# Teaching sustainable resource management using an interactive research tool

Bojana Bajželj[1,3], Richard A. Fenner[1], Elizabeth Curmi[1] and Keith S. Richards[2]

[1] Department of Engineering, University of Cambridge, Trumpington Street, Cambridge, CB2 1PZ, UK
[2] Geography Department, University of Cambridge, Downing Place, Cambridge, CB2 3EN, UK
[3] Corresponding Author's email: bb415@cam.ac.uk

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## Abstract

*Purpose*

Students were given an interactive exercise based on a research model (Foreseer™), developed by an interdisciplinary research team, that explores the interconnectivity of water, energy and land resources. Two groups of students were involved, one of undergraduates and the other of graduates. The aim was to enhance and complement teaching about resource system feedbacks and environmental modelling.

*Methodology*

The Foreseer model represents physical flows of the three resources (water, energy and land) using an interactive visual interface. The exercise was set up by giving students short instructions about how to use the tool to create four scenarios, and an online questionnaire was used to capture their understanding, and their ability to extract information from the model.

*Findings*

The exercise proved to be a helpful way to connect research and teaching in higher education, to the benefit of both. For students, it was an interactive and engaging way to learn about these complex sustainability issues. At the same time, it provided tangible feedback to researchers working on the model about the clarity of its user interface, and its pedagogic value.

*Originality/value*

This exercise represents a novel use of a resource model as a teaching tool in the study of the water, energy and land nexus, and is relevant to sustainability educators as an example of a model centred learning approach on this topic.

# 1 Introduction

The discourse in sustainable development covers increasingly complex themes. The most prominent example in recent years is the increased awareness of the importance of the interconnections amongst major resource systems, all of which are complex in their own right. The Water, Energy and Food nexus (also called the Water, Energy and Land (WEL) Nexus, or simply the Nexus) represents a way of thinking about these connections and their feed-back loops.

Sir John Beddington, former British Government Chief Scientific Advisor, called the interconnections between the three resources, and the associated aggravated consequences which they are expected to create by 2030, "The Perfect Storm" (Beddington, 2009). Energy and water inputs are needed for food production, land is converted for both energy and water infrastructure, and providing water at the right time and place requires energy. All three resources are connected, and more often than not, changes in one will have knock-on effects on the other two. The World Economic Forum's (2011) Global Risks 2011 report echoes Beddington's warnings: "Any strategy that focuses on one part of the water-food-energy nexus without considering its interconnections risks serious unintended consequences."

Considering all three resources together is difficult, both for the research community and in terms of communication to students. This is partly because of early discipline specialisation and the specific focus on priorities within each sector, as well as the departmental structures and boundaries common in most universities (and beyond). Tightly coupled feedback loops between resources create circular knock-on effects that happen almost simultaneously, which is difficult to capture within the standard teaching context and its linear narratives. In the research community the use of computer models is seen as an effective way to include all of the connections in decision-support tools.

An inter-disciplinary team led from the Department of Engineering but with participants from several other Departments including Geography, Business, Plant sciences and Mathematics, is currently developing such a decision-support computer WEL nexus model called Foreseer™ (Allwood *et al.,* 2012). Two foci, on the visualisation of interconnections, and on user interactions, distinguish it from other models. The team's primary driver is an aspiration to provide a tool for improved communication to policy makers, leading to an improved understanding of resource interactions through the transparency of the model. As such, the model is also seen as having the potential to be used as a game-based interactive teaching tool.

Bartosch and Ortiz (2006) contend that game-based learning scenarios are considered an appropriate basis for visualising complex and abstract contents, and point to interactive (online) media and games when presenting the sustainable use of energy. Guerra *et al.* (2011) discuss the use of web- based simulations as pedagogical tools and argue they can stimulate students for example in demonstrating the close relationship between the environment and engineering. In reviewing modelling and educational simulation as a basis for sustainable development, Cruz (2011) concludes that experiencing the science of complexity in modelling and simulation processes reflects for students the complexity of reality and such tools can optimize trans-disciplinarity, which is the basis for sustainable development.

Dielman and Huisingh (2006) discuss the use of games and simulation models to convey key concepts of sustainable development in relation to Kolb's theory of experiential learning (1984). They argue that using tools (such as Foreseer), students are able to influence the system, but usually are not able to steer the system in exactly the direction they would like. This means they must try to understand how the system functions and to find ways to make the necessary changes. These kinds of system simulations can help the user to understand the functioning of leverage points. The use of such models also clearly integrates the important time dimension into the analysis, crucial for an understanding of sustainable development, but often overlooked in teaching strategies. They also provide opportunities for active experimentation that highlights the interdependencies of complex systems.

There is a lack of user interactive tools existing on the topic of the WEL nexus. Other WEL models, such as the CLEWs model (described in Hermann *et al*., 2012 and Howells *et al*., 2013), do not include any user interactive components and are run only by researchers themselves. By contrast, public understanding and participation tools have been developed on the topic of climate change and energy. The so-called 'Stabilization Wedges' concept, developed at Princeton University (Pacala & Socolow, 2004), is a well-known example that seeks to educate about the options necessary to achieve emissions reduction is the USA. Although this concept has been criticised for over-simplification and for failure to include interactions amongst the reduction options, it was very successful as a teaching tool about climate change in the USA, becoming regularly used in upper-level high school curricula (Climate Mitigation Institute, 2013). Another example of a public engagement tool with teaching potential is the Department of Energy and Climate Change (DECC) Carbon Calculator (DECC, 2012). Foreseer is operating conceptually between these three tools: it combines the complexity of a nexus model with the problem-solving approach of the Stabilization Wedges and the dynamic visualisations and user interactions characteristic of the DECC Carbon Calculator.

A decision was made to test the Foreseer research model as a way of explaining nexus ideas to students. It was used within a Land and Water module taken by first-year Geography undergraduates and by the graduate students taking the MPhil in Engineering for Sustainable Development. A particular additional objective was to obtain feedback from the students using the Foreseer tool, to enable us to assess possible ways to improve it.

In this paper we briefly describe the Foreseer tool, and explain both how we have used it in classes, and how we conducted a user study. We show the results of the exercise and discuss how it brought teaching and research activities closer, benefiting both dimensions.

## 2 Background to the Foreseer model

The Foreseer project started as an analysis of global energy systems (Cullen & Allwood, 2010), and expanded to include water (Curmi *et al.,* 2013a), land, and greenhouse gas emissions (Bajželj *et al.,* 2013). Its website implementation (Allwood *et al.,* 2012) however focuses on the connections between water, energy and land systems. For example, agricultural activity is an integral part of the land system, and is also linked to corresponding demands in the water and energy systems; for irrigation water, and for the energy needed in mechanisation and fertiliser production. These connections are treated in the whole resource context – for example, Foreseer is not only concerned with the water footprint of a particular technology, but the complete picture of the water system. This includes the source of water, the stages it goes through before reaching its use, and the alternative uses and trade-offs.

A second important property of the model is that it creates dynamic scenarios for future resource flows, and at the moment, this is fully implemented in a case study based on the state of California until 2050. Economic relationships and consequences are not yet included – all system interactions are based on physical relationships.

The visual representation offered by the Foreseer model is a third major focus. The tool uses coupled dynamic Sankey diagrams in an effort to represent the scale of resource flows, and the relationships between them, intuitively. The model is interactive – users can set and run their own scenarios by changing input parameters, and hence explore the impacts of policy decisions and policy alternatives. User friendliness is therefore very important.

The latest version of the model can be viewed by registering at www.foreseer.group.cam.ac.uk.

## 3 Methodology

In order to be used in teaching, the Foreseer user interface was set at a level of complexity that was deemed appropriate for student interaction over a limited time period. Four scenarios were designed to be run by students in their own time and at their own pace. The scenarios were designed to explore the problem of unsustainable groundwater use in California, the factors contributing to this, and the opportunities for mitigation. This theme emerged as critical through our implementation of Foreseer to California (Curmi *et al*., 2013b). The four scenarios explored the impacts of: (1) population increase and therefore intensification of agricultural production, (2) food trade, (3) the production of biofuels, and (4) mitigation options through different water policies. Along with the main task of observing water sources and uses associated with these scenarios, students were also asked to observe land use changes, energy use for water services, water used in energy production, and embedded resources in imported and exported goods.

The Foreseer tool was used as an addition in two curricula – to supplement a Land and Water module taken by first-year Geography undergraduates, and to supplement a Master's course in Engineering for Sustainable Development. The exercise served a slightly different purpose with the two sets of students. For the Geography undergraduates it was a self-learning exercise to help them understand their core material. Masters students were given the exercise towards the end of their taught programme, when they finalise the decision on the topic of their research thesis. For them it served as an example of the research in the WEL nexus, and as an inspiration for forming their own research questions.

Due to the different purposes and different levels of the two groups, the undergraduates were given a short introduction to the model, along with a discussion on links between water and land issues, whereas the Masters students used this exercise more independently, without being given a demonstration of the model and only a short written briefing. The setup instructions for each scenario were described on a one-page handout that was given to students (see an excerpt from the instructions as Figure 1). Students were required to register in order to be able to use the online version of the Foreseer tool. All groups were asked to conduct the exercise individually in their own time, on a voluntary basis. Their success with using the tool and understanding of underlying principles was measured with an on-line questionnaire set up using SurveyMonkey; the questions are listed in Table 1. The core of the online questionnaire asked participants to extract specific values and results from the models, and to explain the background dynamics and linkages. At the end, students were encouraged to give their own assessment of the tool by identifying any sensitivities, commenting on its usefulness and suggesting further development ideas. At the same time they were asked about their user experience related to technical questions, providing a user test of the model.

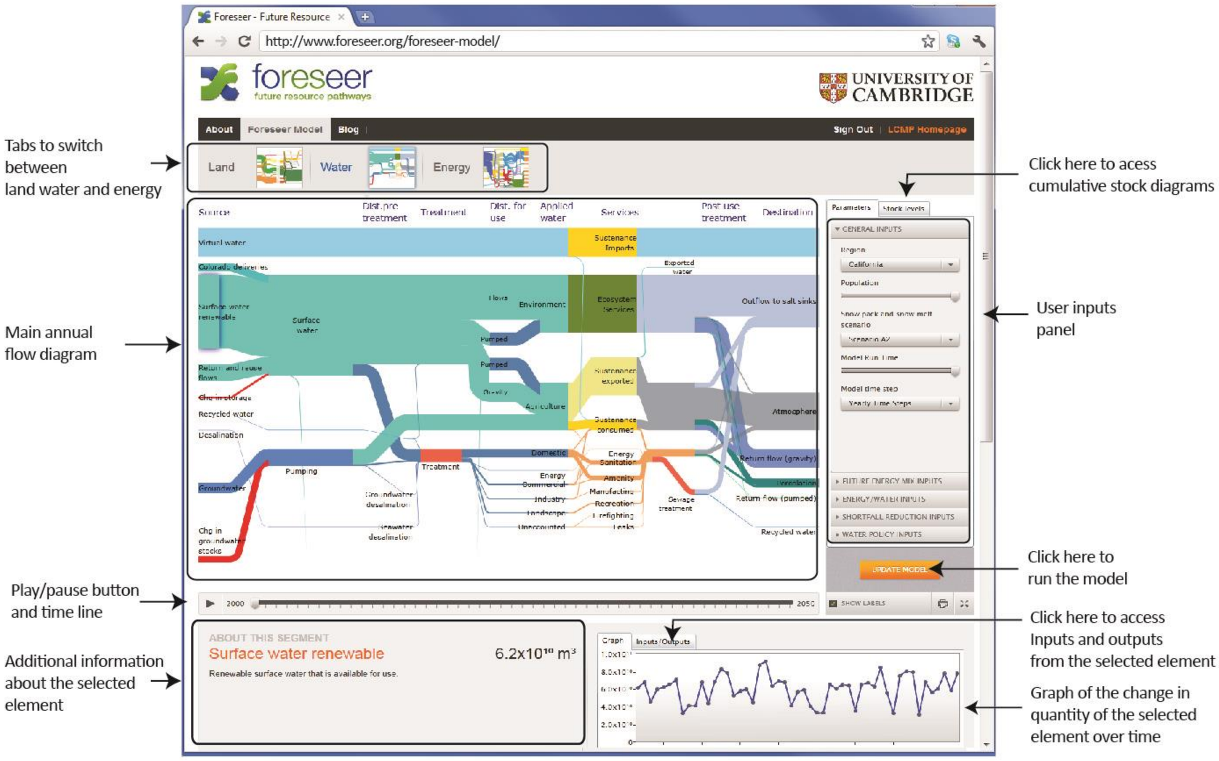


Figure 1: An excerpt from the hand-out given to students, explaining the different part of the online Foreseer model.

Table 1. Complete questionnaire from the exercise.

## Scenario 1

In scenario 1, assume the population in California in 2050 reaches 50 million people (from today's 35 million, as estimated from population growth statistics), and assume that the increase in food demand of this increased population is entirely met by attempting to grow more food in California (Food demand increase met by imports in the "Shortfall reduction inputs" is set to 0). This is the Baseline Scenario.

**Water.**

1. What is the cumulative use of groundwater stocks by 2050?
2. What is the use of external virtual water (avoided water)?
3. How much water is used in energy production?

**Land.**

4. What is the implied shortage of land by 2050 as a result of the increase in food?
5. What are the food imports calculated in carbon amounts?

**Energy.**

6. What is the total amount of energy used for treating and distributing water under this scenario ?

## Scenario 2

This is the same as scenario 1, but this time, the extra food needed for the increased population is assumed to come from food imports. This scenario is more realistic, as environmental legislation is quite strict in California, and forest and shrub land is not likely to be changed into cropland or pasture. This scenario also implies that California may need to shift from export-based agriculture to agriculture that provides more of its own food requirements.

**Water.**

7. What is the cumulative use of groundwater stocks by 2050 in this scenario?
8. What is the annual virtual water demand in 2050?
9. How does it compare to that in the Baseline Scenario?
10. How much water is used in energy production?

**Land.**

11. What is the implied land shortage for this scenario?
12. Has it increased or decreased relative to the Baseline Scenario?
13. Why do you think it has changed?
14. What are the food imports calculated in carbon amounts?

**Energy.**

15. What is the energy required for water services in this scenario?

## Scenario 3

In this scenario, we assume that 10% of liquid fuel demand in California is met through biofuel production within California itself, and that 50% of this is grown on cropland (Miscanthus, second generation biofuels- irrigation needed) and 50% is grown on marginal land (Agave, also a second generation biofuels- no irrigation needed). The extra increase in food needed by the higher population in 2050 is once again met through imports as in 2.

**Water.**

16. What is the cumulative use of groundwater stocks by 2050 under this scenario?
17. How does this compare with the previous two scenarios?
18. Explain briefly the reasons for the difference
19. How much virtual water is needed for food imports?
20. How much water is used in energy production?

**Land.**

21. What is the implied land shortage in this scenario?
22. Why does this shortage arise?
23. What is the final service for fuel production, measured in carbon?
24. What the food import amounts, measured as carbon?

**Energy.**

25. What is the energy production from crop biomass?
26. How does it compare with the demand for oil?
27. Do biofuels represent an important part of the energy mix?
28. What are the effects of growing biofuels on water and land use?
29. How much energy is involved in providing water services in this scenario?

## Scenario 4

This scenario is the same as scenario 3, but introduces water policy mechanisms. There are currently four water policy scenarios available: increasing the % of urban water recycled; increasing the % of recycled water used to recharge aquifers; increasing the % of desalinised water; and increasing the amount of water storage capacity.

30. What is the effect of increasing urban water recycling from the current 8% to 50% on the cumulative use of groundwater stocks?
31. What is the effect of increasing the use of desalinated water by 400 times on cumulative use of groundwater stocks? (Leave recycling water at 50%)
32. What is the effect of implementing all of the policies, as far as permitted, on the cumulative use of groundwater stocks by 2050 (compared to scenario 3)?

## General questions

34. Why do you think it is important to examine water, land and energy resources together? Which connections between the resources seem particularly important for California?
35. Why is it important to look at not only the annual net change to groundwater stocks but also to the cumulative use of groundwater stocks over time?
36. Do you find the animated Sankey diagrams understandable, and effective in conveying messages about changes in resource flows?
37. Did you find Foreseer easy to use? Note any stages where you got stuck and were not sure how to continue. Can you think of any improvements to the tool and the web interface?
38. Can you think of any weaknesses and uncertainties in the analysis given by the Foreseer tool?
39. Can you think of any other scenarios that would be interesting to explore using the Foreseer tool? If so, what other user inputs would be needed to investigate these scenarios?
40. What are two things you've learned by using Foreseer? How far has this exercise helped you to understand the consequences of resource use?

# 4 Results

Student performance (success rate) was assessed by analysing the questionnaire responses in relation to our own knowledge of the expected answers when specific requirements were set in the scenarios. While this is interesting for several reasons discussed here, the real results of this exercise were the learning outcomes for both the students and the researchers. These can only partially be measured by the success rate. Our assessment of learning outcomes is therefore rather preliminary, based on anecdotal evidence from both groups.

## *4.1 Exercise results*

90 first year Geography Undergraduates and 47 Engineering Masters students were invited to use the tool, and complete the exercise and the online questionnaire. Since the participation was voluntary, not all of them became involved, as anticipated. 52 and 23 students respectively from these groups filled in the questionnaire. Students reported spending between 45 minutes to two hours on the exercise in total. The response rate in the first group might have been higher, but this initial exercise revealed a technical problem with the on-line tool which prevented some potential participants from completing the exercise if using Apple computers. Of course, discovery of this problem was itself a very beneficial outcome from the first exercise, and led to software modification that resolved the issue for the second survey.

While the students were not being assessed on the correctness of their answers to the quantitative questions, it is nonetheless interesting to compare how well each group did. For the developers of the model and the study, it was interesting to observe which questions posed problems to the students. Table 1 compares the success rates for each of the questions for both groups, showing that both groups were very successful with ~80% correct answers; and also that all student who started the exercise, also completed it. Given the voluntary participation, this indicates students were motivated by the interactive aspects of the exercise, for example by being able to design their scenarios and test different variations. In the later questions they also reported enjoying the visual aspects, the use of colours and dynamic visualisations.

Generally the differences between the two groups in terms of correct responses were statistically insignificant. For example, by defining the proportion of all correct answers for all students in each group, then comparing the distributions of these proportions between the two groups, a t-test statistic of $t=0.80$ was obtained. Compared to the critical value of $t=1.994$ at the 95% confidence interval for these sample sizes, this is not significant. However, an alternative analysis is to examine each question in turn and compare the proportions of correct responses in the two groups. In a test of the significance of the difference between two independent proportions, with these sample sizes a difference of greater than 20% tends to be statistically significant at $p=0.05$ in a two-tailed test. In Table 1, these cases are shown in bold type; the first year Geography students did slightly better than the Engineering MPhil students, with more significantly better performances, but the aggregate analysis suppressed this information. This can be perhaps explained by undergraduates receiving a short demonstration, while the Masters students did not. However, when analysing the open-ended answers, those provided by MPhil students were more elaborate and also provided a more critical analysis. The questions resulting in greater discrepancies between the two groups were the more complex, comparative ones later in the exercise.

Table 2. Proportions of correct quantitative answers obtained from the Foreseer model by the two groups of students (First year Geography and MPhil Engineering for Sustainable Development). Bold entries indicate proportions that differ significantly at p = 0.05.

| Q no. | 1A Geography | MPhil Engineering | Q no. | 1A Geography | MPhil Engineering |
|---|---|---|---|---|---|
| 1 | 79% | 78% | 17 | 88% | 87% |
| 2 | 92% | 96% | **18** | **92%** | **74%** |
| 3 | 71% | 52% | 19 | 83% | 83% |
| 4 | 81% | 91% | **20** | **50%** | **26%** |
| 5 | 81% | 78% | 21 | 85% | 87% |
| 6 | 90% | 87% | 22 | 90% | 83% |
| 7 | 87% | 87% | **23** | **85%** | **61%** |
| 8 | 94% | 87% | 24 | 79% | 83% |
| 9 | 85% | 74% | 25 | 94% | 83% |
| 10 | 79% | 70% | 26 | 71% | 57% |
| 11 | 90% | 87% | 27 | 90% | 87% |
| 12 | 81% | 83% | 28 | 92% | 91% |
| 13 | 83% | 83% | **29** | **94%** | **74%** |
| **14** | **73%** | **91%** | 30 | 85% | 87% |
| 15 | 90% | 83% | 31 | 83% | 87% |
| 16 | 81% | 83% | 32 | 83% | 78% |
| | | | TOTAL | **84%** | **79%** |

## *4.2 Learning outcomes for students*

Through the scenario building and the targeted questions, the following concepts were covered in the exercise:

- The causes of groundwater depletion in California
- The state of groundwater stocks in the next 40 years in a business-as-usual scenario
- Increasing pressures on land and water resulting from dietary changes and rising population.
- Virtual water and its relationship to food trade
- Food trade implications for land resources
- Food trade implications for energy use (for example, domestic energy use for water pumping decreases with increased food imports)
- Increased pressures on land and water resulting from biofuel production
- Effectiveness of different policies to reduce groundwater depletion

Students learned about these concepts through an interactive use of the tool. It is difficult to assess what students have learned compared to their previous knowledge, but some insight can be gained based on their comments in the online questionnaire:

> "[I've learned that] changes in land use change the way water and energy are used. California is a fertile region and so land use is particularly important regarding the production of biofuels and agriculture, changes in land use have a significant impact on groundwater."

> “I was surprised how strong these links, dependencies and interactions between the three resources are, and adjustments made to one of them will have implications and ramification on the others.”
>
> “I learned a lot about water usage and the water cycle. I have had very little exposure to this in the past so did not know about how it was used and where; this was particularly useful.”

Only one student (from the Masters group) stated that he/she had not gained any new insights beyond what was already known. However, this was clearly an unusual response, and reflects the fact that the Masters students are a relatively heterogeneous and international group (compared to the predominantly UK undergraduates), and may have included one individual who by chance had had significant prior exposure to water resource issues in California (no attempt was made to relate individual student's responses to their personal characteristics).

The last question in the survey asked respondents about their two main take-home messages from the exercise. These answers are also helpful in trying to determine what the students learned. The request to identify two take-home messages was completely open-ended, with no suggestions given to the students. Nonetheless some messages appeared many times, as shown in Figure 1. The open-ended nature of the question made these answers especially interesting in revealing how the main messages for a "casual" user of the tool may differ from those messages that researchers thought the model would communicate, based on our own knowledge and interpretation. While “the interconnectivity of resources” was an expected main message (indeed it was mentioned most frequently), the authors were more surprised by the number of respondents who were particularly struck by the resource intensiveness of biofuel production and by the significance of imports in California[1].

The participation rate in the later, open-ended questions, as well as students’ eagerness to suggest new scenario inputs, improvements and comments, suggest that students were interested and engaged throughout the exercise. Their supplementary written comments were perceived as thoughtful by the researchers and showed good understanding.

[1] A third exercise was conducted in November 2013 with the 2013-14 cohort of first-year Geography undergraduates, and broadly similar results were obtained. Although the Foreseer tool had been developed further, this cohort was provided with access to the same version as the one used by the 2012-2013 cohort. A further 50 students, again being about half of the complete year group, finished the exercise. The 2013-2014 cohort generally performed marginally better than the others in terms of correct quantitative answers, and the take-home messages identified were broadly similar, but with a greater relative emphasis on the Foreseer tool having revealed the strength of interdependence of resource usage. Other messages the students reported having learned from the exercise were rather less frequently identified, with the second most common being about the role of supply-side policies; somewhat surprisingly, over-use of groundwater figured less prominently as a lesson than it had with the two groups who undertook the exercise in the previous academic year.

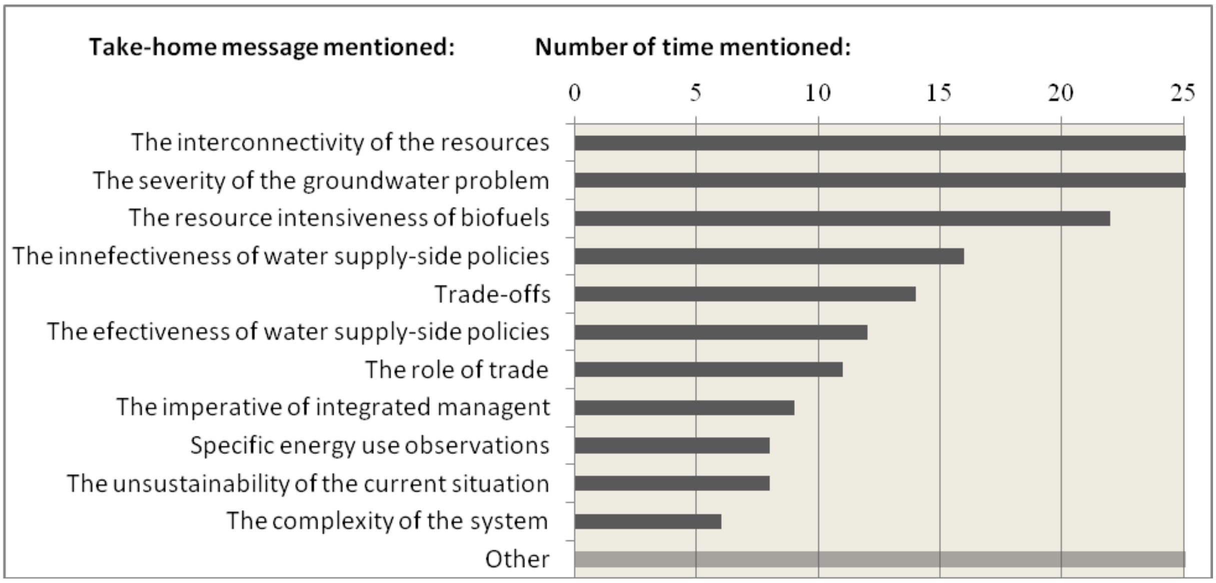


Figure 2: Frequency with which particular take-home messages were mentioned

## *4.3 Learning outcomes for researchers*

The Foreseer research team learned a lot from the feedback received. As noted above, some technical problems with certain browsers and operating systems were revealed and rectified. By investigating the outliers in terms of answers with low success rates, the researchers identified more detailed issues with user interface. For example the low success rate with question no. 20 was related to an awkward positioning of the relevant label in the online visualisation. Similarly the relatively weaker answers to questions about water use in energy were rooted in the flows being so small that the lines in the diagram were very thin and difficult to select with a mouse. Some possible misunderstandings were discovered, for example that it is possible to misinterpret the time axis for the y-axis of the diagram. Many students expressed a wish for more interactive on-screen instructions, and more background information, encouraging us to develop these aspects further.

As is apparent in the questionnaire in Table 1, most questions asked for a value to be extracted from the model, but others also involved some level of subjective interpretation. For example both yes and no were possible answers to the question no. 27 (Do biofuels represent an important part of the energy mix?), as the answer depends on the subjective interpretation of the word “important”. Similarly, a number of students mentioned that they were struck by how little difference alternative water supply policies made, and at same time some other students specifically mentioned the opposite view, that the policies were effective (Figure 2). These contradictory responses partly reflect the way in which different stances and interpretations may result in contrasting opinions, and also underscore the importance of avoiding ambiguity in the questions.

A further question required students to name any reservations and sensitivities they perceived about the model. Many of them correctly noted that any predictive model such as Foreseer is inherently surrounded by uncertainty. Several students observed that such a tool can never include all possible drivers of future change, for example game-changing technologies and possible societal changes. It is encouraging to see that the model is not perceived as giving a false appearance of certainty, although the communication of uncertainty could be further improved. It is also encouraging to see that students approach information with caution and a critical mind. Several students mentioned that they would like to know more about the underlying data, and justifiably identified that the data references were not satisfactory (the referencing system of Foreseer was a work in progress at that stage). This showed their keen awareness of the importance of the reliability of information sources.

While the model was not initially designed to be used in teaching, it is clearly at some level a learning tool, and can therefore be translated to a pedagogic purpose with minimal adjustments. The model is complex, but step-by-step instructions and the building of successively more complex scenarios from simple ones ensured that most students felt confident about using it, after some initial reservations. Many of their comments were along the lines of:

> "[The model was] initially confusing, but improved as I got used to it"

This suggests that while the level of model complexity presented to students was ultimately satisfactory, more could be done to prevent an initial unfavourable reaction that may lead some users to drop out from using it an early stage.

Most students responded enthusiastically, being positive about the visual and dynamic aspects of the tool, stating that they prefer this medium to 'plain text'. Many seemed to have particularly liked the use of animations and bright colours, and there were no problems with the user parameter-input interface. Such positive responses, in conjunction with constructive suggestions and problem identification, have been an encouragement to us as researchers to improve and develop the Foreseer tool.

## 5 Conclusions: bridging the gap between research and teaching

This exercise presented a valuable opportunity for an exchange of knowledge and experience between researchers and students. It may not always be possible to integrate research and teaching activities in a university, particularly in an interactive and participatory manner. One barrier to such exchanges may often be that the research deemed appropriate for scientific purposes is highly specialised and narrow. The Foreseer model, by contrast, is highly interdisciplinary and therefore complex in a different sense; however, it was considered suitable for introduction to students who appear to have been well able to cope with its form of complexity. In our case study, researchers were motivated to contribute to the curriculum so as to gain a 'user study'; and because the visual and cognitive aspects of the model are very important, the opinion of the students was very helpful. In the end, therefore, this exercise proved to be a very helpful way to connect the two main dimensions of higher education, research and teaching; and to the benefit of both.

Sustainable development presents an effective opportunity, as a field in which everyone has a stake, but which is still in early development, to involve students in academic research as valuable collaborators. This fits well with the new paradigms of learning, which sees learners as active constructors of knowledge (Grabinger and Dunlap, 1995). We would like to further, and more formally, evolve the hypothesis on benefits of bringing students and researches closer in the future developments of the Foreseer model.

Based on the comments made by the students and their general success in finding the right answers, the authors conclude that the majority of students gained a better understanding of the interconnectivity of resources and the importance of considering them jointly as a result from this exercise. This exercise was viewed as a valuable supplement to the core learning material by the educators, and was repeated in the subsequent year of the Geography undergraduate course. The use of simulation tools to explore system complexities can provide powerful learning environments for students to explore the impacts of decisions on resource management and allow levels of speculative experimentations, by allowing them to ask “what if” questions and explore the consequences of the outcomes of these decisions. Educationally such an approach can be tailored to the needs of a wide range disciplines, such as the Geography and Engineering cohorts described here, with both groups able to converge on a common understanding of the issues raised.

## References


Allwood, J.M., Bajzelj B., Curmi E., Dennis J., Fenner R.A., Gilligan C.A., Kopec G., Linden P., McMahon R., Pyle J., Ralph D. and Richards K.S. (2012). “Foreseer [computer software]”, available from: www.foreseer.group.cam.ac.uk (accessed 12 December 2013).

Bajželj, B., Allwood, J. M. and Cullen, J. M. (2013). “Designing climate change mitigation plans that add up.”, *Environmental science & technology*, Vol. 47 No. 14,pp. 8062–9.

Bartosch, I. and Ortiz, M. (2013) “BLUKONE - A Blended Learning Teaching Concept for Sustainable Energy Management Competences” presented at the 2nd edition of the New Perspective in Science Education Conference, 14 - 15 March 2013, Florence, Italy. available at: http://conference.pixel-online.net/npse2013/conferenceproceedings.php

Beddington, J. (2009), “Food, Energy, Water and the Climate: A Perfect Storm of Global Events?”, available at: http://www.bis.gov.uk/assets/goscience/docs/p/perfect-storm-paper.pdf (accessed 12 December 2013).

Climate Mitigation Institute (2013), “Stabilization Wedges Game Website”, available at: http://cmi.princeton.edu/wedges/game.php (accessed 15 April 2013)

Cruz, L. (2011) “Modeling and educational simulation as a basis for sustainable development” presented at the 4th International Biennial Symposium Complexity 2011 – for a sustainable development; Education, Complexity, Interdisciplinarity, Transdisciplinarity, June 2011, University of Camaguey, Cuba.

Cullen, J. M. and Allwood, J. M. (2010) “The efficient use of energy: Tracing the global flow of energy from fuel to service.”, *Energy Policy*, Vol. 38 No.1,pp. 75–81.

Curmi, E., Richards, K., Fenner, R.A., Allwood, J. M., Kopec, G. M., & Bajželj, B. (2013a). “An integrated representation of the services provided by global water resources“, *Journal of environmental ,* Vol. 129, pp. 456–62.

Curmi, E., Fenner, R.A., Richards, K., Allwood, J. M., Bajželj, B. and Kopec, G. M. (2013b) “Visualising a Stochastic Model of Californian Water Resources Using Sankey Diagrams”, *Water Resources Management* Vol. 27, pp. 3035–3050.

Department of Energy and Climate Change (2013) “Carbon Calculator website”, available at: http://2050-calculator-tool.decc.gov.uk/ (accessed 15 April 2013)

Dieleman, H. and Huisingh, D. (2006) "Games by which to learn and teach about sustainable development: exploring the relevance of games and experiential learning for sustainability", *Journal of Cleaner Production* Vol(14), pp. 837-47.

Grabinger, R. S. and Dunlap, J. C. (1995) "Rich environments for active learning: a definition", *Research in learning Technology*, Vol. 3 No. 2.

Guerra E., Bolea Y. and Grau A (2011) "Simulation and Modelling of Systems in Engineering Education for the Sustainability" Presented at: The Renewable Energy Case International Conference on Renewable Energies and Power Quality (ICREPQ'11), 13- 15 April 2011, Las Palmas de Gran Canaria, Spain.

Hermann, S., Welsch, M., Segerstrom, R. E., Howells, M. I., Young, C., Alfstad, T., Rogner, H., et al. (2012). Climate, land, energy and water (CLEWs) interlinkages in Burkina Faso : An analysis of agricultural intensification and bioenergy production. *Natural Resources Forum*, 36, 245–262.

Howells, M., Hermann, S., Welsch, M., Bazilian, M., Segerström, R., Alfstad, T., … Ramma, I. (2013). Integrated analysis of climate change, land-use, energy and water strategies. *Nature Climate Change*, 3(7), 621–626. doi:10.1038/nclimate1789

Kolb D. (1984) *Experiential learning, experiences as the source of learning and development*. Englewood Cliffs, New Jersey: Prentice Hall.

Pacala, S., & Socolow, R. (2004). Stabilization wedges: solving the climate problem for the next 50 years with current technologies. *Science*, 305 (5686), 968–72.

World Economic Forum (2011). Global risks 2011 report. http://reports.weforum.org/global-risks-2011/

## Biographical Details:

Bojana Bajželj currently conducting a doctorate at the University of Cambridge as a part of a team developing a water, energy and land nexus model called Foreseer. Her contributions are in the area of land-use, agricultural production and greenhouse gas emissions and she is also interested in the education aspect of the Foreseer model. Before joining University of Cambridge, Bojana worked as environmental consultant. She holds an MSc in Environmental Technology form Imperial College London and a degree in Landscape Architecture from University of Ljubljana.

Dr Richard A. Fenner is a Senior Lecturer in Cambridge University's Engineering Department and is the Course Director for the taught MPhil in Engineering for Sustainable Development. He is a Chartered Civil Engineer and a Fellow of the Chartered Institution of Water and Environmental Management. His research interests are in the general area of maintenance and rehabilitation of water industry buried infrastructure assets, and also in water and wastewater treatment processes. Dr Fenner is co-investigator on the Foreseer project.

Dr Elizabeth Curmi is a Senior Research Associate at the Engineering Department at the University of Cambridge. She is currently working on the water aspects of the Foreseer tool. Before joining the University of Cambridge, Elizabeth received a PhD from the University of York in 2011 in Environmental Management and Economics where she developed a combined hydrological and economic model to test the effectiveness of different water policies in Mediterranean countries. Previous to starting her academic career, she worked as an environmental consultant.

Prof Keith S Richards is a Professor of Geography and Fellow of Emmanuel College in Cambridge. Professor Richards is a fluvial geomorphologist and hydrologist with wide ranging research interests from glacial hydrology to arid zone hydrology, and inter-relationships between hydrological and ecological processes in floodplain environments. He is teaching in the Geographical Tripos (Undergraduate level). Professor Richards is co-investigator on the Foreseer project.