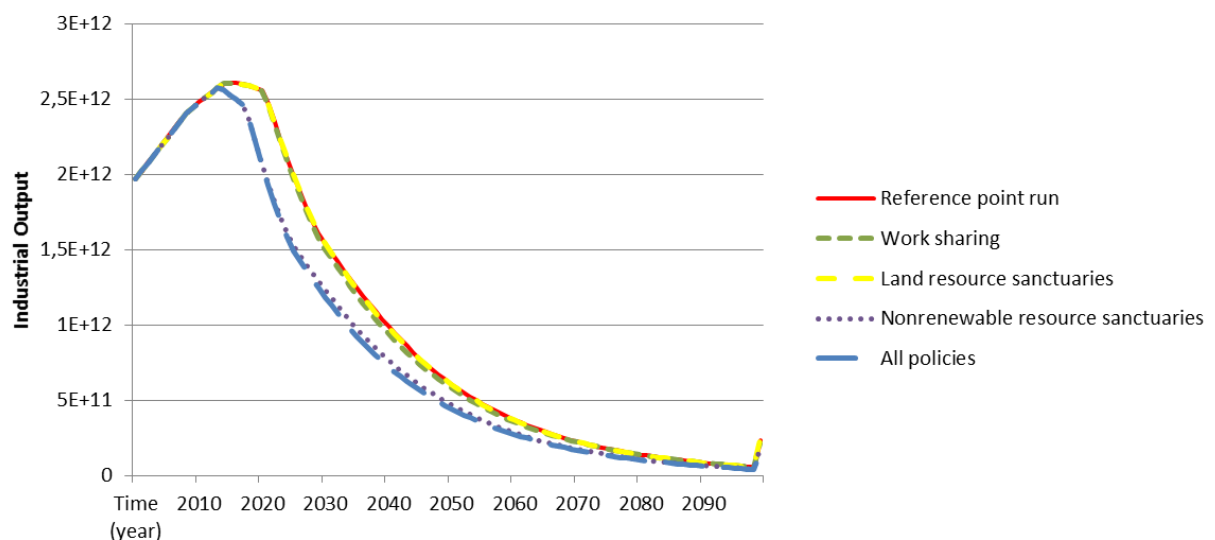


Figure 17: Industrial Output with initial degrowth proposals.

In Figure 18 and Figure 19 we explore the impacts of the degrowth proposals with extreme values. We acknowledge that these extreme values are not realistic; we perform this test only to study how the model behaves under extreme conditions.

In the runs displayed in Figure 18 and Figure 19 the desired working hours was set to 1 hour, and the resource sanctuaries are set to 85% of the value of 2014. The two figures present that under these conditions the system quickly changes; it reaches an Ecological Footprint of 1 much faster and *Industrial Output* decreases significantly. The changes are again strongest for the nonrenewable resource sanctuaries and weakest for the land resource sanctuaries. The effect of the *working hours proposal* lies in between the other two proposals. For all the proposals there is eventually no Industrial Output because at that point all capital is allocated to obtaining new nonrenewable resources.

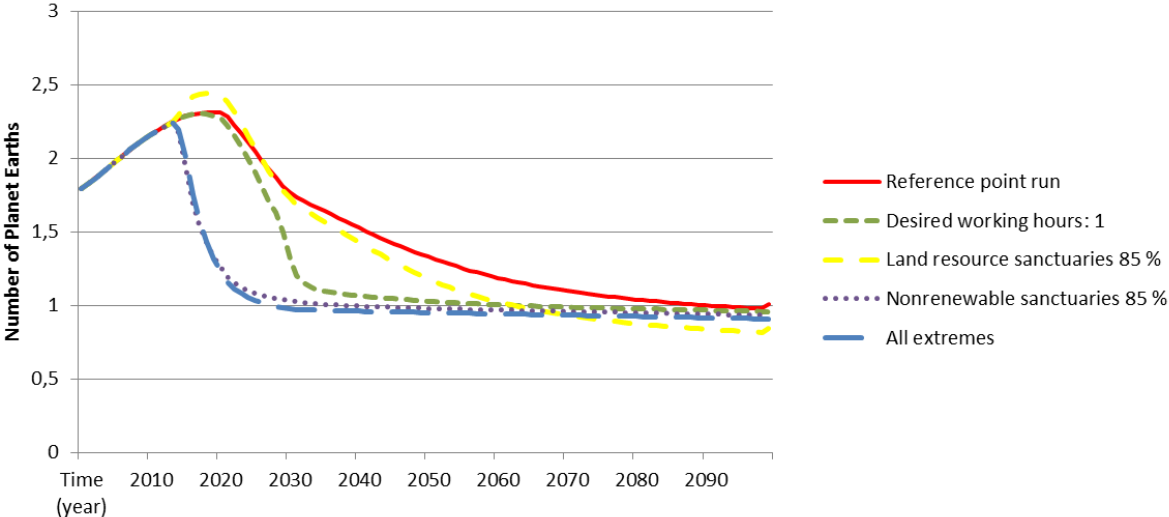


Figure 18: Ecological Footprint with extreme degrowth proposals.

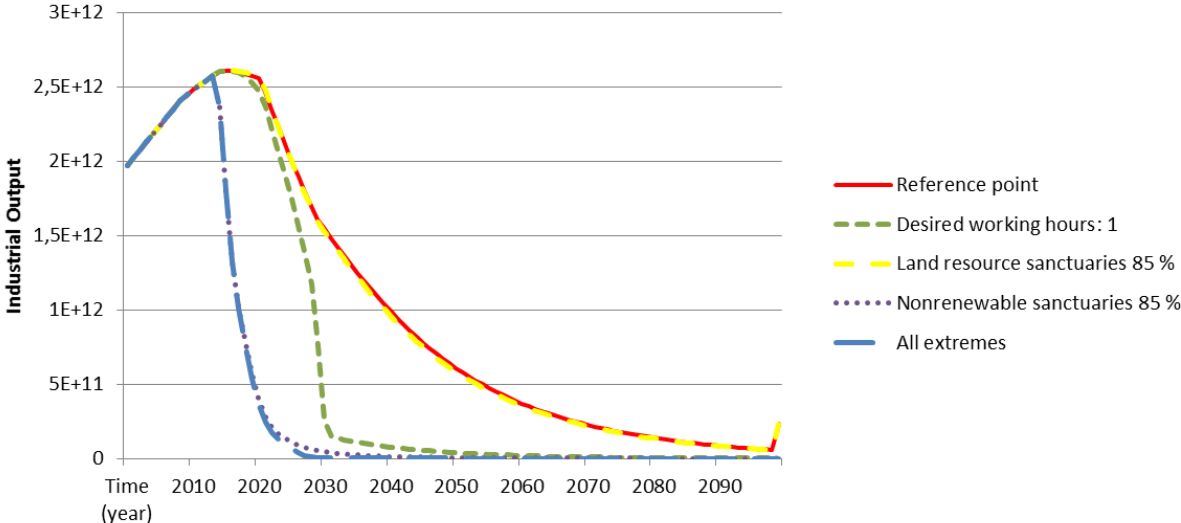


Figure 19: Industrial Output with extreme degrowth proposals.

We acknowledge that the interpretations that can be made of the results of our simulation runs are limited because we only look at two variables of the World3 model. The small effects of the proposals could be explained by the scale of analysis and that the model is much aggregated. Figure 20 shows that both the work sharing and resource sanctuaries proposals fall into the reactive segment. This means that they are strongly affected by other degrowth proposals but their causal effects on others are lower. This could also explain why land resource sanctuaries and work sharing do not have much impact compared to the reference point run. Priority could thus be given to other proposals that have more spill-over effects. Figure 20 does however not explain the bigger effect of the nonrenewable resource sanctuaries pathway. Causal effects of the degrowth proposals on other variables are explored more in the discussion.

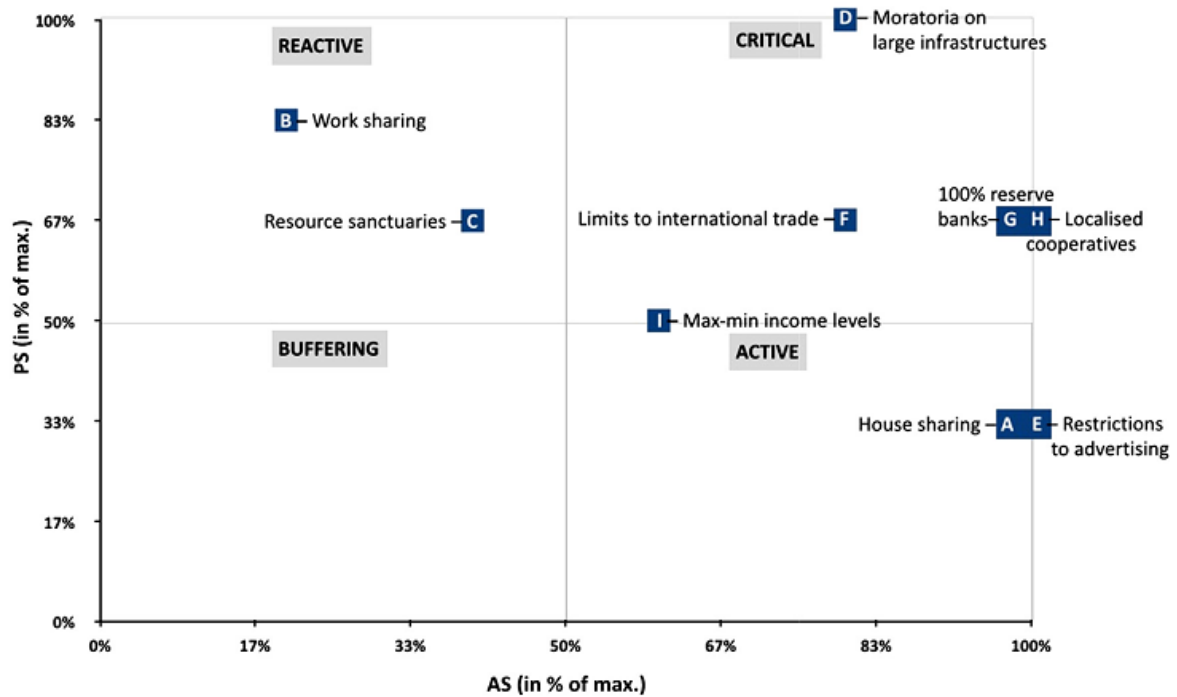


Figure 20: Diagram of the results from the cross-impact matrix (Videira et al., 2014).

Finally, in Figure 21 and Figure 22 we explore the impacts of the degrowth pathways if they were implemented earlier in history. In these runs the policies are implemented in year 1982 to see what would have happened if earlier action had been taken. The results show that earlier implementation of the pathways would have led to more decrease in industrial output and ecological footprint, compared to Figure 16 and Figure 17. This indicates that quicker implementation of the degrowth pathways has more impact and that action needs to be taken sooner rather than later.

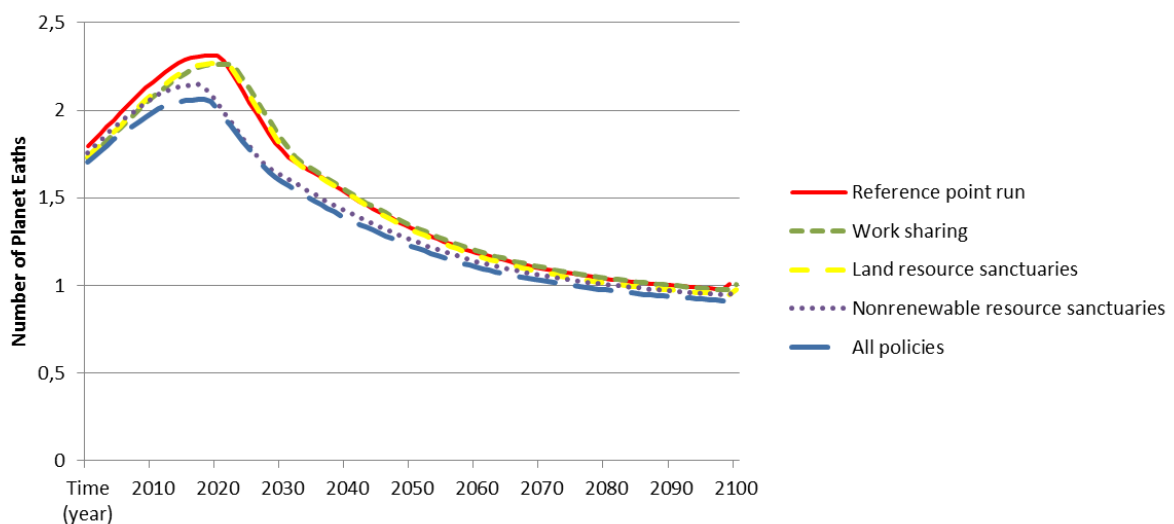


Figure 21: Ecological Footprint with proposals implemented in year 1982.

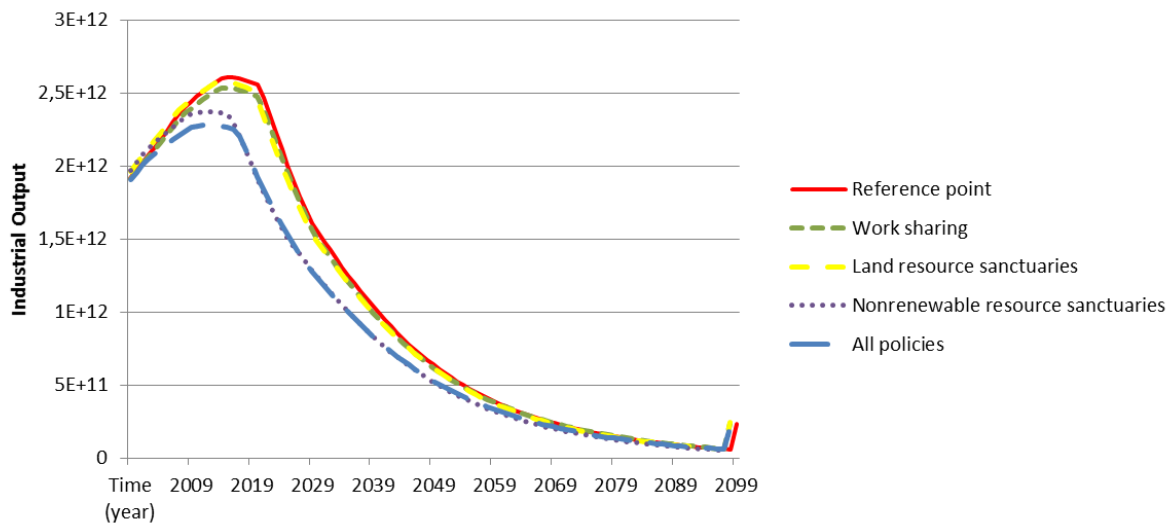


Figure 22: Industrial Output with proposals implemented in year 1982.

Discussion

The starting point for this exercise was to use system dynamics to explore degrowth pathways, and to use a widely known and accepted model as a tool to test scenarios for these pathways. We used the World3 world model to look at scenarios and impacts at a global scale. Modelling on a global scale requires simplifications and aggregation, but could provide useful insights, as degrowth and the related environmental impacts are truly global matters. One of the clear advantages of using a global model is the easy boundary setting as the dynamic behavior is clearly endogenous. New structure was developed and integrated into World3. This approach allowed for simulation of future scenarios on a highly aggregated level. It also allowed for a comparison of the results with a base run scenario. Hence, the discussion could be focused on questions about feasibility, effectiveness and implementation of degrowth proposals - rather than validation and limitations of the model structure at large.

One limitation of using World3 in this project turned out to be that while the model explains the current pattern of the *world system* (Turner, 2008) it would maybe not serve as well in modelling beyond the peak in development – which in the *reference point* run (in the 1972 edition of the book called the *standard run*) is year 2016 for industrial output. Simulations showed that even under extreme (favorable) conditions the system is set to collapse. This has to do with the fact that the base model only considers mainly non-renewable resources (except for food sector) which when used up leads to this behavior pattern. Adjustments to the model to consider renewable resources substitution for non-renewable could be explored in further developments. Further, the model creators states that “*in scenarios that portray collapse, we do not assign any meaning to the behavior of the curves beyond the point where they peak out and start to decline. [...] we do not describe the behavior of any model element after the point where one significant factor has started to collapse. Clearly a collapse of population or industry in the “real world” would change many important relationships and thereby invalidate many of the assumptions we have built into the model.*” (Meadows, Randers, & Meadows, 2004, p. 153). A collapse would thus likely lead to other societal feedback mechanisms taking over in determining future behavior. Our study could be considered valid in a ‘*ceteris paribus*’ setting. That is, given the system structure and model that is presented; this is the behavior that the proposed policies lead to. To better investigate degrowth proposals we would however need to include the dynamics of system level changes i.e. *industrial transformation*. The World3 model could perhaps be used as a foundation for such a model, but it would require changes in the model’s structure.

Such rework of the World3 model would probably benefit from a participatory approach - it could be a requirement for taking into account the diffused knowledge needed for such an exercise (Quist & Vergragt, 2006).

Conclusion

Theories challenging current industrialization patterns and continuous growth in output and efficiency go as far back as at least the 19th century. The concept of degrowth was however more formally introduced in the 1970's, by among others the Club of Rome. Now the topic of degrowth is again on the agenda, offering an alternative to the growth paradigm that has been dominating politics and the economic system since at least the end of the *Second World War*. The raising awareness of the ecological limits of our planet and the current economic and social crisis indicate that an alternative paradigm is needed. Life on earth needs to be redefined, and degrowth might give important contributions to this change. The remaining question is if the transition from a structure promoting economic growth to a degrowth society will be sustainable, democratic and equitable – or a structural collapse.

In this paper we have explored different degrowth proposals and their potential impacts focusing on industrial output and the ecological footprint. Through a causal loop diagram we have identified important feedbacks, showing how interventions in the system can affect large parts of society. This is a promising result if one aims for degrowth proposals to be implemented. On the other hand, the simulations exercise using World3 show less impact of the proposals on an aggregated, global level. Resource sanctuaries on non-renewable resources turned out to be the most promising suggestion, while lowering working hours had no significant impact on either output or the ecological footprint. These results should however be interpreted with caution, since the degrowth proposals were introduced in a model constructed to represent the current growth paradigm. The degrowth pathways were introduced from the year 2014, two years before the system starts to collapse in the base-run. Perhaps the time period was too short in order to avoid this behavior, no matter how effective the proposals, because of the already prolonged overshoot.

This paper shows the potential of system dynamics modelling for designing and testing strategies for a more sustainable society on a global scale. The World3 model does however not only show the limits to growth, it also shows the limits of transformation capabilities within the current societal structure. In order to fully explore the potential of strategies for sustainable development, there is a need for world models that focus on the transformation to sustainability. Instead of just focusing on the current pattern of the world system, such new world models would need to show what is required to transform into sustainable world system. The authors of *Limits to Growth* remained positive, acknowledging the boundaries of our ecological system but also the potential for change. The process of reinventing life on a shrinking earth is underway, and in this process system dynamics models can play an important role.

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Appendix: Description and motivation of CLD

Table 1: In this table we explain our motivation behind the loops in the refined CLDs. We compare the loops of the preliminary CLDs presented by Videira et al. (2014) with the loops in the refined CLDs and explain the added loops that are based on assumptions made in the World3 model.

Loops preliminary Diagrams	Loops Refined CLDs	Label	Description and motivation
'Social Sector'			
R1	Excluded		We find it hard to grasp the variable 'Scale of political economic system' and believe that it is included in other variables such as 'Industrial capital', 'Will of accumulation' and 'Consumption'.
R2	R1 and R7	<i>Much would have more reinforcing loop and Resource-conflicts reinforcing loop</i>	We chose the broader term of 'consumption' instead of merely 'consumption of natural resources' for these loops as we believe it more fully grasps the concept presented. R1 presents the basic loop of increased 'consumption' leading to an increased 'will of accumulation' and vice versa. The R7 loop describes how increased 'demand for natural resources' increases the prevalence of 'conflicts' which in turn increases 'social inequality', 'will of accumulation', 'consumption', 'consumption of natural resources' and further increases the 'demand for natural resources'.
R3	R2	<i>Ethics reinforcing loop</i>	Same loop. The direct link from 'utilitarian view' to 'will of accumulation' corresponds to the importance of the utilitarian view's domination over other ethics, in line with the argument in Videira et al. (2014)
R4	Excluded		We argue that the 'poverty' captures the concept of 'access to goods & services' and decided to not include it.
R5	R6	<i>Poverty-conflict reinforcing loop</i>	As a matter of simplification we included 'social inequality' in the loop.
R6	R4	<i>Exclusion-conflict reinforcing loop</i>	Same loop.
R7	R4	<i>Exclusion-conflict reinforcing loop</i>	The difference between R6 and R7 from the preliminary CLD is that in R6 'conflicts' increases 'social exclusion' via the two variables of 'cooperation' and 'trust' but in R7 there is a direct link from 'conflicts' to 'social exclusion'. As a matter of simplification we chose to only model the former.
R8	R9	<i>Sharing reinforcing loop</i>	In the preliminary CLD, there is both a direct link from 'cooperation' to 'sharing' and a link that goes via 'trust'. As a matter of simplification we chose to model only the latter.

R9	R5	<i>Size of public sector reinforcing loop</i>	Here, we have chosen to more extensively alter the loop. We believe that the reasoning behind the R9 loop in the preliminary CLD is that increased 'will of accumulation' leads to less support for taxes that erodes the public sector and leads to increased 'social inequality' that in turn increase the proliferation of the 'utilitarian view' and hence 'will of accumulation'. In the preliminary CLD the loop goes via increased 'conflicts' which we believe is not necessary the case and perhaps not what the workshop participants intended.
R10	Excluded		We believe that the effects of conflicts leading to an increase in the 'will of accumulation' and 'social inequality' is already captured by the effects of loops R4, R6 and R8 and as a matter of simplification excluded the R10 loop.
B1	Excluded (R5)	<i>(Size of public sector reinforcing loop)</i>	We do not find the balancing loop, but a reinforcing loop similar to R5 in our CLD where increased taxes leads to less social inequality, decrease in 'utilitarian view' and hence decreased 'will of accumulation'.
'Economic sector'			
R1	R3	<i>Capital reinforcing loop</i>	We believe the core of the R1 loop from the preliminary CLD is that increased investments leads to increased output of which a part is allocated to investment and thereby reinforces the effect. In the World3 this is modeled primarily by 'industrial capital'.
R2, R3	Excluded		We did not include the financial market in our model because this is outside the boundary of this study.
R4	R4 & R6	<i>Exclusion-conflict reinforcing loop & Poverty-conflict reinforcing loop</i>	Again, we do not model the financial markets. However, the R4 and R6 loops capture the reinforcing effects of social inequality and conflict.
B1	C3 and C4	<i>Resource demand counteracting loop and Nonrenewable resources counteracting loop</i>	To more fully capture the behavior of World3 we chose to develop B1 loop of the preliminary model. The C3 loop represents the depletion of natural resources by showing that increased 'consumption of natural resources' increases the 'nonrenewable resource usage'. This decreases the amount of 'nonrenewable resources' that are left which leads to more expensive natural resources ('resource price'), decreased 'industrial output' and decreased 'consumption'. Further, there is a more direct effect closer to the B1 loop presented in the preliminary CLD that presents that an increased demand leads to a higher price. As in the preliminary CLD we believe " <i>the negative loop system created by supply and demand in markets (B1) does not seem to be strong enough to control for impacts from increasing resource consumption.</i> " (Videira, Schneider, Sekulova, & Kallis, 2014, s. 64)

'Ecological sector'			
R1, R2, B1	Excluded		Some variables and loops in this preliminary CLD are regarded as uncertain by the participants. Moreover, we do not fully understand the concepts and loops presented in this sector. Because of this uncertainty we decided not to include these loops in our refined CLD.
'World3'			
R8	<i>Arable land-pollution reinforcing loop</i>		The R8 loop represents how in the World3 model an increase in 'arable land' leads to an increase in 'persistent pollution' which further harms 'population' growth. A lower population leads to lower level of 'consumption', lower 'consumption of natural resources', more 'industrial output allocated to investment', more 'industrial capital investment', more 'industrial capital', more 'industrial output', more 'land development' and finally more 'arable land'.
R10	<i>Population-consumption reinforcing loop</i>		The R10 loop represents that an increase in 'population' leads to increased 'consumption' which leads to less 'industrial capital investment', less 'industrial capital', less 'industrial output', less 'persistent pollution' and more population.
R11	<i>Unemployment reinforcing loop</i>		The unemployment reinforcing loop represents that increased 'unemployment' leads to increased 'social inequality', more 'utilitarian view', higher 'will of accumulation', and more 'consumption', less 'industrial capital' and less 'jobs'
C1	<i>Population-pollution counteracting loop</i>		The C1 loop represents that an increased 'population' means an increased 'labor force' which decreases the 'labor utilization fraction' which means an increase in the 'capacity utilization fraction'. That further leads to lower 'industrial output' (as it means that there is not enough labor for full capacity), lower 'land development', lower 'arable land', less 'food' which decreases the population.
C2	<i>Investment counteracting loop</i>		The C2 loop represents that an increase in 'consumption' increases the 'consumption of natural resources', which leads to lower levels of 'industrial output allocated to investment' (as a bigger share of the industrial output is allocated to consumption), lower 'industrial capital investment', lower 'industrial capital', lower 'industrial output' that in turn harms 'consumption'.
C7	<i>Labor utilization counteracting loop</i>		C7 represents that a higher 'labor utilization fraction' means lower 'capacity utilization fraction', higher 'industrial output', more 'consumption', less 'industrial capital investment', less 'jobs' and a lower 'labor utilization fraction'.
C8	<i>Food-population counteracting loop</i>		C8 represents how an increased 'population' increases 'consumption', which in turn means less 'industrial capital investment', less 'industrial output', less 'land development', less 'arable land', less 'food' and finally less 'population'.