Making System Dynamics Cool III: New Hot Teaching & Testing Cases

Erik Pruyt* – E-mail: e.pruyt@tudelft.nl

August 14, 2011

Abstract

This follow-up paper presents seven actual cases for testing and teaching System Dynamics developed and used between January 2010 and January 2011 for one of the largest System Dynamics courses (250+ students per year) at Delft University of Technology in the Netherlands. The cases presented in this paper range from short to long and can be used for teaching and testing introductory/intermediate System Dynamics courses at university level as well as for self study. Additionally, the use of Multiple Choice questions for testing System Dynamics is presented and discussed.

Keywords: System Dynamics Education, Case-Based Teaching and Testing, Fisheries, Radicalization, Energy Transition, Real Estate Boom and Bust, Mineral/Metal Scarcity, Slow Students, Ecosystem Management

1 Introduction

Many 'hot' –i.e. current real-world– teaching and testing cases are used each year in the Introductory System Dynamics courses taught at Delft University of Technology's Faculty of Technology, Policy and Management. Hot cases were found to be excellent tools for motivating students, for illustrating the relevance of SD modeling for real world problem solving, and for showing the way SD could be applied to real world cases. For more (information on) 'hot' teaching/testing cases, see (Pruyt 2009c) and (Pruyt 2010a). Most of the publicly available cases focus on basic to intermediate SD model building skills, and –to a lesser extent– on basic model use and communication skills. Students need some modeling experience/practice in order to be able to deal with these cases but not too much in order to be challenged by the pre-specified nature of the cases. Two computer sessions with tutorials and simple exercises are enough for bringing students to the level required for dealing with the first (the easiest) hot cases.

Making a good hot SD case for a particular level is time consuming and difficult. Preparing a large number of new hot cases is even more challenging and time consuming: 7 to 8 new cases need to be developed every year for the Introductory SD courses at Delft University of Technology. Sharing new cases with colleagues and –at a later stage– students may partly solve this problem. This paper therefore promotes the exchange of teaching/testing cases by sharing several hot cases developed over the last year. These cases can be used for self-study and for teaching and testing purposes at other universities as long as the authorship is respected and the cases are correctly referred to (e.g. 'developed by' or 'based on a case developed by') even for exam cases.

Openness about 'exam grade' cases may also be useful for assessing the overall quality of different SD courses/curricula, and may help to improve them. publishing our cases leads in any

*dr. Erik Pruyt is Assistant Professor System Dynamics at the Faculty of Technology, Policy and Managementof Delft University of Technologywhere he manages and teaches the Introductory System Dynamics courses.

way to more reflection about these cases for teaching and testing –and even the entire setup of SD curricula– too: in this paper we reflect about our use of MC questions for testing purposes, both for testing of general SD skills/knowledge and for testing SD modeling skills, as well as about new (resource poor as opposed to the current resource rich) designs of our SD curriculum. Finally, this paper aims at sharing some of our most recent experiences in teaching SD to large groups of –both bachelor and master– students.

Section 2 provides a quick overview of our SD curriculum, the SD skills focused on in the introductory SD course, cases currently used in the introductory SD course, and an overview of publicly available SD cases developed for and used in Delft University of Technology's Introductory SD courses. The new cases are presented in more detail in section 3. New evaluation modes by means of quick scanning and model-related MC questions are discussed in section 4. New experiences, opportunities for our SD curriculum and conclusions are discussed in section 5. And, last but not least, the appendices contain –refer to– the new cases presented in this paper: appendix A contains the 'Oostvaardersplassen Natural Reserve' case, appendix B contains the 'North-Eastern Bluefin Tuna' case, appendix C contains the 'Boom and Bust in Dubai' case, appendix D contains the 'De/Radicalization' case, appendix E contains the 'Energy Transition' case, appendix F contains the 'Slow Students' case, and appendix G contains the 'Rare Earths Scarcity' case.

2 Case-based SD Teaching & Testing

2.1 The Current SD Curriculum

System Dynamics (SD) is an integral part of two of the study programmes offered at our faculty. Meyers, Slinger, Pruyt, Yucel, and van Daalen (2010) describe the different SD courses in the curriculum and their learning goals, and an explanation of the way in which real world complexity is introduced in a quadruple jump approach over the whole curriculum.

The introductory SD course for bachelor and master students focuses on introducing the SD methodology and on conveying basic and intermediate SD modeling skills. Although most students enter the course without prior SD knowledge, all students have followed an introductory course in Differential Equations and an introductory course in Policy Analysis. Pre-testing shows that a large share of the students is able to read graphs properly and solve elementary stock-flow problems. 'Hot' cases of 1-2.5 pages are used during the 7-week 6-hours-per-week course to demonstrate the use of SD in addressing current issues. The explicit learning goals of the introductory SD course are (i) to have basic knowledge of the SD field/philosophy/method, (ii) to be able to apply the SD method using SD software packages, and (iii) to have a basic understanding of SD model use and to have gained basic experience related to the SD modeling process. Cases used for teaching range from small and simple, over technical, to intermediate/difficult. Exam cases are always intermediate/difficult of about 2 pages. During the exam, students have 3 hours to answer 20 MC questions related to SD methodology/insight/. . . (see section 4) and for solving a hot case. Passing rates range from 55% to 95% per year (exam + retake exam) depending on the student group: passing rates for second year bachelor students are always low (between 55% and 70%), and passing rates for first year master students are always high (between 90% and 100%) although the exams and the course are the same. Hence, the difference in passing rates can only be attributed to time spend on the course, the need to pass the exam[1], the level and maturity of (pre-selected) master students, and most of all, the timing of exam and retake exam[2].

[1]Dutch BSc students can take the exam over and over again whereas foreign MSc students need to pass their first or second attempt.

[2]Master students have 1 week between their exam and their retake exam. Bachelor students formerly had 6 months between their course and exam, and their retake exam – as off last year, they have 3 months between the exam and retake exam.

Case name / theme	Approp. (1 to 5)	**Difficulty for SD101**	**Time needed**	**Specifics**	**References (C=case ; A=analysis)**
Dutch Soft Drugs Policy	3	easy	1:00	qualitative	C & A in (Pruyt 2009b)
Pneumonic Plague	3	easy	1:00	small	C in (Pruyt 2010a)
EVs and lithium scarcity	3	easy	2:00	staged	C in (Pruyt 2009c)
Redevelopment of social housing districts	3	easy	2:00	abstract/highly aggregated	based on (Pruyt 2008a) C in (Pruyt 2009c)
Fall of the Fortis Bank	2		2:00	simplistic	C in (Pruyt 2009d)
Oostvaardersplassen	4	medium	0:45	technical ex.	C in this paper
Flu pandemic	5	medium	2:30	staged, builds up from simple	C in (Pruyt 2010a); A in (Pruyt and Hamarat 2010b)
Cholera in Zimbabwe	4	medium	2:00		C & A in (Pruyt 2009a)
Overfishing of NBF Tuna	4	medium	1:30	staged	C in this paper
Concerted run on DSB Bank	4	difficult	2:30	better than Fortis case	C in (Pruyt 2010a); A in (Pruyt and Hamarat 2010a)
De/Radicalisation	4	difficult	2:30	not staged counterint.	C in this paper A in (Pruyt and Kwakkel 2011)
Energy transition	3	difficult	2:30	bridge to SD project	C in this paper A in (Pruyt, Kwakkel et al. 2011)
Boom & bust in Dubai	3	difficult	2:30	right/wrong	C in this paper
The 'slow students' fine	3	difficult	2:30	pulse train, etc	C in this paper
Mineral/metal scarcity II	4	difficult	2:30	many specific functions	C in this paper A in (Pruyt 2010b)
Mineral/metal scarcity I	1	very difficult	3:00	1 major loop	C in (Pruyt 2010a)
Energy versus Food Security	2	difficult and long	5:00	bridge to SD project	C in (Pruyt 2010a) A in (Pruyt 2008b)

Table 1: Publicly available cases in order of difficulty/length, the author's assessment of their appropriateness for testing intermediate modeling skills from 1 (lowest) to 5 (highest), their difficulty, minimal time needed, specifics, and references

After passing the Introductory SD course, students mandatorily take the SD project course: in this project course, couples of students are supervised over a period of 7 weeks while modeling a less pre-specified and structured case of about 20-25 pages (an example of such a case is provided in (Meyers, Slinger, Pruyt, Yucel, and van Daalen 2010)).

Afterwards, students can do a BSc thesis in SD, follow the Advanced SD course, take Simulation Master Classes, and do an MSc thesis in SD. Students who follow all the SD courses on offer have almost the equivalent of a one-year, fulltime master programme in SD (Pruyt et al. 2009). In their full curriculum, however, students learn a range of problem exploration and structuring methods and study other modeling methods, such as Agent-Based Modeling and Discrete Modeling.

2.2 Publicly Available Hot Teaching & Testing Cases Developed for the Introductory SD Course

Table 1 lists most of the publicly available teaching/testing cases developed and used for this particular Introductory SD course. These fully pre-specified cases typically focus on basic/intermediate SD modeling and simulation skills: mainly model specification, some model testing, some sensitivity testing and scenario analysis, some Causal Loop Diagramming (detailed and aggregated), some focus on the link between structure and behavior, and some policy testing. From the end of week three on, only hot cases are used – some smaller exercises/cases are used during the first three weeks of the course. These hot cases require 95-99% of transpiration (applying trained skills), and only 1-5% of inspiration/insight. Additional MC questions are used during the exams to test insight, knowledge, etc.

Following seven cases –developed between January 2010 and January 2011– are presented below:

- The '*Oostvaardersplassen Case*' is a small but rather technical case with interesting specifications (pulse train, random, lookup, smooth3I, et cetera) about the mismanagement of the Dutch natural reserve 'The Oostvaardersplassen'.

- The '*North-Eastern Bluefin Tuna Fisheries Case*' is a rather small and easy case related to the overfishing of North-Eastern Bluefin tuna and the (in)effectiveness of ICCAT policies.
- The '*Boom and Bust in Dubai Case*' is an intermediate case related to the boom and potential bust of the real estate sector in Dubai.
- The '*De/Radicalisation Case*' is an intermediate case related to the development of activism towards harmless activism (de-radicalization) or extremist activism (radicalization).
- The '*Transition towards Sustainable Energy Systems Case*' is a staged but rather lengthly and difficult case about the competition of new energy technologies against old energy technologies and against other new energy technologies for the same subsidies.
- The '*Slow Students Fine Case*' is a very hot case about a Dutch cabinet policy proposal to fine universities based on the number of (relatively) slow students enrolled. Rather specific functions and structures need to be used in this intermediate case.
- The '*Mineral scarcity II Case*' case is a second case about potential mineral/metal scarcity, easier than the first mineral scarcity case, but still relatively lengthy.

These cases are briefly presented and discussed below in increasing order of difficulty/length of the case. The case descriptions and case questions are available in appendices[3].

3 2010-2011 Cases

3.1 The Oostvaardersplassen Case

The Oostvaardersplassen case is a relatively small, but quite technical System Dynamics case about natural reserve management. The Dutch natural reserve –the Oostvaardersplassen– in which hunting was prohibited for over 27 years, was kept clear of willows and bushes by large herbivores which do not have natural predators in the Netherlands. After the carrying capacity of the area had been reached, the Dutch population was shocked by movies and pictures of massive starvation of these large herbivores at the end of winter.

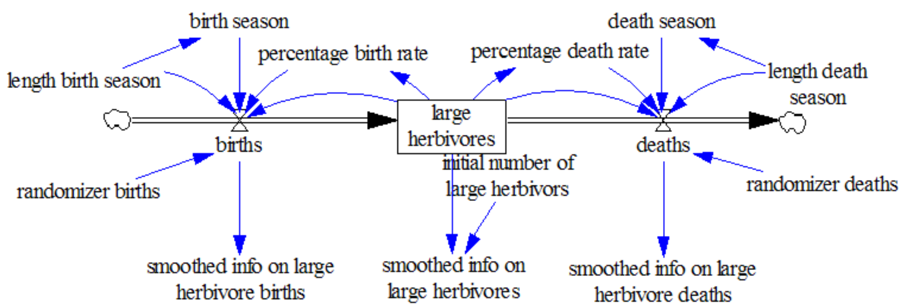


Figure 1: SFD of the small –but technical– OVP simulation model

Students need to make a SD simulation model (see Figure 1) based on the description provided (see section A on page 25). Doing so, they need to use several special functions (pulse train,

[3]The corresponding SD models and answers will be sent upon request to colleagues willing to exchange 'hot' cases. All models are available in Vensim and in Powersim formats, all cases are available in Dutch and English.

random, lookup, and smooth3I functions), test the model, simulate it and draw the dynamics of several variables with a particular seed for the random functions (see Figure 2).

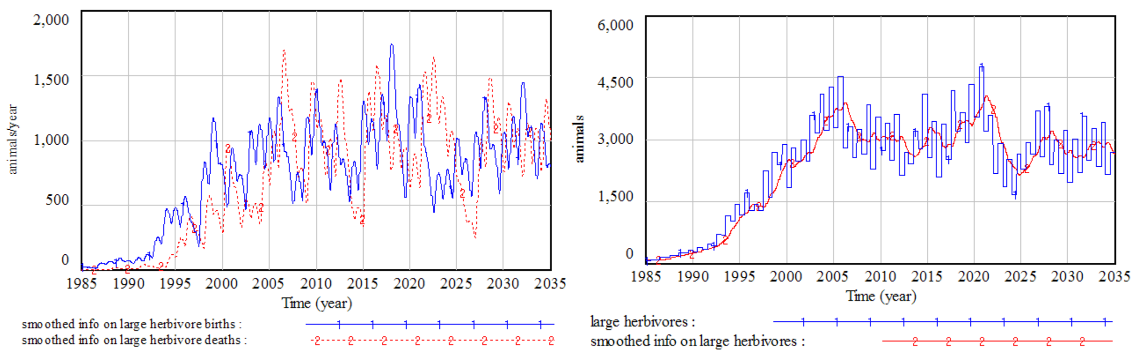


Figure 2: Behaviour of the smoothed flow variables (left) and crude and smoothed stock variable (right)

Then they need to simulate the model again with a different 'seed', and again, and again, and again – after which they are asked to generalize the results/conclusions. Not having been instructed about random functions during the course, students need to find out about them during the exam. They also need to test the model for behavioral sensitivity. They need to make a complete and an aggregated CLD of the model and explain the link between structure and behavior. Finally, they need to come up with a policy, test it, and conclude.

This case was initially developed as a multiple choice question to test flow-stock behavior skills (selecting the behavior of a stock variable that corresponds to given inflow and outflow variables), and used as such during the January 2011 BSc exam. Later, it was reworked into a short –but full– exam case for 'slow students' which always seem to run into time problems.

Surprisingly, average performance and grades were not better for this shorter case than for longer cases. Especially interpretation and distilling general conclusions was rather poor. This may be an indication of too much focus on model construction and too little focus on model use and interpretation.

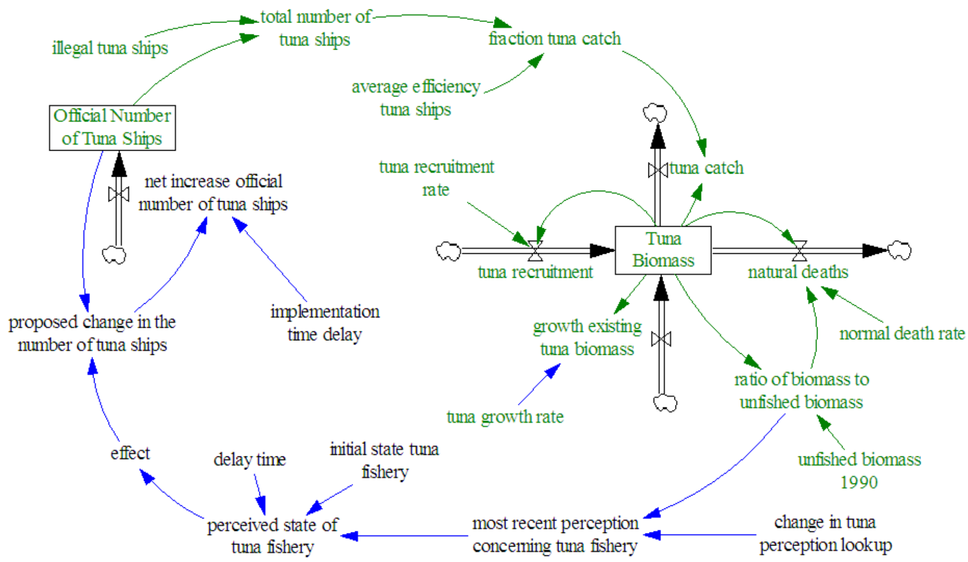
3.2 The North-Eastern Bluefin Tuna Case

The NBF Tuna Fisheries case deals with the overfishing of North-Eastern bluefin tuna and the (in)effectiveness of ICCAT policies. It should be noted that the current version of the case/model is just illustrative/educational: data and policies in the case/model are fictitious. This case is partly inspired / based on (Dudley 2008) and the Fishbanks Game.

First, student are asked to make a SFD of a partial model description (green variables in Figure 3(a)) and to write down the corresponding balance equation (as in Figure 3(b)). They also need to simulate this partial model for different values for the total number of ships (see Figure 4(a)).

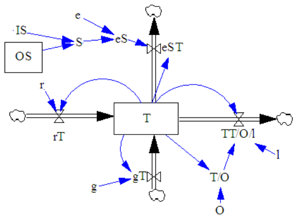
After extending the model (to all variables in Figure 3(a)), students need to simulate the model (Figures 5(a) and (b)), validate it, and test the sensitivity (Figures 5(c) to 5(f)). Their conclusion should be that the model is mainly numerically sensitive to parameter changes – even to a 10% change in the 'effect' lookup – but not behaviourally sensitive.

After realizing that these cases are insufficient – to say the least – students are asked to test whether the 'current policy' would be suffice if the number of *illegal tuna ships* would drop – through strict controlling and sanctioning– from 10000 to 0 in the year 2010: the blue curves in Figures 5(g) and 5(h) show that tuna biomass would take a very long time to recover to about 50% of the initial value and that –following the policy– the official fleets should remain close to

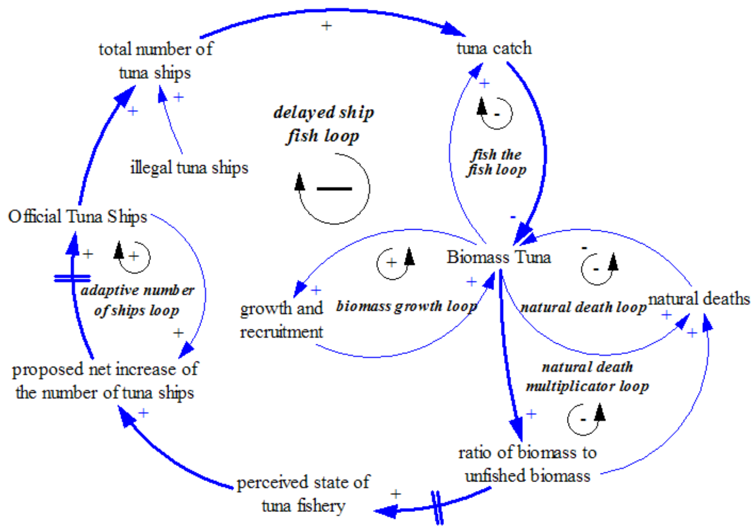


(a) Stock flow diagram of NBF Tuna

$$\frac{\mathbf{dT}}{\mathbf{dt}} = (\mathbf{r} + \mathbf{g} - \mathbf{eS} - \frac{\mathbf{T}}{\mathbf{O}}/\mathbf{l}) * \mathbf{T}$$

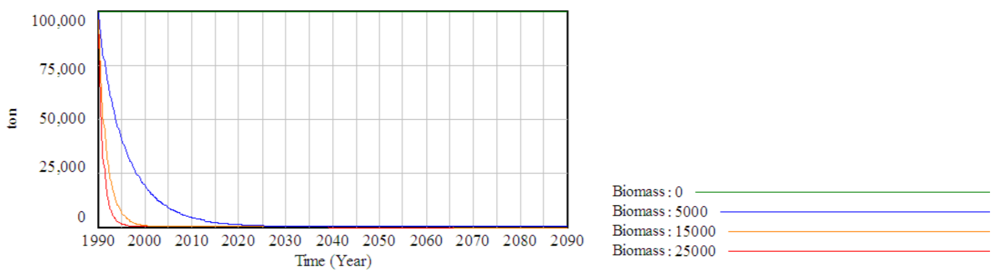


(b) Balance equation



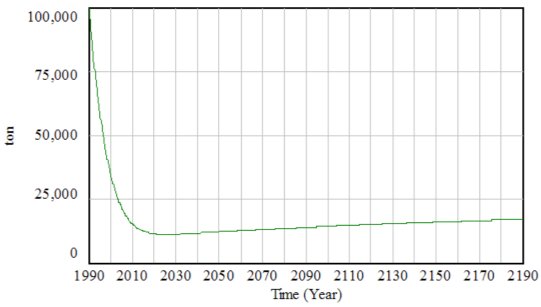
(c) Balance equation

Figure 3: Balance equation and SFD (green variables ∼ balance equation) of the NBF Tuna case

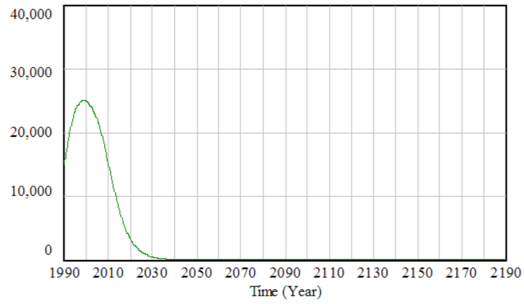


(a) Tuna biomass for 0, 5000, 15000, 25000 tuna fishing boats

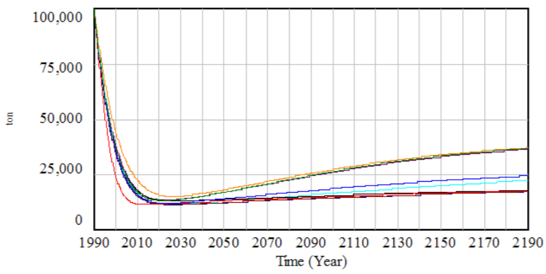
Figure 4: Partial model behavior for different numbers of tuna ships



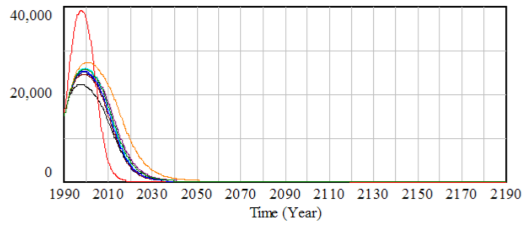
(a) Tuna biomass (base case)



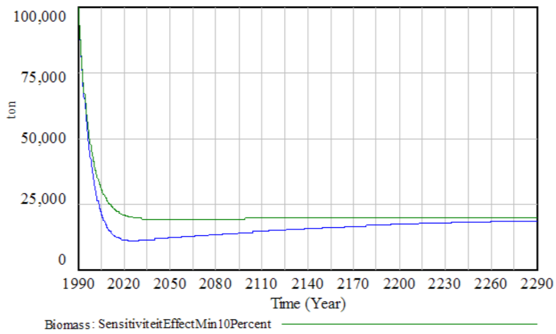
(b) Official tuna fishing boats (base case)



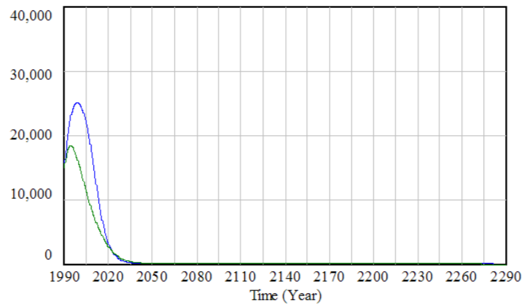
(c) Tuna biomass (parameter sensitivity)



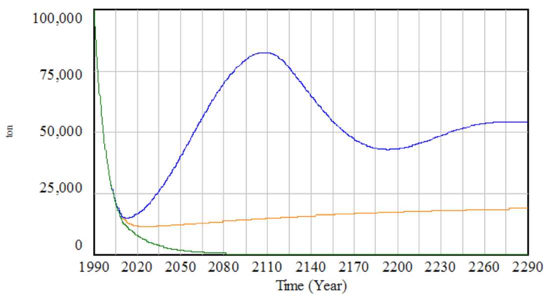
(d) Official tuna fishing boats (parameter sensitivity)



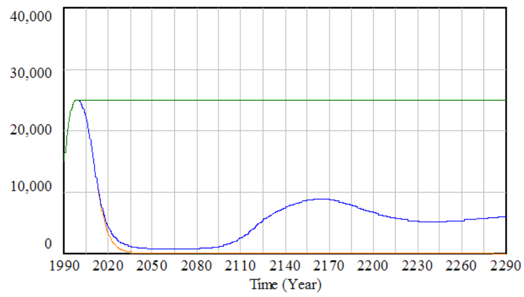
(e) Tuna biomass (lookup sensitivity)



(f) Official tuna fishing boats (lookup sensitivity)



(g) Tuna Biomass



(h) Official number of Tuna Ships

Figure 5: Base case behavior of the NBF Tuna model (a and b), parameter sensitivity (c and d), 'effect' lookup sensitivity (e and f), and what-if behavior (g and h) for the base case (orange), the base case without illegal fishing (blue), and the base case without downsizing of official fleets (green)

zero for a very long time. A second what-if test –what if countries are unwilling to reduce their fleets– leads to even more disastrous consequences (green curves in Figures 5(a) and 5(b)).

Students are asked to make a *causal loop diagram* that can be used to explain the link between structure and behavior to fishermen and policy makers alike: Figure 3(c) would be a rather detailed CLD for doing so. Finally, students are asked to design 2 policy measures that improve the sustainability of the ICCAT policy modeled before. Two final bonus questions aim at challenging excellent students.

3.3 The De/Radicalisation Case

The de-radicalization case allows to explore how/why activism may become more extremist/harmful or moderate/harmless. Students found the case moderately difficult because (i) it is not staged, (ii) it is somewhat explorative, (iii) the effects of policies are rather counter-intuitive, and (iv) it is difficult/impossible to make a highly aggregated CLD of this model.

Students need to model this issue (see Figure 6), test the model, simulate the model over a time horizon of 100 years starting in 1980 and make graphs of key variables (Figure 7(b) and 7(c)).

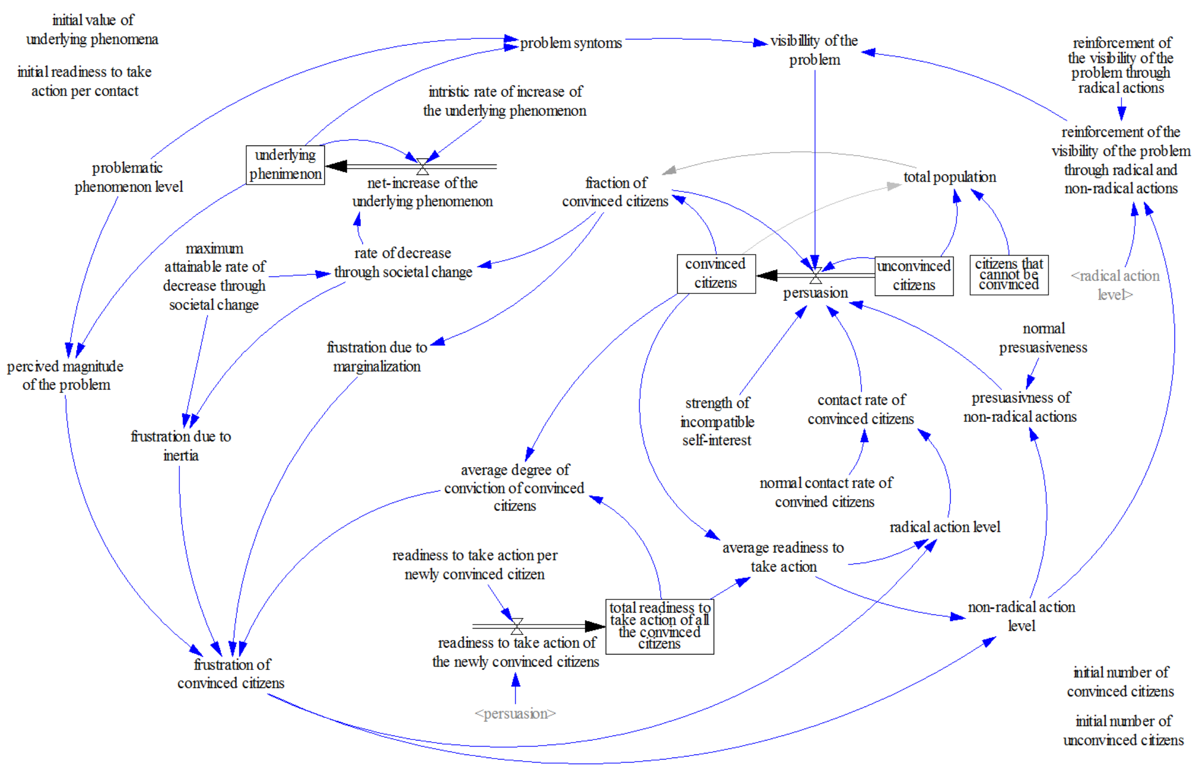
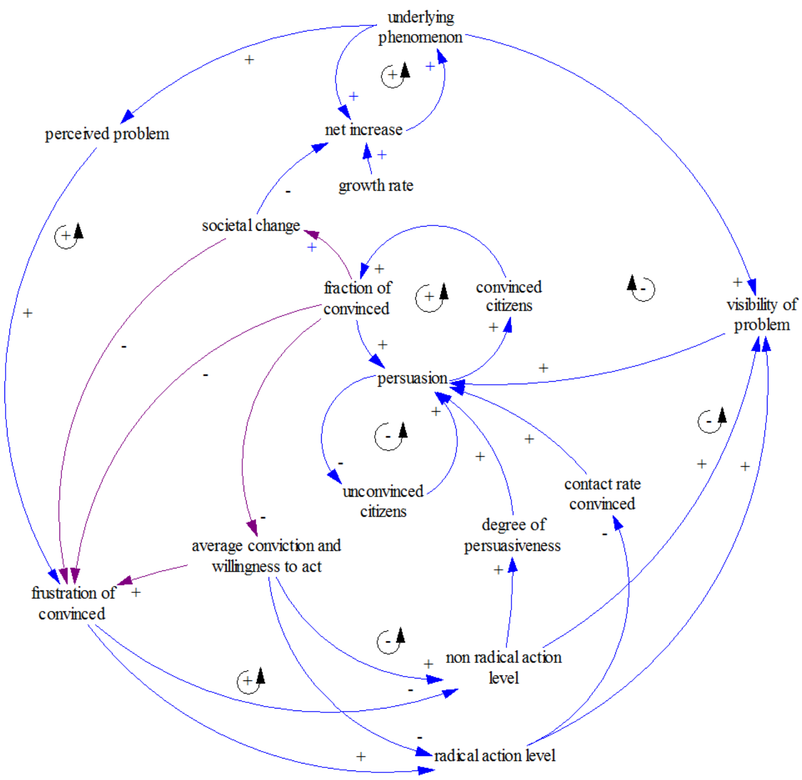


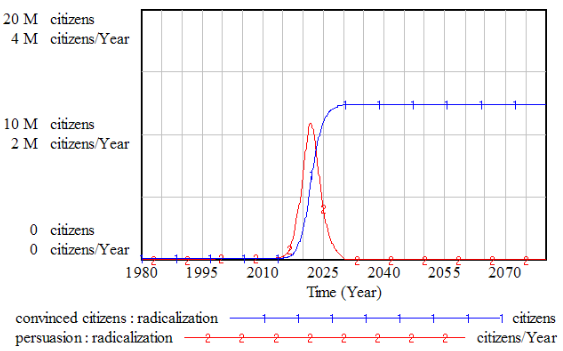
Figure 6: Full Stock-Flow Diagram of the de/radicalisation model

Then they need to test the sensitivity/uncertainty of the model for changes in several parameters (Figure 7(d)) and draw conclusions: significant changes in five out of six parameters lead to a fundamentally different mode of behavior (see Figure 7(d) – the blue curve represents the base case mode of behavior).

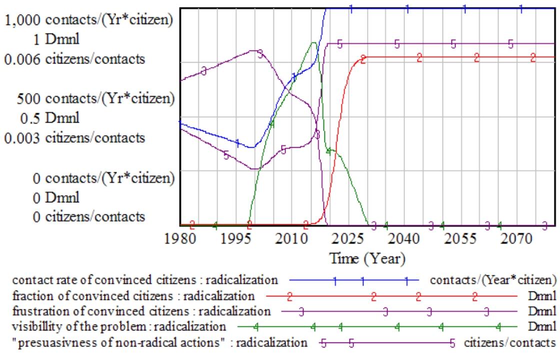
Students are asked to make two interesting and consistent exploratory scenarios based on the results of this sensitivity analysis: the very different scenarios displayed in Figure 7(e) can be distilled since this model is characterized by a strong bifurcation. Students also need to make a CLD of this simulation model, and use it to explain the link between structure and behavior.



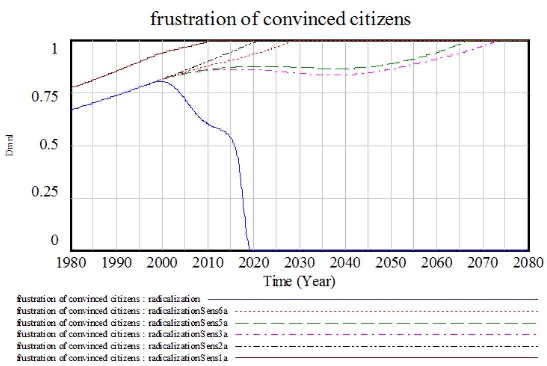
(a) CLD of the de/radicalization model



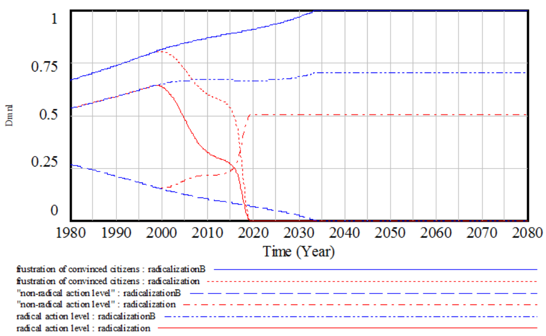
(b) Evolution of the stock of *convinced citizens* (blue –1–) and *persuasion* flow (red –2–) in case of deradicalization



(c) Evolution of main drivers of *persuasion* flow in case of deradicalization



(d) Behavior mode sensitivity (*frustration of convinced citizens*) for 5 out of 6 parameters



(e) Two distinct scenarios: deradicalization (red) versus further radicalization (blue)

Figure 7: CLD of the de/radicalization model (a), and ***deradicalization*** mode (b & c) versus **radicalization** mode (d & e) of the de/radicalization model

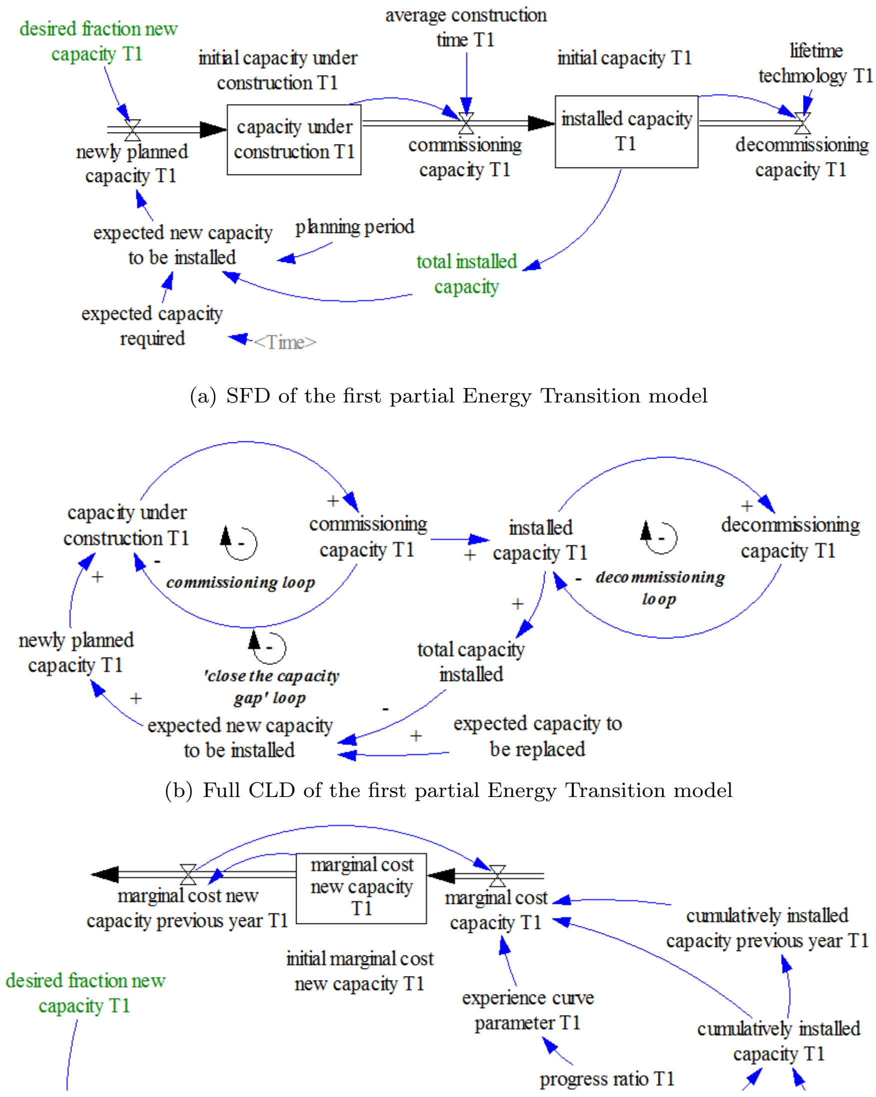
However, this question may be rather hard because it is difficult to make an simple/aggregated CLD of this model – a rather detailed CLD is displayed in Figure 7(a).

Finally, students are asked to formulate (counter-intuitive) policy advice based on the link between structure and behavior, and to give advice related to future refinements and extensions of the model.

3.4 The Transition towards Sustainable Energy Systems Case

This case deals with the competition of new energy technologies with existing technologies and other new technologies, and could be extended to spreading/concentrating subsidies for innovative renewable energy technologies. The *Energy Transition towards Sustainability* case description can be found in appendix E on page 31. Students found this staged case difficult and lengthy.

First students need to make a SDF (Figure 8(a)) and a detailed CLD (Figure 8(b)) of a small part of the model description. Second, students need to add a learning curve structure 8(c)) and plot the *marginal cost*.



(a) SFD of the first partial Energy Transition model

(b) Full CLD of the first partial Energy Transition model

(c) SFD of the learning curve added to the first SFD

Figure 8: Partial SFDs and CLD of the Energy Transition model

Then they need to extend the model with a sustainable alternative (Figures 9(a) and 9(b)), simulate it, and make graphs. Students also need to explain how this structure generates this behavior. They need to test the sensitivity of the model for changes in the parameters of the learning curve and for changes in a function. Finally students need to add another sustainable technology (Figure 9(c)) and test the influence of spreading investments over two alternatives.

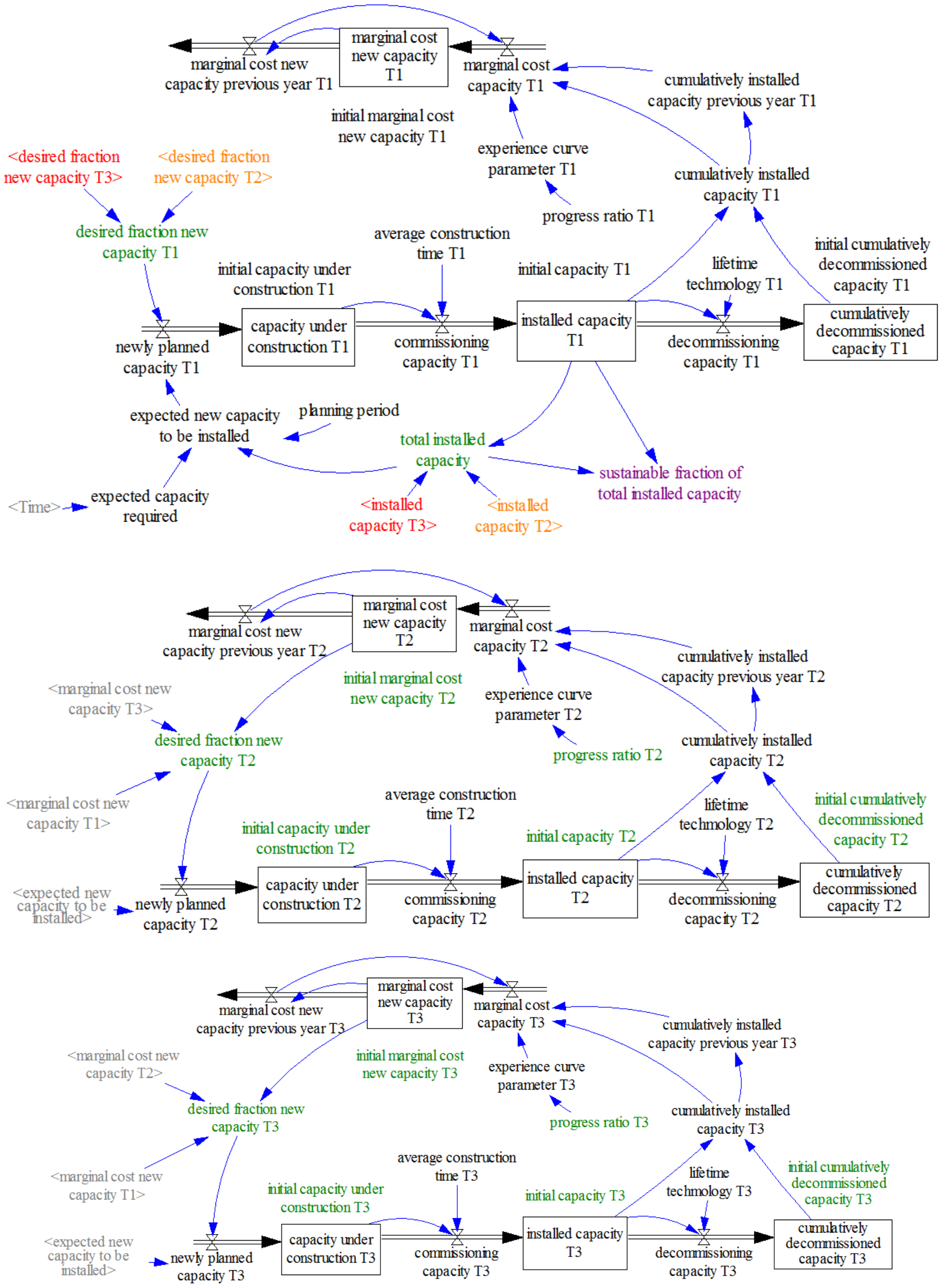


Figure 9: SFD of three competing Energy Technologies

3.5 The Boom and Bust in Dubai Case

The 'Boom and Bust in Dubai' case was developed specifically for testing purposes. It was inspired by a news paper article about 'The miraculous recovery of Dubai' (NRC Handelsblad 2010) (see Figure 12(a) on page 16). The case description can be found in appendix C on page 29.

First, students need to make a Stock Flow Diagram (green variables in Figure 10(a)) and a detailed CLD (green variables in Figure 10(b)) of the first part of the case description. Second, they need to extend the simulation model to the full description (Figure 10). They need to be able to specify the right max(0,. . .), min, delay, and lookup/graph functions. Their models generate nonsensical behaviours if one or more of the crucial functions are poorly specified.

They need to verify, validate, simulate, and plot graphs of the model, first without crisis settings (see Figures 11(a) and 11(b)). Later they need to add crisis settings to the model and test whether that leads to the unfolding of a real estate bust after month 10 (see Figure 11(c) and 11(d)).

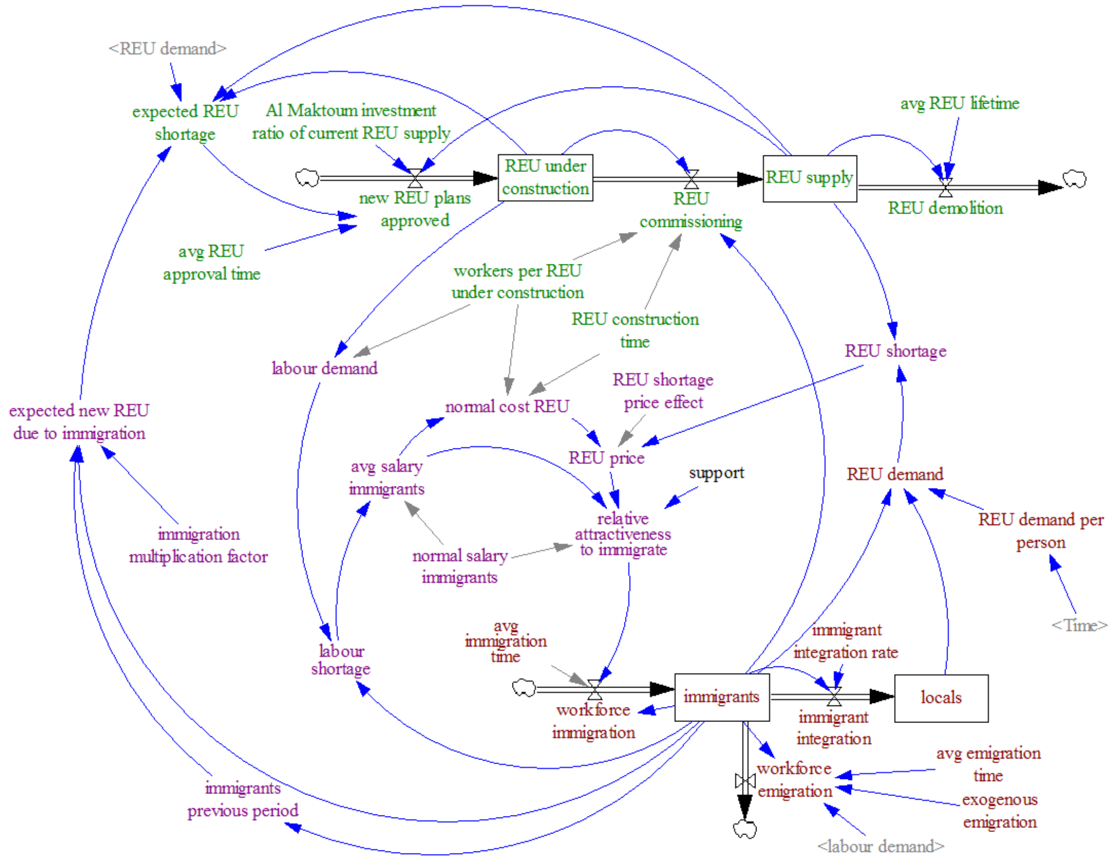
These changes not being enough to generate a true collapse, students need to test the influence of the uncertainty related to the *average immigration time* (1 – 3 months) (Figure 11(e)) and the *REU construction time* (1 – 4 months) with crisis settings (Figure 11(f)) on the number of *immigrants*, and their combined effects without crisis settings (Figure 11(g)). After these simulations, students should recognize that two different modes of behavior can be simulated with combinations of different values for these two parameters (exponential growth and a partial collapse followed by exponential growth), that total collapses without redress are not experienced without crisis settings, contrary to simulation *with* crisis settings.

Students should also be able to deduct that the exponential growth is caused by: more immigrants, more REU needed, more REU under construction, more immigrants, etc. The partial collapse is caused by an initial surplus of immigrants and REU under construction for runs with small values of the immigration time and construction time in which the construction time is smaller than the immigration time. Hence, the REU under construction initially in the pipeline are completed before new immigrants can be attracted.

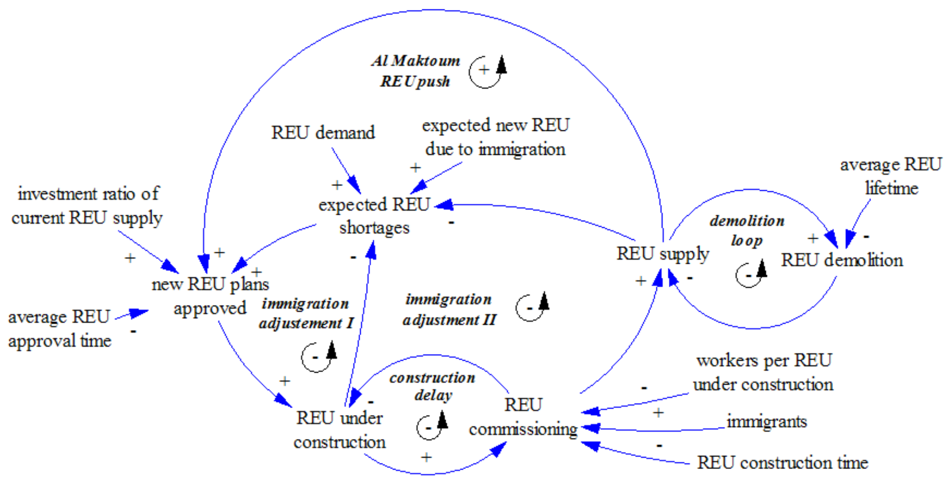
However, only a very small fraction of our students was able to distill these conclusions during the time-constrained exam: only those few students were able to make an appropriate aggregated *causal loop diagram* of the model (see Figure 12(b)) for explaining the link between system structure and behavior and providing appropriate policy advice derived from the model.

This case served as a testing case on 25 October 2010 for a group of 45 MSc students and on 18 January 2010 for a group of 70 BSc students during their time-constrained exam of the introductory SD course. The passing rates were rather low because (i) passing rate at the exam are always low compared to passing rates at the retake exam, and (ii) because the case cannot be solved (at all) without the correct min-max specifications.

Building blocks addressed in this case include stock-flow modelling and detailed and aggregated causal loop diagramming of aging chains, formulation of special functions (lookup functions and time series), and exploring plausible model behaviour. In teaching, this case may be used in the last weeks of the introductory SD course (see (Pruyt et al. 2009)).

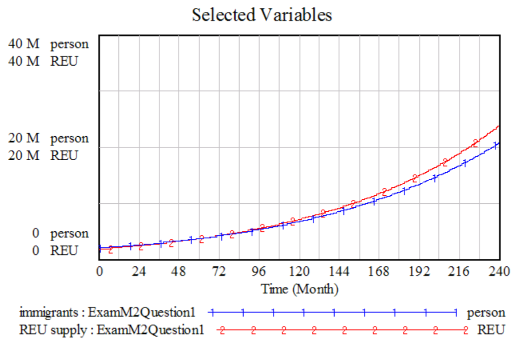


(a) SFD of preliminary model (in green) embedded in the SFD of the full model

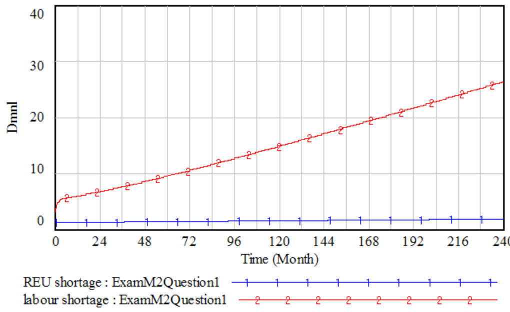


(b) Complete CLD of preliminary SFD – in other words, of the green variables

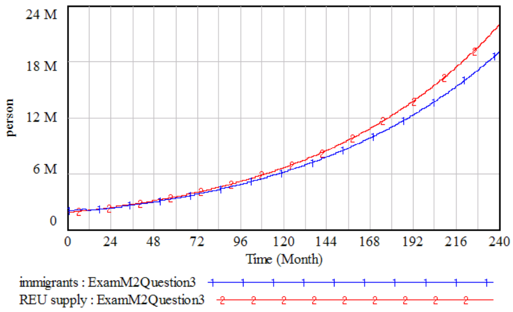
Figure 10: Full SFD and partial detailed CLD of the Boom and Bust model



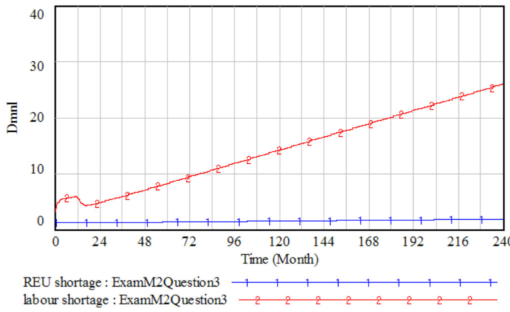
(a) Immigrant and REU supply without crisis settings



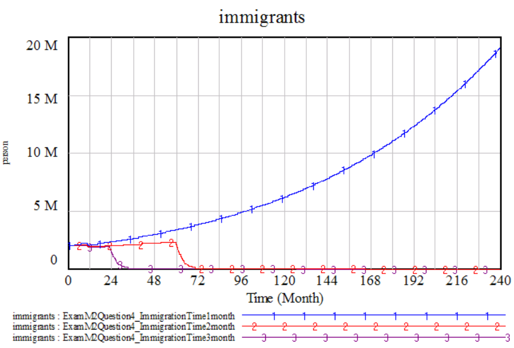
(b) Labour and REU Shortage without crisis settings



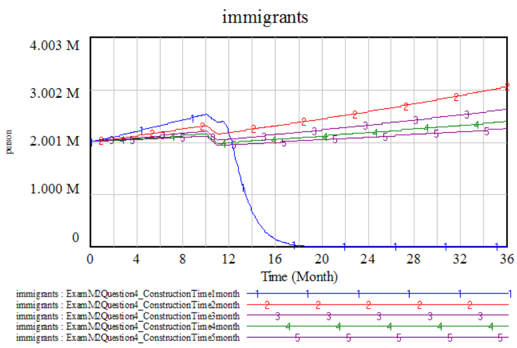
(c) Immigrant and REU supply with crisis settings



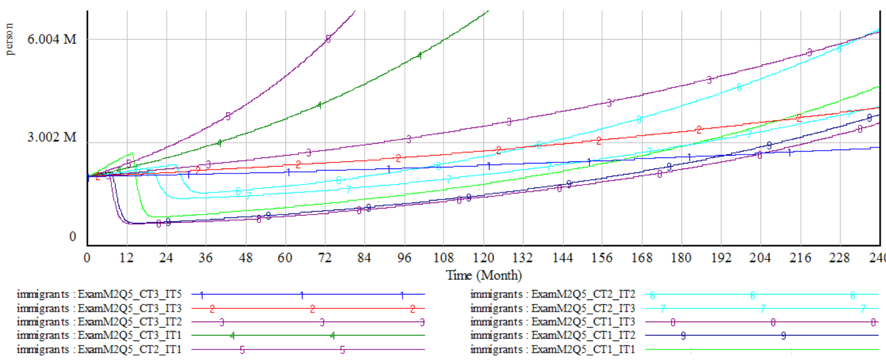
(d) Labour and REU Shortage with crisis settings



(e) changes in immigration time with crisis settings

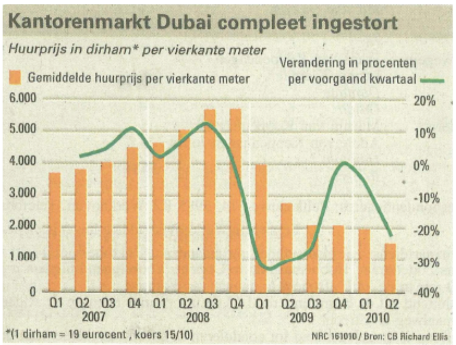


(f) changes in construction time with crisis settings – **detail**

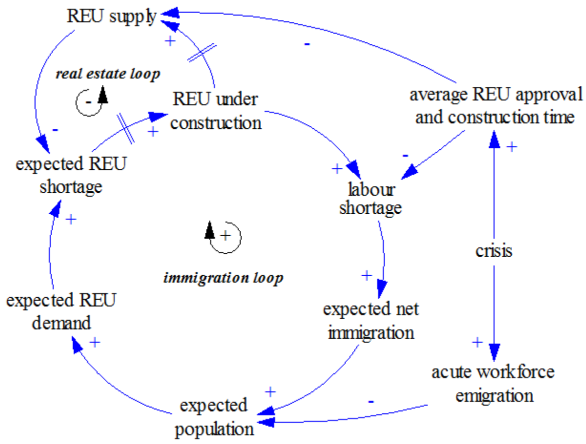


(g) changes in construction times **without** crisis settings

Figure 11: Plots with crisis settings (a and b), plots without crisis settings (c and d), sensitivity/uncertainty analysis related to the immigration time (e), construction time (f), and combinations of immigration and construction times (g)



(a) 'Business market Dubai collapsed' – Orange bars: rental price per m^2 in dirham; Green curve: percentage change to previous quarter



(b) Aggregated CLD

Figure 12: Graph from the newspaper article (Source: NRC Handelsblad 16/10/2010) and aggregated CLD of the model partly explaining the behavior

3.6 The Slow Students Fine Case

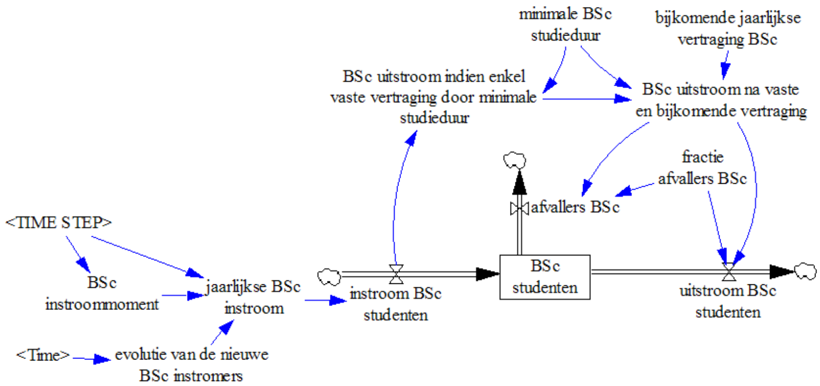
One of the most recent cases –the 'Slow Students Fine' case– was too hot too last: the case was developed one day before the exam of 18 January 2011 (precisely because this hot issue was on every student's mind), but was outdated less than two weeks later (when the strongly opposed policy proposal was partly abolished after mass demonstrations).

In 2010, the new Dutch cabinet Rutte-I launched plans to fine 'slow students' –students in higher education with more than one year delay– €3000 per extra year on top of their normal annual college fee (for Dutch students) of about €1900. The plans specified that the institutes for higher education needed to pass on the additional college fee of their slow students to the government, but also that these institutes for higher education needed to pay an additional annual fine of €3000 per slow student. These plans aroused serious opposition and protests, also from the institutes for higher education because these proposed policies were expected to seriously hurt those institutes for higher education –especially the three technical universities and other difficult studies– and to lead to undesired side-effects (eroding goals, massive lay-offs, et cetera). These plans were also argued to be damaging to the (future) Dutch knowledge economy, and running counter to the ambition to return in the top of the world of 'knowledge and innovation countries' by 2020 (Kennis and Innovatie Agenda 18/01/2011).

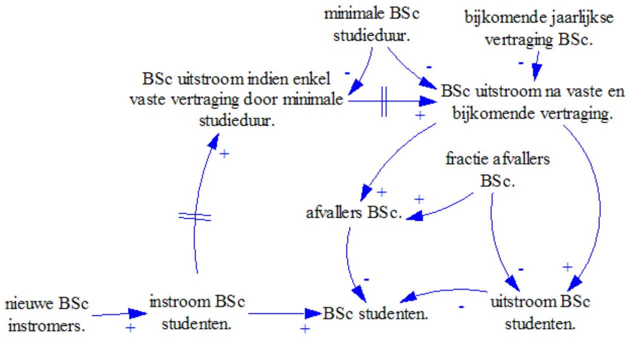
More than 80000 out of 550000 students in the Netherlands had –at that time– accumulated more than one year of study delay. Especially the technical studies have –because of the level of difficulty– a large fraction of slow students: 22.5% of the students need 4 years instead of 3 to finish their Bachelor of Science (BSc). At Delft University of Technology, the fraction was even higher because of the difficulty of the studies as well as the dazzling student life.

But such fines for slow students imposed upon the institutes of higher education would hurt all students since they would reduce the overall educational amount of money available (there is no subsidy for slow students) without providing the tools to speed them up or kick them out (no numerus clausus, no binding targets, et cetera). In the proposed form, it was simply a distributive code for the largest budget cuts in Dutch higher education in decades (€360+ million).

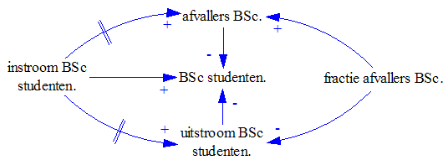
In the corresponding staged case, students first of all need to model the through-put of BSc



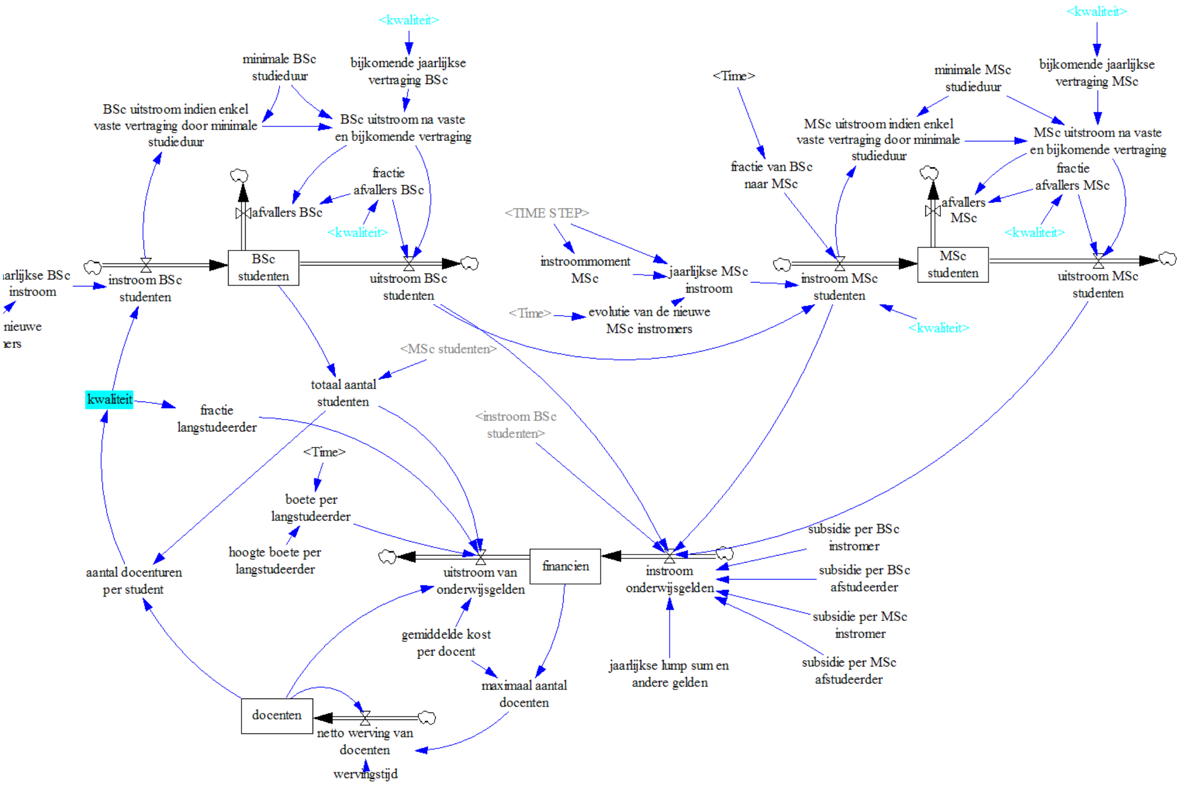
(a) SFD of the 'BSc' submodel



(b) Detailed CLD of the 'BSc' submodel



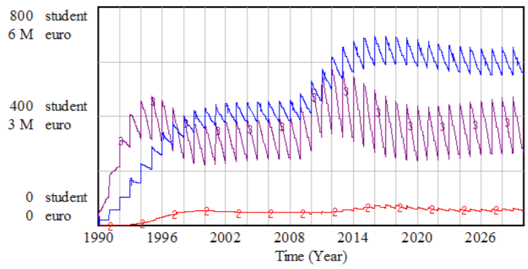
(c) Aggregated CLD of the 'BSc' submodel



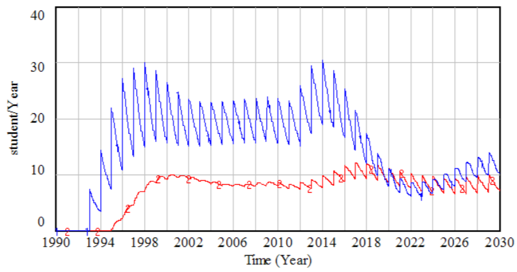
(d) SFD of the entire 'slow students' model

Figure 13: SFDs and CLDs of the BSc submodel and the entire 'slow students' model (in Dutch)

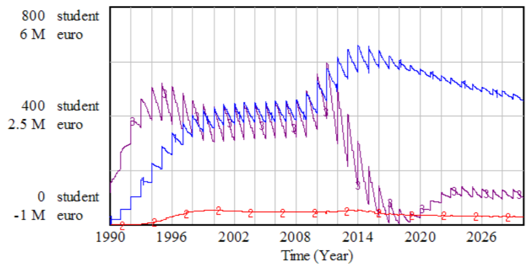
students and make corresponding detailed and aggregated CLDs (see Figure 13). They need to extend the description with a submodel about the through-put of MSc students (copy-past with changes), and a simplified submodel about the functioning of the faculty (finances and personnel) (see Figure 13(d) for the full SFD). Then they need to simulate the evolution of the faculty without the fine system (Figures 14(a) and 14(b)) and with the fine system (Figures 14(c) and 14(d)), perform several what-if analyses, make/discuss two proposed corrections and propose other adaptations/changes.



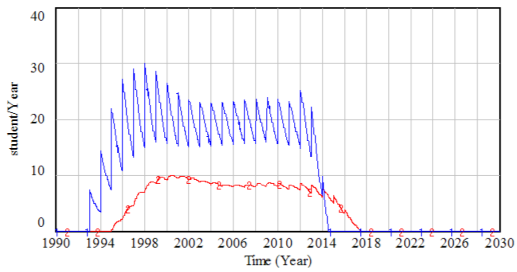
(a) Without fines for teaching to slow students: BSc students (blue –1–), MSc students (red –2–), and amount of money available for education (purple –3–)



(b) Without fines for teaching to slow students: outflow of BSc students (blue – 1–) and outflow of MSc students (red –2–)



(c) With fines for teaching to slow students: BSc students (blue –1–), MSc students (red –2–), and amount of money available for education (purple –3–)

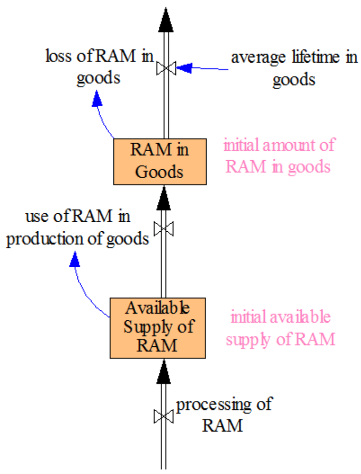


(d) With fines for teaching to slow students: outflow of BSc students (blue – 1–) and outflow of MSc students (red –2–)

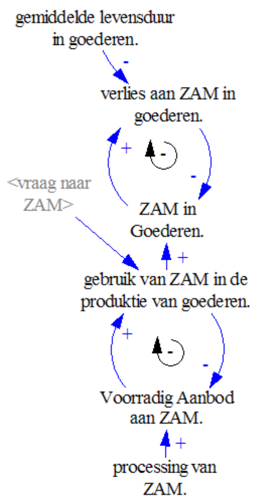
Figure 14: Left hand side: BSc students (blue –1–), MSc students (red –2–), and amount of money available for education (purple –3–); Right hand side: outflow of BSc students (blue – 1–) and outflow of MSc students (red –2–)

Building blocks addressed in this case include stock-flow modelling and detailed and aggregated causal loop diagramming of aging chains, formulating special functions (lookup functions and time series), and exploring plausible model behaviour. In teaching, this case could be used in week 6 or 7 of the curriculum (see (Pruyt et al. 2009)).

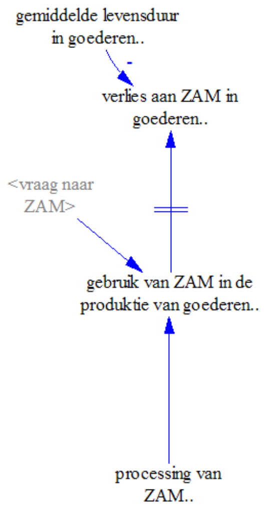
This case may have been too hot. Several things happened in the days and weeks after using this exam question which made the question obsolete. Three days after the exam, mass demonstrations took place in the Netherlands against these proposals. However, the cabinet refused to make any changes. But on 1 February, the '*Raad of State*' (the legal advisor of the state and highest administrative/legal court) published its negative advice against the fines imposed upon the universities based on their number of slow students. After this negative advice, the cabinet turned the fines for slow students into a lower contribution to the universities of exactly the amount those fines were projected to generate. . . The introduction of fines imposed upon students was postponed, not abolished.



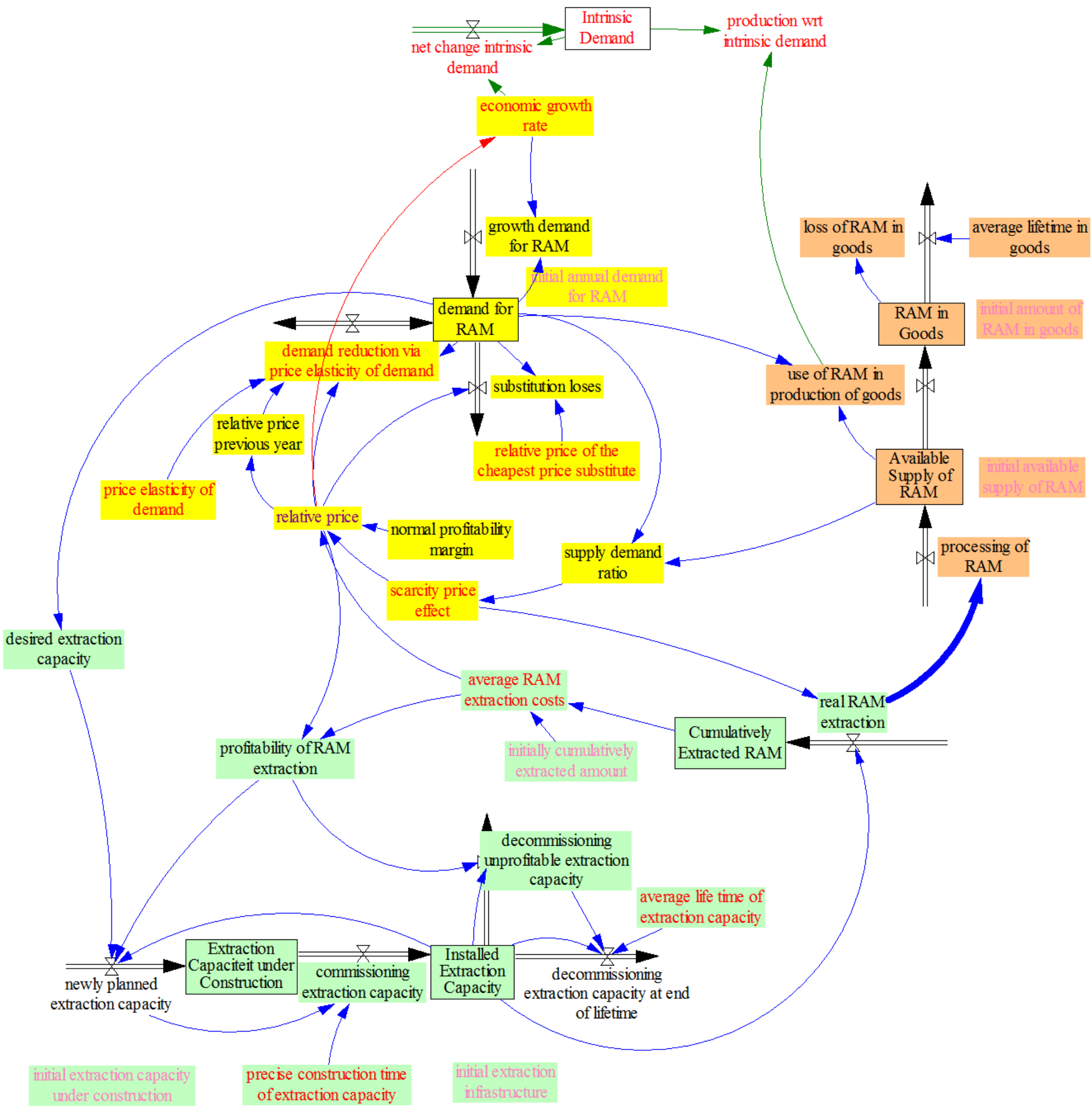
(a) First submodel



(b) Full CLD of first submodel



(c) Aggregated CLD



(d) Full SFD of the REM model

Figure 15: Partial SFD, partial CLDs, and full SFD of the REM model

3.7 The Rare Earths Scarcity II Case

Expected or plausible mineral/metal scarcity issues were, still are, and will continue to be hot issues. Several SD simulation models about particular mineral/metal scarcity issues have been and still are being developed by our research team. Pruyt (2010a) already presented a generic teaching and testing case about mineral/metal scarcity. Most students found that case too difficult for the (exam of the) introductory SD course. Moreover, better SD models about mineral/metal scarcity have been developed by our team, such as the generic model presented in (Pruyt 2010b). Hence, the author further simplified the model presented in (Pruyt 2010b) and turned it into the 'Rare Earths Scarcity II Case'.

In this new scarcity case, students first need to make a small SFD, a detailed CLD and an aggregated CLD from the first description (see Figures 15(a)(b)(c)). This very simple submodel needs to be extended in two further steps: with the demand for REM (variables in yellow in Figure 15(d)) and mining/processing industries (variables in green in Figure 15(d)).

Students need to perform the necessary verification and validation tests, extend the model with an '*intrinsic demand*' structure and related scarcity output indicator, and simulate the behavior of key variables (see Figures 16(a) and 16(b)). Then students need to investigate what would happen if the '*initial extraction capacity under construction*' would be zero (see Figures 16(c) and 16(d)), and what would happen if the '*initial extraction capacity under construction*' would be zero and the 'economic growth rate' would amount to 3% instead of 5% from 2011 on (see Figures 16(e) and 16(f)).

Following up on the what-if analyses, students need to perform a sensitivity analysis. Finally, they need to make an aggregated CLD of the model (see Figure 17) and explain the link between structure and behavior.

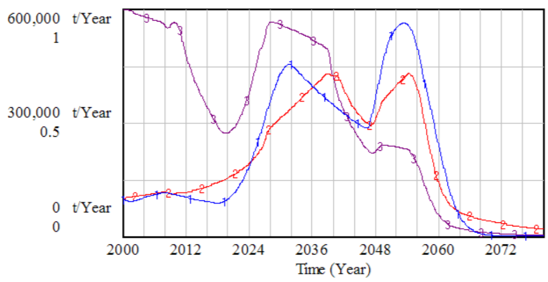
4 From Detailed Evaluation to MC and Quick Scan Evaluation

Not only is it time consuming to make appropriate exam models, it is also time consuming to correct them properly. At least, it was. Until the end of 2010, exam models were evaluated in detail by lecturer and assistants – on average 30 minutes per exam... Significant cuts in the number of student assistants available for the introductory courses forced the author to test new ways of evaluating exam models without eroding the goals and quality of the course and exams.

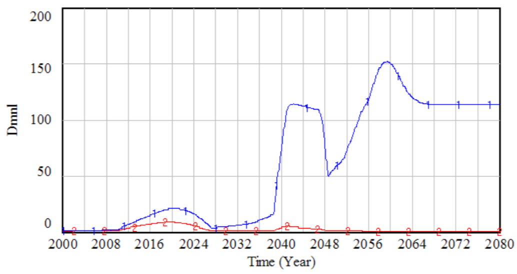
In January 2011, the author tested the use of MC questions about the modeling and simulation in combination with quick scanning of the model (about 5 minutes per model) and compared it to detailed grading of the same models (about 30 minutes per model). Almost all students obtained lower grades via the MC questions and higher grades via the quick model scan, resulting in averages similar to the detailed grades. Although it takes more time to prepare exams with MC questions about the modeling and simulation, there is an enormous time gain with this new approach: for 200 exams, the difference amounts to about 70 hours (200 exams x 25 minutes difference per exam - 180 additional minutes to develop a MC version times 3 versions minus 210 minutes extra consistency checks and administration).

Introducing MC questions to evaluate students' modeling and simulation of the exam case also led to the realization that students were over-tested in terms of specification (special functions and delays), model testing and sensitivity analysis, unit/dimension analysis, CLD and SFD modeling, and linking structure and behavior. Apart from the case, students also have to answer 20 MC questions deal with:

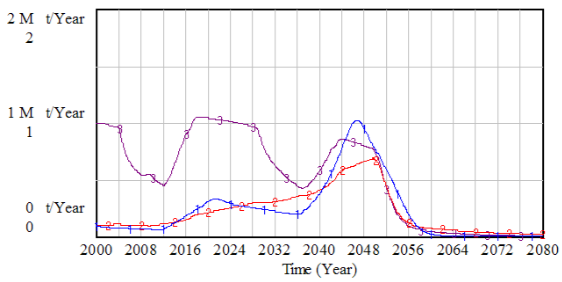
- SD Philosophy, SD Methodology, or 'SD speak'
- Formulation (special functions and delays)



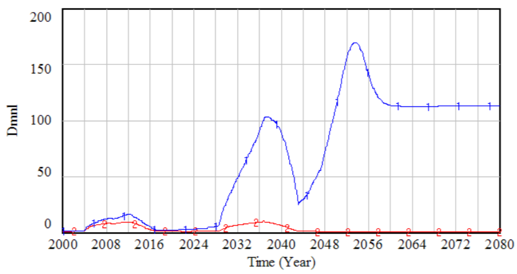
(a) Base case behavior: *installed extraction capacity* (blue –1–), *demand for REM* (red –2–), the output indicator (purple –3–)



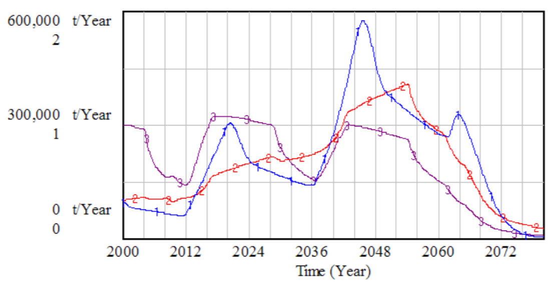
(b) Base case behavior: the *relative price* (blue –1–) and *scarcity price effect* (red –2–)



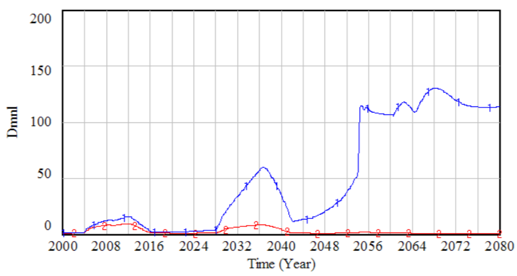
(c) What-if 1: *installed extraction capacity* (blue –1–), *demand for REM* (red –2–), the output indicator (purple –3–)



(d) What-if 1: the *relative price* (blue –1–) and *scarcity price effect* (red –2–)



(e) What-if 2: *installed extraction capacity* (blue –1–), *demand for REM* (red –2–), the output indicator (purple –3–)



(f) What-if 2: the *relative price* (blue –1–) and *scarcity price effect* (red –2–)

Figure 16: Left hand side: Base case and what-if behaviors of the *installed extraction capacity* (blue –1–), *demand for REM* (red –2–), the output indicator (purple –3–); Right hand side: Base case and what-if behaviors of the *relative price* (blue –1–) and *scarcity price effect* (red –2–)

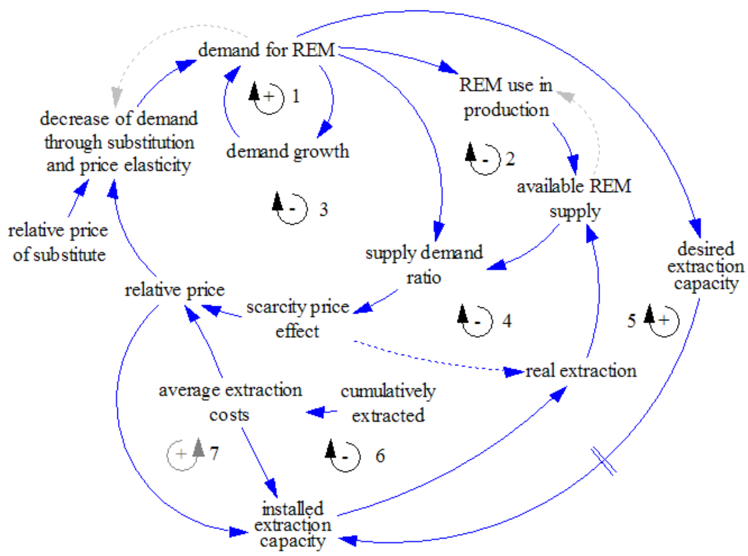


Figure 17: Aggregated CLD of the REM scarcity model

- Link between structure and behaviour
- From CLD to SFD and from SFD to CLD
- Calculation/assessment (of behaviour)
- Archetype to fit the description
- Model testing and sensitivity analysis
- Units/dimensions
- Policies

Hence, the number of traditional MC questions could be reduced and could be oriented towards SD Philosophy/Methodology, 'SD speak', calculation/assessment (of behaviour), fitting archetypes to descriptions, and policy analysis. This will save time – time most students lack during the exam.

5 Future Changes to the SD Curriculum

The high level attained by students after the introductory SD course –mainly because of the use of these hot teaching and testing cases– also makes that the curriculum could –and may need to– be changed.

The well-specified cases used during the SD project may now be replaced by less structured cases with less supervision. The project used in the SD project course taught to about 45 master students per year will therefore change from the academic year 2011-2012 on into an almost entirely unstructured hot case. From then on, pairs of students will be able to choose between two topics –proposed and mainly supervised by two senior lecturers. The relatively large number of junior supervisors could then be reduced to a few junior supervisors helping pairs of students with technical problems. The case topics will be chosen from current research topics of the senior lecturers. That way, models developed by the students may at a later stage be used for research purposes, for example to explore model uncertainty and explore the robustness of policies for different model specifications.

The Advanced SD course could –and may need to– be changed too: even more time could be spent on really advanced issues (eigenvalue elasticity analysis, multi-player serious gaming, Exploratory System Dynamics Modelling and Analysis, et cetera).

6 Conclusions, Lessons Learned, Proposal

All new testing/teaching cases developed over the last two years for this introductory SD course have been based on 'hot' issues.

The use of 'hot' cases may well be the main cause of a significant improvement of the SD modelling skills: although it is difficult to prove, it seems that the use of these testing/teaching cases has accomplished more than the other measures discussed in (Pruyt et al. 2009). Moreover, using 'hot' cases is a good way to enthuse students and to arouse their interest in applying SD in case of real-world issues. Applying SD to 'hot' issues illustrates the relevance of SD for dealing with real-world complex issues, which takes SD testing/teaching models one step further than being didactically responsible exercises. Although actual real-world testing/teaching cases are often more motivating, they are also more difficult than exercises developed in the first (and only) place to test/teach, because they need to be sufficiently close to the complex issue at hand to be relevant and credible as a 'real-world case'.

The main goal for introducing such cases –to bridge the gap between the introductory SD course and the SD project course by raising the level of difficulty of the introductory SD course– has been reached. Students now learn all basic SD modelling skills (and more) where they ought to learn these basic skills: in the introductory course. Hence, the SD modelling skills of those passing the Introductory SD course are high enough to allow the SD project to be organised in a different –less resource intensive– mode. This allows us to change the SD project course into what a SD project course should be: an almost real-world project –with little but high quality supervision– in which an unstructured and complex issue is structured, modeled, tested, simulated, analysed, used for policy testing, and communicated in time to problem owners / stakeholders.

Two previous papers presenting 'hot teaching and testing cases' have also lead to the start up a small (informal) network of university-level lecturers interested in sharing 'hot' testing/teaching cases. However, it may be desirable to set up a 'central case depository' managed by the System Dynamics Society and to make agreements on a set of criteria and a specific standard/format.

A depository should set minimal quality standards –but more importantly– should be open to different types of cases (see for example the cases in (Ford 1999), (Sterman 2000), (Martin Garcia 2006), the D-series, (Meyers, Slinger, Pruyt, Yucel, and van Daalen 2010), etc), and should make a distinction between lecturers and students for levels of access. The Proceedings of the International System Dynamics Conference may –in the absence of a depository– be useful for sharing cases.

Enjoy! But use with care. . .

References

Dudley, R. (2008). A basis for understanding fishery management dynamics. *System Dynamics Review 24*, 129. doi: 10.1002/sdr.392. 5

Ford, A. (1999). *Modeling the environment: an introduction to system dynamics models of environmental systems*. Washington (D.C.): Island Press. 23

Martin Garcia, J. (2006). *Theory and practical exercises of System Dynamics*. 23

Meyers, W., J. Slinger, E. Pruyt, G. Yucel, and C. van Daalen (2010, July). Essential Skills for System Dynamics Practitioners: A Delft University of Technology Perspective. In *Proceedings of the 28th International Conference of the System Dynamics Society*, Seoul, Korea. `http://systemdynamics.org/conferences/2010/proceed/papers/P1096.pdf`. 2, 3, 23

NRC Handelsblad (2010, 16 October). Miraculeus herstel van Dubai. NRC Handelsblad. 13

Pruyt, E. (2008a, July). Dealing with multiple perspectives: Using (cultural) profiles in System Dynamics. In *Proceedings of the 26th International Conference of the System Dynamics Society*, Athens, Greece. System Dynamics Society. http://systemdynamics.org/conferences/2008/proceed/papers/PRUYT424.pdf. 3

Pruyt, E. (2008b, July). Food or energy? Is that the question? In *Proceedings of the 26th International Conference of the System Dynamics Society*, Athens, Greece. System Dynamics Society. http://systemdynamics.org/conferences/2008/proceed/papers/PRUYT372.pdf. 3

Pruyt, E. (2009a, July). Cholera in Zimbabwe. In *Proceedings of the 27th International Conference of the System Dynamics Society*, Albuquerque, USA. System Dynamics Society. http://www.systemdynamics.org/conferences/2009/proceed/papers/P1357.pdf. 3

Pruyt, E. (2009b, July). The Dutch soft drugs debate: A qualitative System Dynamics analysis. In *Proceedings of the 27th International Conference of the System Dynamics Society*, Albuquerque, USA. System Dynamics Society. http://www.systemdynamics.org/conferences/2009/proceed/papers/P1356.pdf. 3

Pruyt, E. (2009c, July). Making System Dynamics Cool? Using Hot Testing & Teaching Cases. In *Proceedings of the 27th International Conference of the System Dynamics Society*, Albuquerque, USA. System Dynamics Society. http://www.systemdynamics.org/conferences/2009/proceed/papers/P1167.pdf. 1, 3

Pruyt, E. (2009d, July). Saving a Bank? The Case of the Fortis Bank. In *Proceedings of the 27th International Conference of the System Dynamics Society*, Albuquerque, USA. System Dynamics Society. http://www.systemdynamics.org/conferences/2009/proceed/papers/P1273.pdf. 3

Pruyt, E. (2010a, July). Making System Dynamics Cool II: New hot testing and teaching cases of increasing complexity. In *Proceedings of the 28th International Conference of the System Dynamics Society*, Seoul, Korea. System Dynamics Society. http://systemdynamics.org/conferences/2010/proceed/papers/P1026.pdf. 1, 3, 20

Pruyt, E. (2010b). Scarcity of minerals and metals: A generic exploratory system dynamics model. In *Proceedings of the 28th International Conference of the System Dynamics Society*, Seoul, Korea. System Dynamics Society. http://systemdynamics.org/conferences/2010/proceed/papers/P1268.pdf. 3, 20

Pruyt, E. et al. (2009, July). Hop, step, step and jump towards real-world complexity at Delft University of Technology. In *Proceedings of the 27th International Conference of the System Dynamics Society*, Albuquerque, USA. System Dynamics Society. http://www.systemdynamics.org/conferences/2009/proceed/papers/P1140.pdf. 3, 13, 18, 23

Pruyt, E. and C. Hamarat (2010a). The concerted run on the DSB Bank: An Exploratory System Dynamics Approach. In *Proceedings of the 28th International Conference of the System Dynamics Society*, Seoul, Korea. System Dynamics Society. http://systemdynamics.org/conferences/2010/proceed/papers/P1027.pdf. 3

Pruyt, E. and C. Hamarat (2010b). The Influenza A(H1N1)v Pandemic: An Exploratory System Dynamics Approach. In *Proceedings of the 28th International Conference of the System Dynamics Society*, Seoul, Korea. System Dynamics Society. http://systemdynamics.org/conferences/2010/proceed/papers/P1389.pdf. 3

Pruyt, E. and J. Kwakkel (2011, July). De/radicalization: Analysis of an exploratory SD model. In *Proceedings of the 29th International Conference of the System Dynamics Society*, Washington, USA. System Dynamics Society. 3, 31

Pruyt, E., J. Kwakkel, G. Yucel, and C. Hamarat (2011, July). Energy transitions towards sustainability: A staged exploration of complexity and deep uncertainty. In *Proceedings of the 29th International Conference of the System Dynamics Society*, Washington, USA. System Dynamics Society. 31

Sterman, J. (2000). *Business dynamics: systems thinking and modeling for a complex world.* Irwin/McGraw-Hill: Boston. 23

APPENDIX – APPENDIX – APPENDIX – APPENDIX

A Mass Starvation in the Oostvaardersplassen (/25)

The swampy natural reserve the 'Oostvaardersplassen' (OVP) –approximately the area between Almere and Lelystad in South Flevoland, the Netherlands– was created when it was decided –some time after the impoldering– to create a large area where geese could pass the molting season. Large herbivores were needed in order to keep the area free of willows and other brushwood. Hence, a small group of Heck cows were introduced in 1983, followed by Konik horses in 1984 and red deer in 1992. The area was supposed to bring back Dutch primal nature: the area would be left to nature – no hunting would be allowed.

The three populations of herbivores increased prosperous, at the beginning even exponentially, as could be expected with herbivores without natural enemies on such an large pasture area. However, the last couple of years, a large fraction of the large herbivores did not survive the winter. Movies of many of the animals dying of starvation caused major public outrage and discussions whether the area should be managed or not and thus whether animals should be shot or not, and if so, when (just before the winter season or just before dying).

Make a System Dynamics simulation model about the large herbivores in the Oostvaardersplassen based on following information.

Suppose that there were 75 *large herbivores* in the Oostvaardersplassen in 1985. One could model the *births* as the product of the number of *large herbivores*, the *percentage birth rate*, the *birth season* and the *birth randomizer* divided by the *length of the birth season.* And one could model the *deaths* as the product of the number of *large herbivores*, the *percentage death rate*, the *death season* and the *death randomizer* divided by the *length of the death season.*

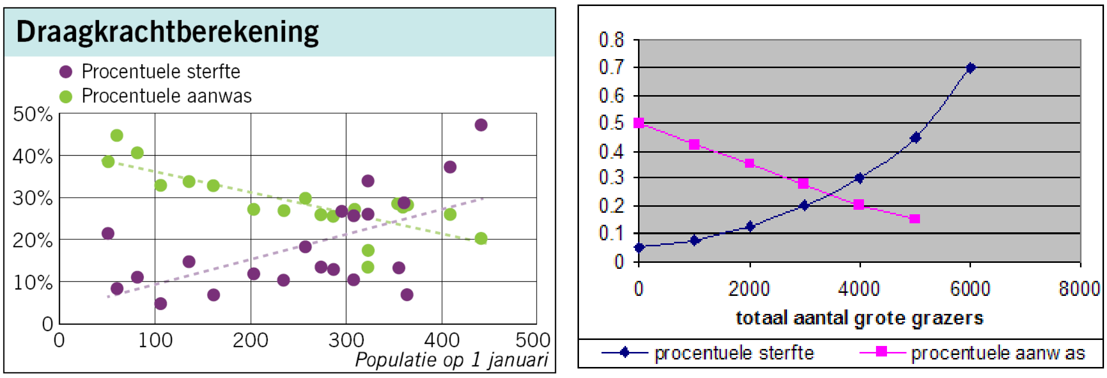
The *birth season* could be modeled with a *pulse train* starting in 1982.5 with the *length of the birth season* and a frequency of 1 year until the final simulation time. The *death season* could be modeled with a *pulse train* starting in 1982 with the *length of the death season* and a frequency of 1 year until the final simulation time. Make your model such that the *length of the death season* and the *length of the death season* equal the time step.

Suppose that you obtain the information in Figure 18(a) regarding past assessments of two aspects of the carrying capacity of the area for Heck cows and that you generalize the information regarding Heck cows to all large grazers in the Oostvaardersplassen as in graph 18(b). Use the assessments displayed in Figure 18(b) to model the *percentage birth rate* of the *large herbivores* and the *percentage death rate* of the *large herbivores.*

Also add a *birth randomizer* distributed normally between 0 and 2 with average 1 and standard deviation 0.5 and seed 2 (the seed is a number from which a (pseudo-)random number is generated). And add a *death randomizer* distributed uniformly between 0.5 and 3 with seed 3.

The information related to the three output indicators of interest (number of *herbivores*, *births* and *deaths*) still needs to be smoothed for at least two reasons:

- Since the OVP reserve is a rather large OERwildlife reserve, it is impossible to monitor the exact numbers of births, deaths and large herbivores over time: assessment of these



(a) Carrying capacity for Heck cows in the OVP – Source: NRC Handelsblad 11/12/2010

(b) Generalized carrying capacity curves for all large herbivores in the OVP

Figure 18: Carrying capacity and generalized carrying capacity for the OVP

evolutions could, at best, be made based on periodic assessments (right before and right after the *birth season* and *death season*) and some additional calculations/smoothing.

- Rather discrete modelling constructs used in the description above may lead to discrete flow behaviours that need to be turned back to continuous evolutions.

Add therefore a variable *smoothed info on large herbivore births* to smooth the *births* according to third order exponential smoothing with a delay of 1 year. Do the same for the variables *smoothed info on large herbivores* and the *smoothed info on large herbivore deaths*.

1. (/10) Make a SD simulation model based on the description and information provided above.
2. (/2) Test the model: list two useful validation tests (except sensitivity analysis – see below), perform them, and briefly describe results/conclusions.
3. (/4) Simulate the model and draw the evolution of the births and deaths (in the same graph), as well as the number of *large herbivores*. Simulate the model again with a different 'seed' and draw the results. Do this again, and again, and again. Generalise and conclude.
4. (/2) Perform the necessary sensitivity analyses. To which parameters and assumptions/functions is the model behaviourally sensitive? Briefly describe the analyses performed and draw only the interesting outcomes.
5. (/4) Make a complete and an aggregated CLD of this model.
6. (/1) Explain the link between structure and behaviour.
7. (/2) Policy? Implement it in the model and test it. What is your conclusion and why?

B The Bluefin Tuna Files (/25)

Tuna experts fear that the Atlantic bluefin tuna may be extinct in few years from today. According to environmental organisations, the collapse of the East-Atlantic bluefin tuna is imminent as a consequence of systematic overfishing and illegal catches in the Mediterranean. Hence, their call for a moratorium in the eastern part of the Atlantic Ocean and the Mediterranean.

The East-Atlantic bluefin tuna is a migratory predator that commutes between the Atlantic Ocean and the Mediterranean Sea. Almost the entire catch is exported to Japan for its thriving sushi and sashimi markets. The tuna population has been in sharp decline in recent years and many tuna experts considered the most recent meeting of the 'International Commission for the Conservation of Atlantic Tunas', ICCAT[4] for short, as the last chance to remedy the situation...

Beginning of the eighties, drastic catch restrictions were agreed upon for the Western part of the Atlantic Ocean. But those drastic measures were too little too late. The population only stabilised in the nineties at only 20 percent of the 1975 level.

It is clear that action needs to be taken now to save the East-Atlantic bluefin tuna. That is why you are asked to make a SD simulation model concerning this threatened tuna species (from now simply called tuna).

Fish in the Sea (/8)

The *current tuna fish biomass*, estimated to amount to the *un-fished tuna biomass*[5] of 100000 tonnes in the year 1990, increases through *growth of the current tuna biomass* and *delayed tuna recruitment*[6], decreases through *natural tuna fish deaths* and *tuna fish catches*.

The *growth of the current tuna biomass* is equal to the *current tuna biomass* times the *rate of tuna growth* of 'adult tuna fish' of 4% per year. The *delayed tuna recruitment* equals the *current tuna biomass* multiplied by the *tuna recruitment rate* of 1% per year, but is delayed (exactly) 4 years[7].

The *natural tuna fish deaths* is estimated to amount to the *current tuna biomass* multiplied by the *ratio of current biomass to un-fished biomass* over the *normal tuna lifetime* of 20 years. The *ratio of current biomass to un-fished biomass* is simply the *current tuna biomass* divided by the *un-fished tuna biomass*.

And *tuna fish catches* depend on the *current tuna biomass* and the *tuna catch fraction*. The *tuna catch fraction* depends in turn on the *total number of tuna fishing boats* and the *tuna boat efficiency* of 0.0004% per boat per year. [Assume for now that:] The *total number of tuna fishing boats* is composed of 15000 *official tuna fishing boats* [this constant will be turned into a variable in the next section] and 10000 *illegal tuna fishing boats*.

1. (/6) Make a first System Dynamics simulation model of this issue.
2. (/1) Simulate the model. What happens with a fixed *total number of fishing boats* of 25000, 15000, and 5000? What would be the *total number of fishing boats* that would keep the tuna biomass in equilibrium at the current level? Draw the four results in terms of the *current tuna biomass*, both on your computer and on your exam copy.
3. (/1) Write this system as a balance equation (make sure to choose appropriate symbols and explain their meaning).

Fishery and Fleet Management (/17)

The International Commission for the Conservation of Atlantic Tunas (ICCAT) is an intergovernmental fishery organization responsible for the conservation of tunas and tuna-like species in the Atlantic Ocean and its adjacent seas, more specifically the Mediterranean. ICCAT fleet size regulations are among the most important measures for preventing the extinction of the bluefin tuna homing in the East Atlantic-Mediterranean. ICCAT's functioning and policy-making can be seen as a high-level policy loop. This high-level ICCAT-policy loop may be summarised as follows:

The *ratio of current biomass to un-fished biomass* is estimated and interpreted with a '*change in tuna fishery perception*' function in order to form the *latest perception of the tuna fishery*

[4]The ICCAT is an intergovernmental fishery-organisation responsible for the preservation of tuna and tuna-like in the Atlantic Ocean and bordering seas, like the Mediterranean.

[5]The *un-fished tuna biomass* is the estimated tuna biomass without any (previous or current) tuna fishing.

[6]Recruitment means reaching a certain size or reproductive stage. With fisheries, recruitment usually refers to the age a fish can be caught and counted in nets.

[7]Tuna is assumed to mature at four years of age in the Mediterranean. It is also assumed here that harvesting tuna under the age of 4 is not interesting from economic and ecological points of view and/or feasible altogether.

status. The '*change in tuna fishery perception*' function connects following points: (0,-10), (0.25,-2), (0.5,0), (0.75,1.5), (1,10). This *latest perception of tuna fishery status* is smoothed into the *ICCAT perceived state of tuna fishery* using a *time needed to change the tuna fishery perception* of 2 years, starting from the *initial ICCAT state of tuna fishery* in the year 1990 of 10 (which corresponds to 'excellent').

The *official number of tuna fishing boats*, initially 15000, increases (and decreases) by means of the *net increase of the official number of tuna fishing boats* equal to the *proposed change in tuna fishing boats* divided by the *time to implement the tuna boat policy* of about 2 years.

The *proposed change in tuna fishing boats* equals the *effect of ICCAT's perceived state of tuna fishery on the number of tuna fishing boats* times the *official number of tuna fishing boats.* Given past and expected ICCAT states and decisions, you can assume that this *effect of ICCAT's perceived state of tuna fishery on the number of tuna fishing boats* amounts to -0.9 for *ICCAT's perceived state of tuna fishery* of -10, to -0.5 for *ICCAT's perceived state of tuna fishery* of -7.5, to -0.25 for *ICCAT's perceived state of tuna fishery* of -5, to -0.1 for *ICCAT's perceived state of tuna fishery* of -2.5, to 0 for *ICCAT's perceived state of tuna fishery* of 0, to 0.075 for *ICCAT's perceived state of tuna fishery* of 2.5, to 0.15 for *ICCAT's perceived state of tuna fishery* of 5, to 0.21 for *ICCAT's perceived state of tuna fishery* of 7.5, and to 0.25 for *ICCAT's perceived state of tuna fishery* of 10 or more.

1. (/5) Extend the simulation model with the information provided above and save it. Verify the model briefly. Simulate the model and make graphs of the *official number of tuna fishing boats* and *current tuna biomass.*

2. (/1) Validate the model. List 2 validation tests (with the exception of sensitivity testing), perform them and describe the results/conclusions (briefly).

3. (/2) Test the sensitivity of the model (more specifically of the *official number of tuna fishing boats* and the *current tuna biomass*) for changes in 3 parameters of your own choice (choose them well!!!) as well as the *effect of ICCAT's perceived state of tuna fishery on the number of tuna fishing boats.* Briefly describe the tests you performed, as well as your results and conclusions.

4. (/1.5) What happens to the *current tuna biomass* and *official number of tuna fishing boats* if the number of *illegal fishing boats* falls –due to strict controls and severe punishments– from 10000 down to 0 in 2010? Apply, rename the model, and draw and briefly describe the results. [Preserve this drastic reduction of the number of *illegal fishing boats* described in this what-if question for the remainder of the questions.]

5. (/1.5) What happens if countries studiously refuse to scale down their tuna fishing fleets, in other words, if the *net increase of the official number of tuna fishing boats* does not become negative? Apply, rename the model, and draw and briefly describe the results.

6. (/4) Make an extremely aggregated *causal loop diagram* of the model to explain the main feedback loops. Use it to explain the link between structure and behaviour.

7. (/2) ICCAT policy making is heavily criticized for its unsustainability. Devise 2 feasible policies to improve the sustainability of the current high-level ICCAT policy-loop. Describe them, implement them (rename your model), test them separately and (if possible) together, and briefly describe your conclusions: is this ICCAT+ policy more sustainable?

Fishery and Fleet Management in a Changing World? (/ 4 Bonus)

1. (/2) It is well known that the ecosystem capacity for Tuna keeps on deteriorating (pollution, overfishing of species predated on by tuna, etc) and that the efficiency of tuna boats keeps on increasing. Model both evolutions and test the appropriateness of the 'ICCAT policy' and the 'ICCAT+ policy' (the ICCAT policy plus the policies devised in the previous question) given these evolutions. Draw and describe your outcomes and conclusions.

2. (/2) From an individual fishery perspective, it makes sense to catch the fattest (and consequently the oldest) fish. But the older age classes actually contribute more to reproduction... Adapt the model accordingly. What does this information mean for the effectiveness of the 'ICCAT policy' and your 'ICCAT+ policy'?

C Case: Real Estate Boom and Bust in Dubai (/25)

Two weeks ago, Dubai announced that it overcame the crisis which started after Dubai World's announcement that it had to default on its debt. However, it seems a bit premature to assume that all problems have been solved. Following the real estate bubble burst 11 months ago, the real estate market is threatened today by permanent lack of occupancy (especially many buildings of poor quality in the desert).

C.1 Real Estate Sector (/6)

The phrase 'Real Estate Unit' (or REU) is used in the remainder of the text to refer to one house/appartment or one 1-person office space. Suppose that the *REU supply* initially consists of 1.800.000 of these REUs. The *REU supply* decreases by means of *REU demolition* after an *average REU lifetime* of almost 42 years (or 500 months).

The *REU supply* increases through *REU commissioning* of *REU under construction*. *REU commissioning* normally equals the number of *immigrants* divided by the product of the *REU construction time* and the number of *workers per REU under construction* of 25 persons per REU. Note that *REU commissioning* can never be greater than the *REU under construction* over the *REU construction time* of 3 months. Set the initial value of *REU under construction* to the number of *immigrants* times the *REU construction time* divided by the *workers per REU under construction.*

REU under construction increases by means of *new REU plans approved.* New REU plans are approved in response to non-negative estimates of *expected REU shortage*s over an *average REU approval time* of 1 month as well as in response to investment desires of the ruling Al Maktoum family. Suppose that the Al Maktoum family invests an *investment ratio of current REU supply* of 1% of the *REU supply.* Suppose that the official calculation of the *expected REU shortage* does not take into account demolition and therefore equals the *REU demand* minus the *REU supply* minus the *REU under construction* plus the *expected new REU due to immigration.*

1. (/2) Make a SD model of this description.
2. (/1) How do we call such stock-flow structures?
3. (/3) Make a complete causal loop diagram of this (partial) simulation model.

C.2 Population: locals and immigrants (/0)

Suppose for the sake of simplicity that *locals* –initially 220.000– do not work as workers (at least not in the real estate construction business), that all *immigrants* –initially 2.000.000– are active on the labor market (in other words, immigrants come to Dubai without families or inactive family members are simply not entered into the statistics / are not counted as immigrants in your model), and that all immigrants work in the real estate construction sector.

The number of *immigrants* increases through *workforce immigration*, and decreases through *workforce emigration* and through *integration*. *Workforce immigration* –which should always be positive– can be modelled as the *relative attractiveness to immigrate* times the number of existing *immigrants* over the *average immigration time* of 1 month. The normal *workforce emigration* –which cannot become negative– can be modelled as the number of *immigrants* minus the *labor demand*, divided by the *average emigration time* of 1 month. *Immigrants* can become *locals* if/when they integrate and find a self-sustaining job outside the REU business: this *integration* flow amounts to the *immigrant integration rate* of 0.001 per month times the number of *immigrants*.

Both *immigrants* and *locals* need REUs: their total *REU demand* is the product of the sum of these populations and the *REU demand per person*. Suppose that the *REU demand per person* increases linearly from 1 REU per person at the start of the simulation time to 2 REUs per person at the end of a 20 year time horizon.

C.3 Linking population to real estate to population to . . . (/19)

Define *labor shortage* as the *labor demand* over the available number of *immigrants*. *Labor demand* is the product of *workers per REU under construction* and the *REU under construction*.

Suppose that the *average immigrant salary* amounts to the *labor shortage* times a *normal immigrant salary* of 1000 dollar per person per month. The *relative attractiveness to immigrate* is directly proportional to the *average immigrant salary* divided by the *normal immigrant salary* and inversely proportional to the *REU price* divided by 960. The proportionality coefficient is equal to 1. Dividing by 960 is motivated by the assumption that 75% of the housing cost is subsidized by the companies and/or the Emirate, and a mortgage with a duration of 20 years can be obtained for the remaining amount.

The *REU price* equals the *normal REU cost* times the *REU shortage price effect* applied to the *REU shortage*. The *normal REU cost* amounts to $50.000 per REU (material costs) plus the product of the *average immigrant salary*, the *REU construction time*, and the number of *workers per REU under construction*. The *REU shortage price effect* consists of a curve connecting following couples (0,0.6), (10,4), (50,7.5), (100,10). *REU shortage* can be defined as the *REU demand* over the *REU supply*.

The *expected new REU due to immigration* equals the product of the *immigration multiplication factor* of 1 and the difference between the number of *immigrants* and the number of *immigrants in the previous period*. '*Immigrants in the previous period*' refers of course to the number of *immigrants* in the previous time period.

1. (/5) Extend the simulation model with the information provided above. Verify the model briefly. Simulate the model and make graphs of the *immigrants*, the *REU supply*, the *REU shortage* and *labor shortage*.

2. (/1) Validate the model. List 2 validation tests (with the exception of uncertainty testing), perform them and briefly describe the results/conclusions.

3. (/3) Use the model to try to simulate the unfolding of the real estate bust after month 10:

   - Let the Al Maktoum family's *investment ratio of current REU* fall instantly from 1% to 0% at the beginning of month 10 .
   - Add following non-negative term to the formula of *workforce emigration*: *exogenous emigration/average emigration time* that allows you to simulate an exogenous emigration of 200.000 immigrants in month 10.

   Save your model using a new name. Simulate the model and make graphs of the *immigrants*, the *REU supply*, and a combined graph of the *REU shortage* and *labor shortage*. Are these changes enough to generate a real estate bust (collapse)?

4. (/3) Keep the crisis settings from the previous question. Now, test the influence of the uncertainty related to the *average immigration time* –test for instance *average immigration times* of 1 month, 2 months, and 3 months– on the number of *immigrants*. Make a graph of the effects in terms of *immigrants*. Do the same for the uncertainty related to the *REU construction time* –test for instance *REU construction times* of 1 month, 2 months, 3 months, and 4 months.

5. (/2) Remove the crisis settings, and test the combined effect of different *average immigration times* and *REU construction times* on the number of *immigrants* without crisis settings. Briefly discuss your results and explain these effects and what causes them.

6. (/3) Make an extremely aggregated *causal loop diagram* of the model without crisis settings which allows you to explain the main feedback effects in case of an *average immigration time* that does not lead to a collapse. Use the CLD to briefly explain the link between system structure and behavior (in other words: why does the system not collapse?). Now, make a new aggregated *causal loop diagram* or adapt the previous one (use a different color) to the case of an *average immigration time* of 1 month. Again, use the CLD to briefly explain the link between system structure and behavior.

7. (/1) Suppose that the ruling family still wants to turn Dubai into the regional capital. The boom needs to be sustained in order to do so: what do you advice the ruling family to do –without spending/losing too much money– in order to sustain a continued boom? Limit your policy advice to two 2 sentences.

8. (/1) This model is just a preliminary model. What would you add/change/. . . to improve the model and make it really useful for real-world policy analysis? Don't do it.

D De/Radicalization (/25)

For this case description, readers are referred to (Pruyt and Kwakkel 2011).

E Energy Transition towards Sustainability (/25)

For this case description, readers are referred to (Pruyt, Kwakkel, Yucel, and Hamarat 2011).

F The 'Slow Students Fine' Case (/25)

A mass demonstration was organised on 21 January 2011 –a few days after the SD exam– in order to demonstrate against proposed legislation to fine 'slow students' and universities teaching to 'slow students'. Students were asked to model the potential consequences for our faculty based on the description below.

The BSc Student (/10)

First, model the inflow of BSc students. Annually, there is an *annual inflow* in the BSc studies at the *BSc inflow moment*. Suppose for reasons of simplicity that this inflow moment happens once a year – use a PULSE TRAIN(start, width, tbetween, end) with a *width* equal to the *time step*. Model the *annual BSc inflow* as the *evolution of the new BSc inflow* divided by the *time step* times the *BSc inflow moment*. Suppose that the *evolution of the new BSc inflow* gradually increased from 20 new BSc students in 1990 to 90 new BSc students in 1995 to 120 new BSc students in 2000 to 130 new BSc students in 2008 to 200 new BSc students in 2010 and that it stabilizes at 200 until the year 2030. The real *inflow of BSc students* is then the product of the *annual BSc inflow* and the *quality* (the lower the quality, the lower the inflow will be). For now, set the *quality* equal to 100%.

The inflow of BSc students is added to the group of *BSc students*. The group of *BSc students* decreases through the *outflow BSc students* when/if students obtain their BSc or as *BSc quitters*. Model the outflow of *BSc quitters* simplistically (but not entirely correctly) as the *fraction of BSc quitters* times the *BSc outflow after fixed and additional delay*. Suppose that 30% of the students quits the first year, 10% the second year, and 5% the third year. The *fraction of BSc quitters* –always between 0 and 1– is then the sum of these quit fractions divided by the *quality* (the lower the quality of the studies, the more quitters). Those who do not drop, obtain their BSc diploma, eventually: the *outflow of BSc students* then equals the *BSc outflow after fixed and additional delay* multiplied by the complement of the *fraction of BSc quitters*. Model the *BSc outflow after fixed and additional delay* as the first order delay of the '*BSc outflow if only minimal fixed delay*' with a total delay time equal to the product of the *minimal BSc study time* of 3 years and the *additional yearly delay BSc* of (on average) 50% divided by the *quality*. And model the variable '*BSc outflow if only minimal fixed delay*' as the delay of the *inflow of BSc students* with a fixed *minimal BSc study time* of exactly 3 years.

1. (/7) Make a SD model of the description above.
2. (/3) Make a complete *Causal Loop Diagram* (CLD) and a strongly aggregated *Causal Loop Diagram* of this partial simulation model.

The MSc Student (/3)

Model now the throughput of MSc students: almost the same applies to MSc students as to BSc students. Following details are different:

The *inflow of MSc students* equals the *quality* of the education times the sum of the *annual MSc inflow* of *new* students (not flowing semi-automatically from the BSc studies) and the product of the *outflow of BSc students* and the *fraction of* BSc students that flow semi-automatically from the *BSc to the MSc*. The *evolution of the new MSc inflow* was 0 students per year until 2007, started with 2 students per year in 2008, rose to 5 students per year in 2010, and is assumed to grow to 15 students per year in 2015 and 20 in 2020 after which it is assumed to remain constant. The *fraction of* students that flows semi-automatically internally from *BSc to MSc* was about 100% before the year 2008 – suppose that it fell to 80% of the students in 2008 and afterwards. The *minimal MSc study time* is equal to 2 years. And the *fraction of MSc quitters* –always between 0 and 1– is lower too: 10% in the first year and 10% in the second year. In summary: the structure of the MSc students submodel is the same as the BSc students submodel – a hand full of new MSc students is absorbed by a larger –maar decreasing– group of students flowing semi-automatically from the BSc to the MSc.

1. (/3) Extend the SD model with the description above.

The Faculty (/6)

The *quality* is a function of the *professor hours per student*: if the number of *professor hours per student* is 0 then the *quality* is 10%, if it is 50 then the *quality* is 60%, if it is 100 then the *quality* is 90%, if it is 150 or more then the *quality* is 100%.

Model the *professor hours per student* as a third order delay of one year of the product of 1000 hours per professor and the number of *professors* divided by the *total number of students*. Make sure in the previous formula that the denominator cannot become 0.

Model the number of *professors* –initially 5 in 1990– and the increase and decrease of the number of *professors* in a rather simplistic way: suppose that the *net hiring of professors* equals the difference between the *maximum number of professors* and the number of *professors*, divided by the average *hiring time*. The *hiring time* (and here firing time) for (good) professors is rather long – on average 2 years from the moment a new professor is actually needed. The *maximum number of professors* then equals the *amount of money available for education* divided by the *average cost of a professor* of €100000 per professor per year.

The *amount of money available for education* –initially 0– is increased by the *inflow of money available for education* and decreased by the *outflow of money available for education*. Without a fine for slow students, the *outflow of money available for education* approximately amounts to the number of *professors* times the *average cost of a professor*.

The *fraction of slow students* seems to be –at least partly– a function of the *quality* of the education: if the *quality* is 0% then the *fraction of slow students* is 90%, if the *quality* is 25%

then the *fraction of slow students* is equal to 85%, if the *quality* is 50% then the *fraction of slow students* is equal to 66%, if the *quality* is 75% then the *fraction of slow students* is equal to 40%, if the *quality* is equal to 100% then the *fraction of slow students* is equal to 25%.

The *inflow of money available for education* equals the *subsidy per new BSc student* times the*inflow of BSc students* plus the *subsidy per BSc graduate* times the*outflow BSc students* plus the *subsidy per new MSc student* times the*inflow of MSc students* plus the *subsidy per MSc graduate* times the *outflow of MSc students* plus the *annual lump sum and other subsidies.* The *subsidy per new BSc student* amounts to €15000, the *subsidy per BSc graduate* €5000, the *subsidy per new MSc student* €5000, and the *subsidy per MSc graduate* €5000. Suppose that the *annual lump sum and other subsidies for educational purposes* amount to an additional €1 million.

1. (/3) Extend the SD model based on the description above.
2. (/3) Simulate the model without fines for slow students from the year 1990 until the year 2030. Make graphs of following variables: *BSc students* and *MSc students*, *outflow of BSc students* and *outflow of MSc students*, *professors*, and *amount of money available for education.* Is the faculty healthy without the proposed system of fines?

And now with fines for slow students. . . (/9)

But what does the proposed system of fines for slow students mean for the faculty? Model therefore the system of fines as follows. With the system of fines the *outflow of money available for education* becomes *fraction of slow students* times the *total number of students* times the*fine per slow student* plus the number of *professors* times the *average cost of a professor.* Anticipating (at least) one year delay caused by opposition and demonstrations, you can assume that fines for slow students will only be introduced from 2012 on. From then on, the *fine per slow student* would amount to €3000 per year. This is of course only part of the picture: increased tuition fees to be paid by slow students are not taken into account here.

1. (/3) Extend the SD model with the description provided above.
2. (/2) Simulate the model *with* the system of fines. Make graphs of following variables: *BSc students* and *MSc students*, *outflow of BSc students* and *outflow of MSc students*, *professors*, and *amount of money available for education.* Is the faculty healthy with the proposed system of fines?
3. (/1) What if the number of new students increases until 2020 to 300 BSc students per year and to 60 new MSc students per year?
4. (/1) The cabinet is furious: they claim your model is totally wrong because the *outflow of money available for education* still needs to be divided by a factor 2.5 (the average number of study years of BSc and MSc). Is that correct? What would be the consequence?
5. (/1) After the previous proposed correction has been made, the cabinet now argues that the LOOKUP function of the *fraction of slow student*s needs to be adapted too – the cabinet assumes after all that students will study faster in the new system. Change the lookup, discuss the new function and the consequences of this change for the faculty.
6. (/1) It should be clear that this model requires further adaptation: how would you make it more realistic and better? Describe what and how, do it, and describe the results of these changes/corrections.

G Case: Scarce 'Rare Earths' (/25)

From Extraction and Processing to Production of Goods (/4)

Rare Earths Metals (REM) are often used in very small quantities in modern appliances or applications. Assume that the *REM in goods* initially amounts to 2000000 ton. *REM in goods* are lost after an *average lifetime in goods* of some 15 years (recycling of REM is (currently) not feasible). The *use of REM in the production of goods* depends on the *demand for REM* or the *available supply of REM* –initially equal to 250000 ton– if the *available supply of REM* is smaller than the *demand for REM*. The *available supply of REM* only increases through *processing of REM* which in turn follows the *real REM extraction*.

1. (/1) Make a SD model of the description above.
2. (/3) Make a complete *Causal Loop Diagram* (CLD) and a strongly aggregated *Causal Loop Diagram* of this partial simulation model.

Demand and Supply of REM (/4)

The *demand for REM* –initially equal to 100000 tons in 2000– increases in principle by means of an *increase of the demand for REM* and decreases through a *decrease of demand through price elasticity of demand* of door *substitution losses*.

The *increase of the demand for REM* is simply the product of the *economic growth rate* and the *demand for REM*. Suppose for reasons of simplicity that the *economic growth rate* was equal to 3% until the year 2009, that it fell to -10% in 2009, and that it jumped to 8% in 2010. Assume that the *economic growth rate* remains constant at 5% from 2011 on.

The *decrease of demand through price elasticity of demand* could be modeled as:

$$-price\ elasticity\ of\ demand * demand\ for\ REM * \frac{\frac{1}{relative\ price} - \frac{1}{relative\ price\ of\ the\ previous\ year}}{\frac{1}{relative\ price\ of\ the\ previous\ year}}$$

With the *relative price* equal to the product of the *average REM extraction costs*, the *scarcity price effect* and (1 plus the *normal profit margin* of 15%). Suppose that the *price elasticity of demand* is 10%.

If the *relative price* is greater than the *relative price of the cheapest price substitute* then the *substitution losses* increase to the product of the *demand for REM*, $\frac{1}{relatieve\ prijs}$, and the difference between the *relative price* and the *relative price of the cheapest price substitute*. The *substitution losses* due to price substitution effects are in other words non-negative. Suppose that the *relative price of the cheapest price substitute* is constant at 100 (in other words 100 times the normal price of REM).

Suppose also that the *scarcity price effect* amounts to 100 if the *supply demand ratio* is 0, 10 if the *supply demand ratio* is 0.55, 1 if the *supply demand ratio* is 1.1, 0.75 if the *supply demand ratio* is 2.2, 0.5 if the *supply demand ratio* is 11, 0.2 if the *supply demand ratio* is 22. The *supply demand ratio* is equal to the *available supply of REM* divided by the *demand for REM*.

1. (/4) Extend the SD model following the description provided above.

Commissioning and Decommissioning of Extraction Capacity (/17)

Suppose that the mining industry is myopic and has limited foresight: the *desired extraction capacity* is then equal to the *demand for REM*. The *newly planned extraction capacity* then equals the product of the *profitability of REM extraction* between 0 and 1 and the difference between the *desired extraction capacity* and the *installed extraction capacity* (Note: the value of the latter difference necessarily lies between 0 and the value of the *installed extraction capacity*).

The *newly planned extraction capacity* increases the *extraction capacity under construction* –initially equal to 60000. The *extraction capacity under construction* decreases through *commissioning of extraction capacity* which exactly delays the *newly planned extraction capacity* with the *precise construction time of extraction capacity* of 8 years. The *commissioning of extraction capacity* initially equals the *extraction capacity under construction* divided by the *precise construction time of extraction capacity*.

The *commissioning of extraction capacity* leads of course to an increase of the *installed extraction capacity*, initially equal to 100000. The *installed extraction capacity* decreases on the one hand through *decommissioning of extraction capacity* and on the other hand through *decommissioning of unprofitable extraction capacity*. Model the *decommissioning of unprofitable extraction capacity* as follows: *installed extraction capacity* * (-MIN(*profitability of REM extraction*,0)).

The *decommissioning of extraction capacity* then equals the *installed extraction capacity* divided by the *average lifetime of extraction capacity* minus the *decommissioning of unprofitable extraction capacity*. Note that formula of the *decommissioning of extraction capacity* needs to be non-negative. Set the *average lifetime of extraction capacity* at 30 year.

The maximum REM extraction is equal to the *installed extraction capacity*. The *real REM extraction* normally equals the *installed extraction capacity*, unless the *scarcity price effect* is smaller than 1, then it equals the *installed extraction capacity* times the *scarcity price effect*.

Cumulation of the *real REM extraction* gives the *cumulatively extracted REM* –initially equal to 4000000 ton. The difference between the *cumulatively extracted REM* and the *initial cumulatively extracted amount* is needed to calculate the *average REM extraction costs*. To do so, use a function with the difference between the *cumulatively extracted REM* and the *initial cumulatively extracted amount* as argument and following couples: (0, 1), (2.000.000, 2), (4.000.000, 4), (6.000.000, 8), (8.000.000, 16), (10.000.000, 32), (12.000.000, 64), (14.000.000, 128), (16.000.000, 256), (18.000.000, 512).

Finally, the *profitability of REM extraction* is equal to the difference of the *relative price* and the *average REM extraction costs*, divided by the *average REM extraction costs*.

1. (/7) Extend the SD model with the description provided above.
2. (/3) Perform the necessary verification and validation.
3. (/1) Extend the model: model the '*intrinsic demand*' – in other words, the demand in the absence of *decrease of demand through price elasticity of demand* and *substitution losses* – and make an output indicator '*fraction produced of intrinsic demand*' that allows to visualize the *use of REM in the production of goods* in function of the *intrinsic demand* over time.
4. (/1) Simulate and draw the behavior of the output indicator, of the *demand for REM*, of the *installed extraction capacity*, the *scarcity price effect* and the *relative price*.
5. (/1) What happens if the '*initial extraction capacity under construction*' is 0? Compare, draw and conclude.
6. (/1) What happens if –on top of the previous what-if– the 'economic growth rate' amounts to 3% from 2011 on? Compare, draw and conclude.
7. (/2) Perform a sensitivity analysis. For which parameters and functions is the model behaviorally sensitive? Draw (only) interesting outcomes.
8. (/1) Make an aggregated CLD and explain the link between structure and behavior.