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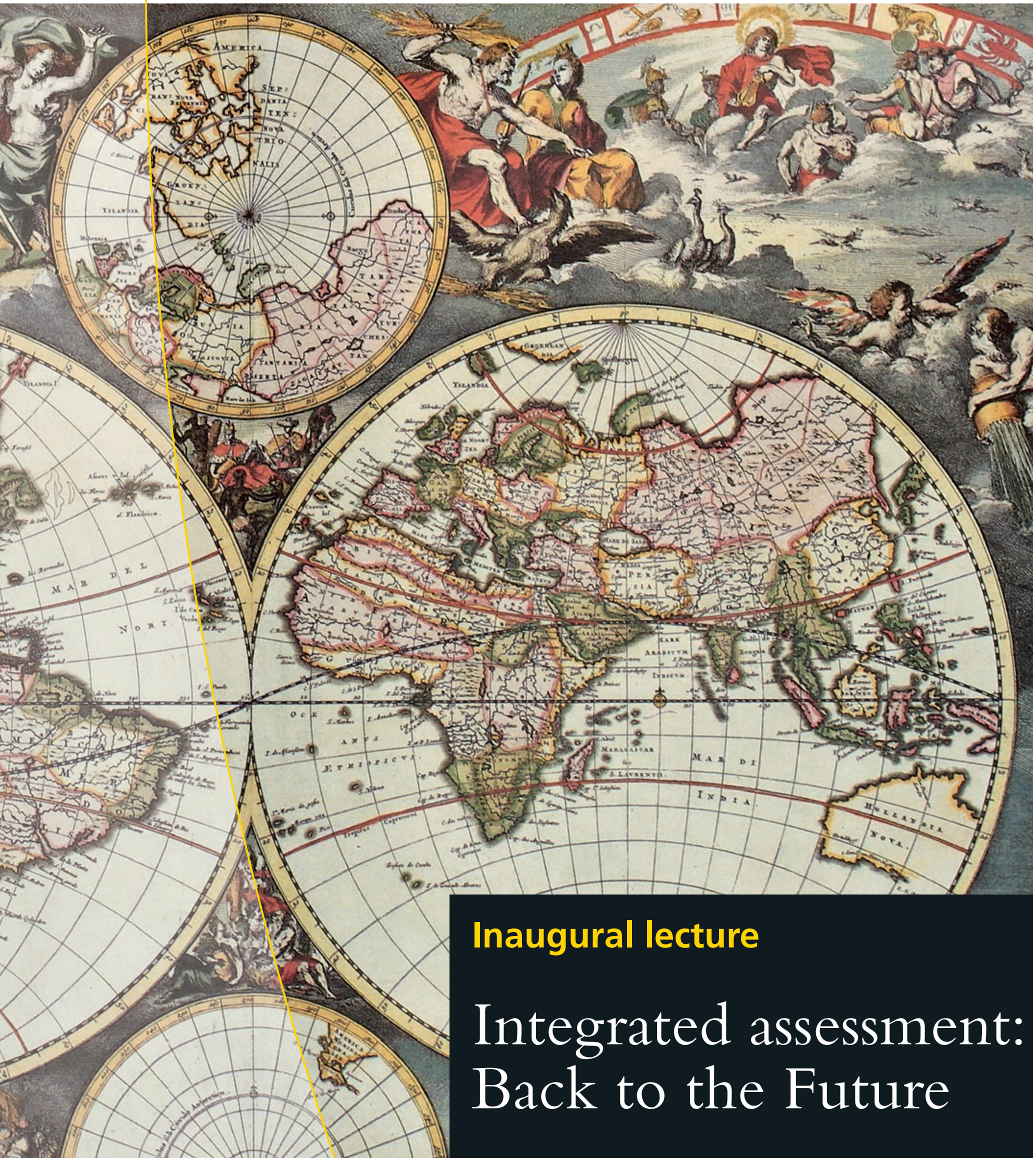

Inaugural lecture

# Integrated assessment: Back to the Future

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# Integrated assessment: Back to the Future

Inaugural lecture, delivered upon acceptance of the Chair in Integrated assessment of global environmental change, at Utrecht University's Faculty of Geosciences of Utrecht University, on 11 May 2015 by Detlef van Vuuren.

## COLOPHON

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## 1 Introduction

Rector Magnificus and everyone present. I would like to thank you for the opportunity to speak here today. Perhaps, when you came in, some of you will have recognised the rather grand organ music from the film 'Back to the Future' – a film that will be mentioned a number of times today as an analogue for our work[1]. In any event, the subject of my inaugural address certainly deserves an introductory fanfare. Because what I would like to talk about today is something that would seem quite impossible; namely, whether we as scientists can 'predict' the future and by doing so help solve sustainability problems, such as climate change and hunger. In my address, I will discuss the great societal need for such 'forecasts' while realising that science's ability to cater for this need is obviously limited. There are, however, certain other tools we can use, as I will explain.

To make such a big question more digestible, I have divided up my talk into four sections. First, I would like to consider the present state of play with regard to global sustainability issues. Next, I will turn to the precise meaning of the words in the title of today's address: 'integrated assessment'. Then I will talk about the essence of the research that I want to focus on, that being the use of integrated assessment models to explore visions for the future. Finally, I will consider some logical research steps involved.

## 2 Back to the Future

But first, just as in the 'Back to the Future' film, I would like to make a big leap back in time. We are here in the University Hall of Utrecht University, in the room where, in 1579, the Union of Utrecht was signed. A Treaty between the Dutch provinces in which they made far-reaching agreements with one another on military cooperation and religious freedom, providing the basis for the Republic of the Seven United Netherlands that was founded only a few years later. This practice is still the same today; nations enter into extensive treaties with one another – many including ambitious promises. I will mention a few of them in the field of sustainable development. Nations, worldwide, promised in the Rio treaty of 1992, for example, to end poverty (UNCED, 1992) and, in the same year, in the United Nations Framework Convention on Climate Change (UNFCCC, 1992) to prevent climate change from reaching possibly dangerous levels; in the Convention on Biodiversity, nations then promised to prevent a further degradation of nature (CBD, 1992);

1 Back to the Future is a 1985 US comic science fiction film. Sequels were released in 1989 and 1990. The films are centred around two characters that can travel through time.

in the UN Millennium Summit, several long-term targets were set – the Millennium Development Goals – for human development (UN, 2000), in addition to a whole host of other, goals related to health, air pollution, soil depletion and access to energy. The list of the promises is long. The real question is, of course, how much progress have we made on these issues since the 1990s, when most of them were formulated?

We can see this in Figure 1. But before we look at that more closely, I would first like to discuss the x-axis (i.e. time), presenting the period from 1970 to 2050. People generally prefer to occupy themselves with things that may happen in the next few days or at most in the next year, and so 2050 seems a long way away. But the future might be closer than we think. In 2050, most of us here today will still be alive. And indeed, some of the people who will be there in 2100 have already been born. More important, perhaps, is that – all being well – the investments we make today in the energy supply or infrastructure will still be fully operational by 2050. And the environmental effects even more so; the effect of the $CO_2$ emissions from power stations today will remain with us for many centuries to come.

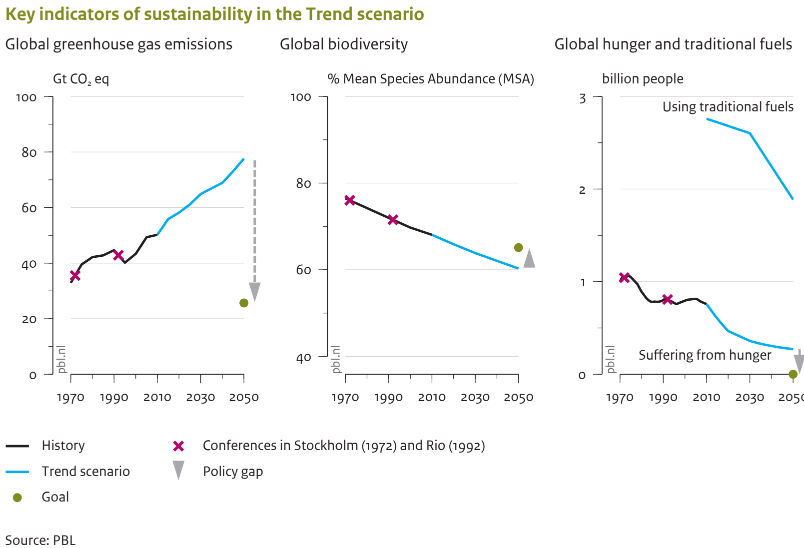



*Figure 1: Historical progress with respect to sustainable development targets and expected future trends, based on a continuation of current policies (PBL, 2012; van Vuuren et al., 2015)*

The same also applies to the effects that some land-use decisions have on biodiversity. This means that it is important for long-term effects to be taken into account in the decisions we take today.

Now let's first concentrate on the historical achievements in Figure 1 (the black lines). The figure shows – as examples – the recent trends in hunger, biodiversity and climate change. In terms of hunger, there has been a slight improvement in the roughly one billion people who did not have enough to eat in 1990 compared with the approximately 800 million now. The loss of nature worldwide, however, has continued unabated, according to various assessments (MA, 2004; PBL, 2012; van Vuuren et al., 2006), while the increase in greenhouse gas emissions over the last 10 years has accelerated at an unprecedented rate (IPCC, 2014b).

In the next part of my address, I will talk about how we can use models to make projections, but now – to use the terminology of the film world – I would like to give you a *sneak preview*. Figure 1 also shows the possible trends for each topic assuming no change in policy. In this situation, we can expect a further decline in the quality of the global environment, as shown for biodiversity and greenhouse gas emissions. For hunger – given the expected economic growth – it would appear that we are moving in the right direction, but at the same time, absolute poverty is not expected to be eradicated by 2050. In other words, in many cases, the goals formulated in the international agreements will not be achieved either fully or on time.

Clearly, the interest in sustainable development matters has been waning, in recent years (CBS et al., 2014). However, based on the previously made agreements, as well as the importance of good stewardship of this planet (our welfare depends on it – and we have only the one, after all) and given the lack of success of the present policy – I would argue that greater priority should be given to the future of the environment and development. In short, we need to get Back to the Future, in terms of policy interests. Below, I will mainly consider the type of information that will be needed in this context.

## 3 Integrated assessment

There are three main and overlapping questions which I consider to be a priority in the context of sustainable development. The first question is how can we provide affordable energy for everyone and ensure a sustainable climate at the same time? The second question is how can we ensure that there is enough food for nine billion people while maintaining the quality of nature? Water plays an important part in this, too. Finally, there is the question of how this can be combined with various other sustainability issues; for example, surrounding nitrogen, as well as important aspirations related to human development in the area of healthcare.

In science, these sorts of questions are termed 'wicked problems' (e.g. Horst and Webber, 1973); problems that are difficult to solve. The difficulty with these types of issues is that there is no simple or straightforward answer, they are surrounded by major uncertainties, associated with differing ideological values and are highly complex. Complex in the sense that, often, inertia plays a key role, which implies that we have to look to the long term. But also the fact that these problems are played out at different levels of scale (locally and globally). And finally, these problems are also complex because there are many feedbacks and relationships with other issues. To take just one example, the agriculture sector is affected by climate change through increasing drought on the one hand, but is itself also the cause of climate change through deforestation on the other.

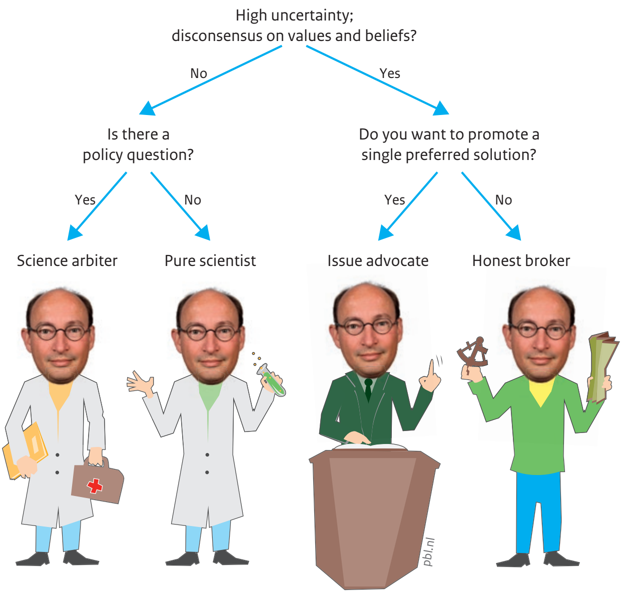
How difficult it is to deal with 'wicked problems' is illustrated in an article recently published in Nature (Geden, 2015) in which the author accuses the Intergovernmental Panel on Climate Change (IPCC) – of which I am one of the authors – of possibly having an integrity problem. The question raised is that of whether climate scientists are too much in alignment with policymakers when they pretend that climate change could still be limited to a global temperature increase of 2°C. Are all sorts of 'dubious concepts', such as negative emissions, now being put forward so we do not have to admit that we have failed? I do not agree with the substance of the arguments made in said article, but it illustrates how difficult it is for scientists to deal with such 'wicked problems' without being drawn into debates on opinions, values and expectations. Further on, I will indicate why I believe Geden's interpretation is not correct.

The problem is essentially that the success of '*normal* science' (Funtowicz and Ravetz, 1993) is primarily based on what is called the 'controlled experiment'. In its most ideal form, these are laboratory experiments in which everything is repeatable and transparent and neatly matches the scientific maxim of a defined problem. This ideal situation however cannot be applied to policy matters surrounding 'wicked problems'. Take the matter of a seemingly simple policy question of whether it would be a good idea to use wind turbines to produce energy without causing climate change. Immediately, various complex issues arise concerning the costs and benefits of wind turbines; as well as those of their possible alternatives. A main concern, for instance, involves the impact on people's appreciation of the naturalness of landscapes, which is directly related to normative values and opinion.

Policy questions are thus often broad, value-related and associated with future impacts (what if…?). For the 'wicked' questions raised a few paragraphs earlier, this is clearly the case; resulting in a mismatch between *normal* science and policy.

A few years ago, Roger Pielke published a book (Pielke, 2007) that may help us somewhat in identifying ways in which knowledge could be used for policy purposes (Figure 2). The first question he raises is precisely the dilemma mentioned above – about the many uncertainties and value-related questions involved. Other researchers addressing the science – policy dialogue in this context have also identified this as critical (Funtowicz and Ravetz, 1993, Hisschemöller et al., 2009). If there is relatively little uncertainty or involvement of values; Pielke's scheme indicates that the next question is whether there really is a clearly

**Different positions in the science–policy dialogue according to Pielke**




Source: Based on Pielke 2007

Figure 2: *Different roles in the science–policy dialogue, according to Pielke (2007). The different figures (representations of Detlef van Vuuren) aim to illustrate some aspects of each role.*

defined policy question to be answered. If so, the interaction between scientists and policymakers can be best described as that between policymakers and expert consultants exchanging clear questions and relatively clearly defined answers. Think, for instance, of the question: 'What would be the best place to build a bridge?' In case the question is not more clearly defined, there would be room for more 'fundamental research', comparable to the Funtowicz and Ravetz use of the concept of *normal* science. The situation with regard to our 'wicked problems' as presented earlier, however, is completely different. Here, there are certainly major uncertainties and value-related questions. Pielke indicates that there is now another fundamental decision to be made: do you, as a scientist, want to play a role by recommending certain possible solutions or would you prefer to contribute by ensuring that others are better equipped to make their decisions? The role in the first case is that of an 'issue advocate' (like that of a scientist working for an environmental NGO). A great role, as long as it is clear what basic principles apply. The second role is that of an 'honest broker'. A scientist who does his or her best to describe all the options as neutrally as possible, raising matters for discussion and thus facilitating public debate. The risk for scientists here is that of supporting, intentionally or otherwise, a specific position in a value-laden dispute without being transparent on key assumptions, referred to by Pielke as a 'stealth issue advocate'. The role of the honest broker is far from easy, as shown, for instance, by the critique on the Fourth Assessment Report of IPCC a few years ago, and the subsequent PBL review (PBL, 2010). Nevertheless, Pielke asserts that the role of 'honest broker' is a role for which there is a particular need, and one that organisations such as PBL and IPCC, for whom I work, aim to fulfil.

If the role of 'honest broker' is such a difficult one, is it possible to provide practitioners in assessment a bit more support? In order for a scientific institute or scientist to be a good honest broker, there are at least three conditions to be met:

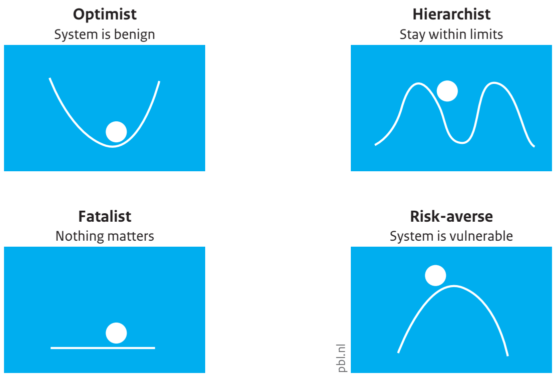
1. be cognisant of the fact that questions are value-related,
2. try to show what the decisions are as well as the pros and cons of each of the options,
3. be policy-relevant – which means that it is not possible to avoid the 'what if' questions.

Fortunately, there are a few tools to help us.

*Value-laden questions*

Providing information on disputed, value-laden questions is far from easy: it requires scientists to somehow map out all possibilities, including those going beyond one's own beliefs and opinions, or the ones that seem most attractive to important stakeholders. One may even question whether this can be done perfectly: instead of aiming for a value-free

Different perspectives on environmental risk




Source: PBL

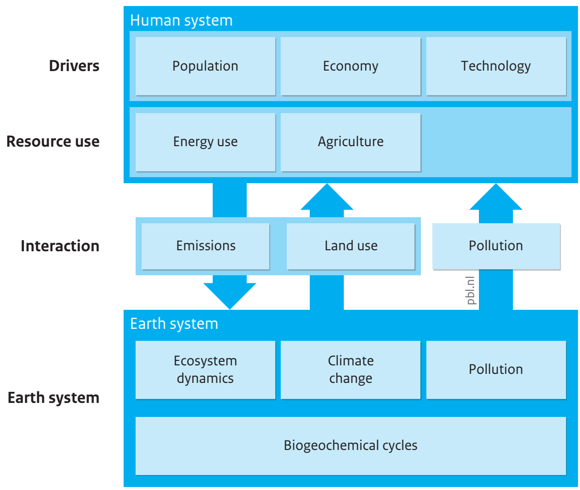
Figure 3: *Different perspectives on environmental risk*

assessment (which would not be possible) the task would be aware of values (and the entanglement of the values with facts). To (pragmatically) deal with at least a range of key uncertainties and values, it helps greatly to work with a conceptual framework to reveal the value-related elements (including awareness of possible own biases). In the past, several people, including Bert de Vries and Klaas van Egmond at PBL, have done a great deal of work on this subject. One of the research avenues was that on the use of the Cultural Theory (Rotmans and de Vries, 1997; Thompson et al., 1990) as part of assessment work in order to show that people can have very different interpretations of the same situation (worldview) and the preferred response (management style). One elements of this is that people perceive environmental risks in quite different ways. For some, referred to here as optimists, the Earth essentially resembles a ping-pong ball in a bowl. You can give the ball a push, but the robustness of the system will ensure that a new balance is soon found. To others, referred to here as risk-avoiding, the Earth system resembles a ping-pong ball on a mountain. Just one push and it all comes crashing down. Other positions include those of the hierarchist and fatalist (see Figure 3). It is important to realise that, given all the uncertainties in the environmental system, different views, within limits, could be true and, therefore, in research, it is useful to develop arguments based on all of them. One of the ways in which this would need to be addressed in our explorations of the future, is in the form of different scenarios that explore the full range of plausible assumptions, responding both to optimistic and risk-averse positions with respect to, for instance, assumptions on technology development and sensitivity of the climate system.

*Provide options and be policy-relevant*

With regard to the other two qualifications of an honest broker: To be able to investigate and weigh up the options and address questions on matters affecting the future, we need to have tools to explore these various future scenarios. I personally know of only two possible tools that could do this for us. One is the car from 'Back to the Future', which can travel through time. But, of course, that is not a very realistic option. The other alternative is to use computer models to create 'scenarios' for the future. Such models make it possible for us to travel through time in a virtual manner and, therefore, explore the various possible consequences of decisions taken today. They can cope with the complexity of the relationships between all kinds of problems and the possible advantages and drawbacks of decisions. And, to a certain extent, they also help to resolve the problem I mentioned earlier of the controlled experiment; because they provide the environment in which to conduct such experiments.

**Generic framework for integrated assessment models**




Source: PBL

Figure 4: *Generic framework for integrated assessment models*

**Integrated Assessment model-based scenario analysis**
So, what do the models that can help us to explore possible future developments look like – and what are their characteristics? The sort of models we need in the context of global environmental and sustainable development problems are *integrated assessment models*. These types of models specifically describe the interaction between the human and the environment system. The word '*integrated*' for these models refers to the fact that they integrate information to be able to incorporate all the relevant aspects (economics, technology, climate knowledge). The word '*assessment*' refers to the exploration or estimation aspect of using these models in answering policy questions. This underlines the fact that these models are not designed to make predict, as our understanding of the underlying complex systems and the associated uncertainties do not allow us to do so.

There are several types of integrated assessment models, ranging from rather small models focused on cost-benefit analysis to more complex models looking more at the underlying processes of interaction. The integrated model which I and my colleagues work with is the IMAGE model[2] Figure 4 shows a generic framework of integrated assessment models. The models, first of all, describe developments in population, economy, and technology over the next century, or make assumptions about these factors. In addition, the models describe how energy consumption and food production could then evolve, given the changes in demand. This then leads to pressure on the Earth system in the form of emissions and land use. For the Earth system, these models describe matters such as ecosystem behaviour, climate change and the changes in the major cycles, such as those of carbon and water. Furthermore, the models can look at the feedback of changes in the Earth system on the human system.

When building such models, we therefore need to find the relationships between the different factors mentioned in the previous paragraph that will affect future developments. For instance, how does food consumption develop over time? From the past, we know that people tend to change their diet and their total consumption level as their income increases. Data will show, for instance, that there is a clear relationship between meat consumption and income levels in various countries. In the model, we try to turn these relationships into mathematical equations, preferably at such a level that we can still

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2 This model was developed at PBL, under the leadership of people such as Jan Rotmans, Joe Alcamo, Rik Leemans, Bert de Vries and Tom Kram. The documentation of the most recent version of the model was published in 2014 Stehfest, E., Van Vuuren, D. P., Kram, T. & Bouwman, A. F. (eds.) 2014. *IMAGE 3.0*: PBL Netherlands Environmental Assessment Agency, and is available on the internet in the form of a wiki: http://themasites.pbl.nl/models/image/index.php/Welcome_to_IMAGE_3.0_Documentation

understand the different relevant processes. It is also important to use the data to estimate the level of uncertainty in these relationships so that this can adequately represented in the models. In other parts of integrated assessment models, we use similar relationships between income and transport levels and income and the use of steel. In the earth system part, the model includes relationships to describe, for instance, the relationship between greenhouse gas emissions and their concentration levels, and level of climate change. In our work, we therefore try to identify the most important relationships describing future global change, define them and turn them into model code.

It is important to remember that future scenarios and change processes are much more complex than we can ever describe with models. De Vries et al argued that, in describing reality, there are three distinct levels to be taken into account (De Vries et al., 1993) (Figure 5). First, the physical world, the one we directly perceive, with our forests, our land use, our cities and factories, the climate change and the availability or lack of food. But this physical world is directly connected with the world of our behavioural rules; a world in which factors that we cannot see but that have a direct influence on how we act also play a role, such as prices and human laws (second level). All these behavioural rules are again dependent on an even higher level of abstraction, namely that of our culture and value patterns (third level).

Models are excellent tools to understand those processes for which we can make mathematical descriptions with a certain degree of certainty. This, first of all, include the processes that occur at the 'physical world level' in Figure 5, but to a certain extent also the intermediate level. An example of the latter are economic models describing the interaction between prices and consumption patterns. However, the processes that occur at the third level and their interaction with the intermediate level are much more difficult to describe by mathematical equations. There are, however, other scientific methods to study these processes, such as those applied in social sciences. As the processes at behavioural processes at the second level and the value patterns at the third level still play a key role in describing future pathways, we also need to capture them to some degree in scenario exercises. We do so by generating so-called storylines that describe consistent little stories about the future with respect to elements that are hard to capture in models such as societal attitude towards environmental problems, the extent of international cooperation, and the attitudes with respect to lifestyle change. Such a storyline could, for instance, indicate that society would prioritise economic growth. In a next step, we could translate such storylines into model inputs such as the rate of technology development and investment patterns. The combination of storylines, input parameters and models allows us to map possible futures and use an explicit scheme to reveal values and opinions. It,

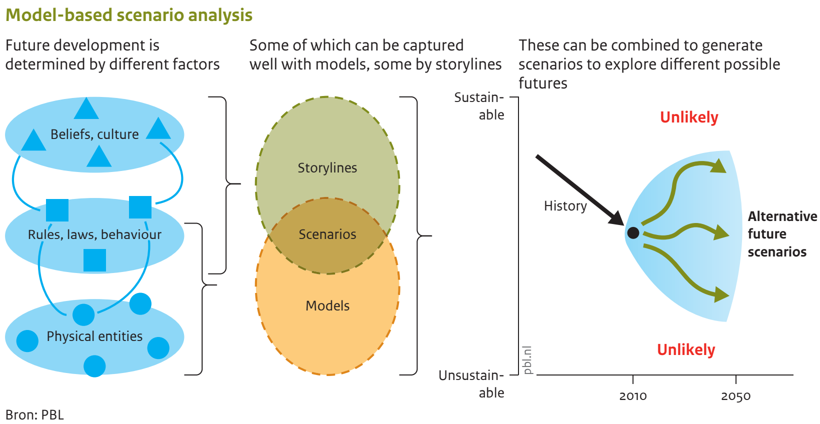



Figure 5: *The role of models in describing sustainability problems and transition scenarios (based on De Vries et al., 1993).*

however, also emphasises some of important limitation of models in describing the key processes involved in future changes.

To summarise, we thus use the models to create alternative 'scenarios'. These are not intended to be predictions, but instead are coherent, internally consistent and plausible descriptions of how the world may unfold. Scenarios may focus on describing alternative developments based on different socio-economic procceses, but they can also focus on the different ways in which society wants to achieve certain goals (e.g. technological solutions versus lifestyle). By using model-based scenarios and assessments that take different values into account, we can contribute to decision-making processes in a role as honest broker by examining the effects of many different measures, goals and pathways. As indicated by the co-chair of Working Group III of IPCC, Ottmar Edenhofer, you could certainly compare this role with that of map-makers; we act as explorers of possible pathways, showing the consequences of various end points and various routes of achieving them (Edenhofer and Kowarsch, 2015). By doing this, we can show the real controversies and trade-offs and contribute to a more constructive debate.

# 4 Back to the Future

I will now turn to the third subject I want to discuss, and that is how we can use these types of models to explore desired future scenarios. For this I would like to return to the international treaties I mentioned earlier and all the golden promises they make. Imagine that the y-axis in Figure 6 shows a scale where the high-end represents a situation in which all sustainability goals society has committed itself to will be achieved over the next twenty or thirty year – simultaneously -, while the low end represents a situation based on the reverse, i.e. a further degradation of the environment and limited development.

The question which I now would like to examine is not *whether* we will reach these sustainability goals, but *how* we can do so, and what we may expect to come up against on the way. This, in my opinion, corresponds best to our role as 'honest broker', as it is interesting for stakeholders to be able to see what the achievement of the various objectives and goals would involve (and possibly either act upon this information or re-evaluate the targets). This is to some extent also related to one of the first comments made by the present PBL Director-General, Maarten Hajer, when he accepted his post some years ago. He noted that among environmental researchers there is a particular tendency to point out everything that could go wrong if present trends continue, but he pointed out that people are much more motivated by positive pictures. In his essay 'The Energetic

**Backcasting analysis, working back from a sustainable end point to determine actions for today**

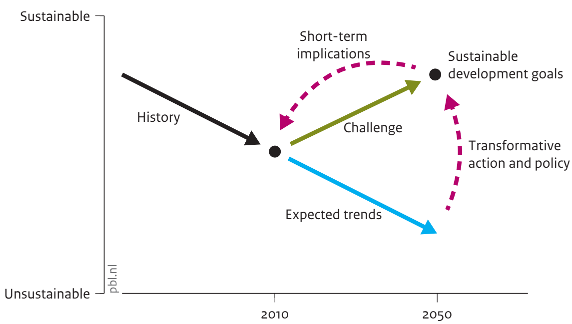



Figure 6: *Normative scenarios as a means to explore how to reach various environmental and development goals*

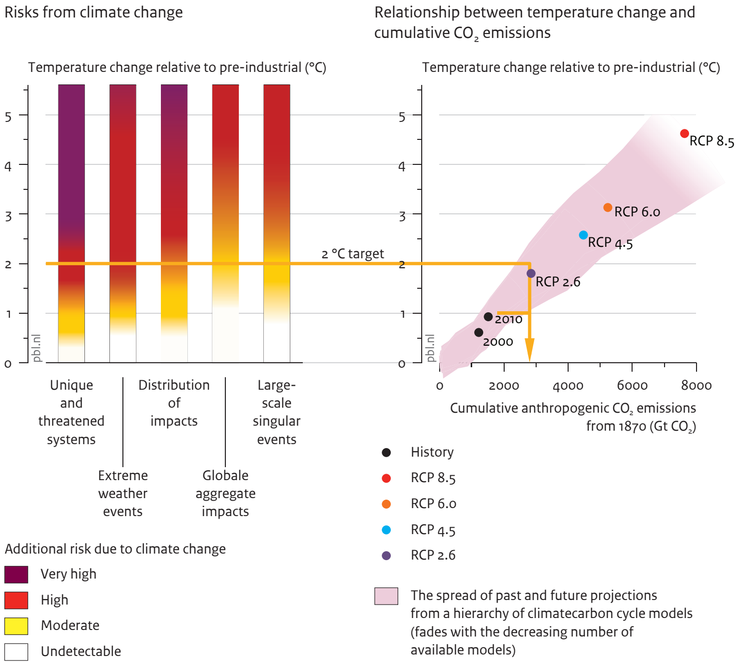
Society', he underlines this with the example that Martin Luther King's famous speech was not about 'I have a nightmare' but about 'I have a dream' (Hajer, 2011). So, if our dream was to be to meet our international agreements, what would we need for that? We could describe such an analysis as going 'Back to the Future'. We could begin by looking at a continuation of the present trends and policies using our models (our trend scenario). Next, we could compare these in relation to the goals. We could then use models to explore what would have to be different in order for the goals in these international treaties to be achieved. In a next step, we could analyse what would be required in the short term to indeed bring about change.

So far, my presentation has been fairly abstract, I would like to make it now a bit more concrete. I will do this using two of the leading key questions on sustainable development presented earlier: How to provide the world with energy while keeping climate change under control? And how to feed nine billion people while providing adequate protection for nature?

**How to provide the world with energy while keeping climate change under control?**
Let's start with the first example. The left-hand side of Figure 7 shows how the IPCC has attempted to relate the risks of climate change to the average warming of the Earth (IPCC, 2014a). The possible impacts of climate change have been described here in five categories. These are impacts on extremely sensitive systems, such as coral reefs and mountains, risks due to the effect of weather extremes, local impacts also affecting the food supply, global effects and even serious disruption of the natural system, such as the shutdown of the Gulf Stream. The risk of these impacts occurring is then shown by the colour scheme, in which red represents high risk and yellow and white less or even no risk. It should be noted, by the way, that IPCC faces the enormously complicated task here of communicating the likely consequences of climate change as well as those impacts with a very small probability but very serious consequences. This communication needs to be done in a way that decision makers as well as a broader public can understand. Interestingly, I believe it is the category of "small probability but very serious consequences" risks that is might be the most important to look at – as here the risks of climate change already seem more extensive than the levels we accept for some other environmental problems, such as industrial risks. Anyway, it is up to society to indicate which risks are acceptable and which are not; those related to a 3 °C or perhaps a 1.5 °C warming. International negotiations have, in principle, already expressed an interest in aiming for a 2 °C target.

The right-hand panel of Figure 7 – taken from Working Group I of the IPCC (IPCC, 2013) – shows total $CO_2$ emissions over time along one axis and global mean temperature

**Relationship between risks from climate change, global temperature change and cumulative $CO_2$ emissions**




Source: IPCC SPM 2014

Figure 7: *Various reasons for concern with respect to climate change in relation to global mean temperature increase (left-hand side) and the relationship between cumulative $CO_2$ emissions and temperature increase (right-hand side)*

along the other (thus linking the two panels). Because a considerable proportion of the $CO_2$ emissions only disappears slowly from the air, cumulative emissions provide a good measure of the overall change in climate. You could see this as the $CO_2$ budget that society could spend. The coloured band shows the relationship as well as the overall uncertainty as currently estimated by scientists. This shows that, among scientists, there is actually no doubt anymore about the question of whether higher $CO_2$ emissions lead to a greater temperature rise. At the same time there is still considerable uncertainty about the precise

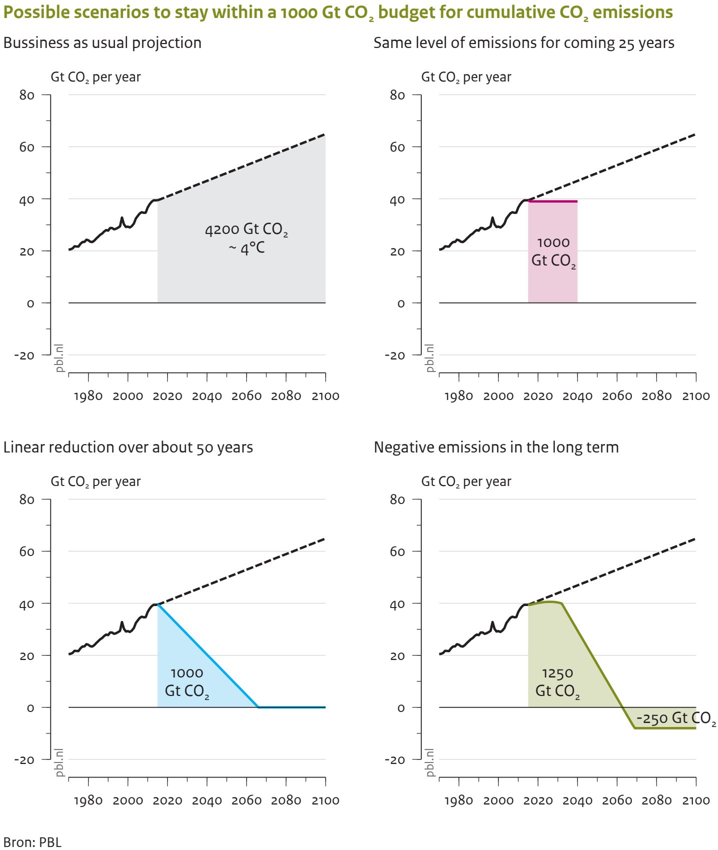



Figure 8: *Possible scenarios to stay within a 1000 $GtCO_2$ eq budget*

relationship. If we now assume a maximum increase of 2 °C, we can use this graph to read how much the total emissions may be in order to remain below that limit. If we select a point far down the coloured band, we could possibly meet the 2 °C goal, but there is still also a considerable chance of exceeding it. The reverse applies if we take a point higher up the coloured band. Because we can assume that governments would want to achieve the 2 °C goal with a reasonable level of confidence, a sort of consensus has been reached within the scientific community of reading the graph on a certainty level of there being about a two-thirds chance of actually achieving that goal. In which event approximately another 1000 $GtCO_2$ may still be emitted (see also Friedlingstein et al., 2014). Note, however, that this means that two thirds of the original $CO_2$ budget of around 3000 $GtCO_2$ to stay below the 2 °C, measured from the end of the 19th century, has already been used up.

What does constraining the future $CO_2$ budget to 1000 $GtCO_2$ mean? In essence, this is the key question for the climate negotiators later this year in Paris. This figure shows the historical and current emissions and a possible projection of the annual emissions after 2015. The $CO_2$ budget is therefore in each panel slowly being used up by the sum of the annual emissions over time. Given the further growth in the world population and the increase in economic activities, our models definitely anticipate an increase in energy consumption. And as long as this energy comes from fossil fuels, $CO_2$ emissions will continue to rise. In the left upper panel of Figure 8, I have used a simple line here instead of the actual model results, but it gives a reasonable representation of our projections. The line leads to roughly 4000 $GtCO_2$ emissions up to 2100, corresponding to an expected temperature rise of more than 4 °C. While historically, the lion's share of the emissions originated from so-called developed countries, currently most of the increase in emissions is not from developed countries but from today's poorer countries.

In contrast, what using only a carbon budget of 1000 $GtCO_2$ at present day's emissions would look like is indicated in the upper right panel. We can continue for perhaps another 25 years at the same level of emissions. But this is, of course, not a workable scenario to achieve the 2 °C target; emissions would then suddenly have to be zero, by 2040. Please note that the real negotiations in Paris are even more complex, as they not only address the timing of reduction, but also how the emissions should be divided between the countries (or perhaps even more problematically, how to allocate the reductions). While the increase is taking place mainly in the poorer countries, it is the rich countries that have caused the problem in the past – and they generally also still have the highest emissions per capita.

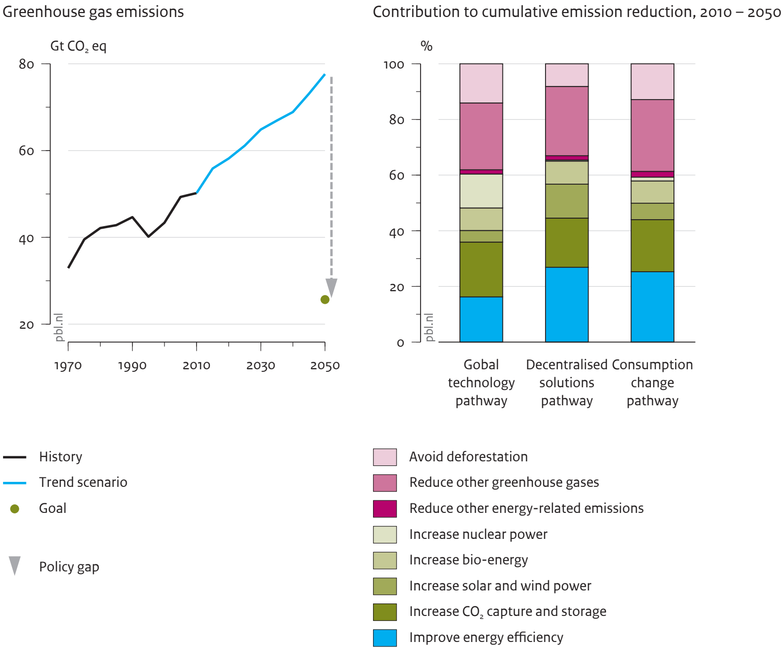
But back to our problem at the global scale. We can also express the 1000 $GtCO_2$ budget in an entirely different way – as shown in the lower left panel. We now see a linear reduction over about 50 years also amounting to 1000 $GtCO_2$. It illustrates how tight the budget is given that the life of many of the technologies we currently employ is about 40 to 50 years. Therefore, in order to comply with this scenario, we would have to switch over the coming 5 to 10 years, on a global scale, from an energy system mainly based on fossil fuels to a situation in which all new investments must be $CO_2$-free within a reasonable time period. Politically, this would seem to be a long way off.

But, if we want to try anyway to fill the gap between the emissions under the policy-free projection and the 1000 $GtCO_2$, there are various options available, such as renewable energy, carbon capture and underground storage, energy efficiency and bio-energy and lifestyle change. Unfortunately, all these options also have not only benefits but also drawbacks, which should not be overlooked. Earlier, I mentioned the possible opposition to wind energy. But how about nuclear, then? Or the underground storage of $CO_2$? Only energy efficiency appears to have only limited drawbacks, but it is clear that we will not reach a situation of zero emissions based on energy efficiency alone.

In terms of timing, we still have a couple of other options. Perhaps somewhere around 2030, we could speed up the emission reduction through faster depreciation of capital, changing existing power plants (retrofit) or making rapid lifestyle changes. Another option is that of negative emissions in the long term. This would be possible by combining bio-energy with carbon sequestration (Azar et al., 2010). Technically, there seem to be few obstacles in engineering this technology. The possibility of having this option means that, in the short term, there is still some additional room, but only on the basis of an expectation of what we can do in the future. By using this option, we are making ourselves dependent on a combination of two controversial technologies, i.e. the unproven carbon sequestration method and bio-energy. Both options requires space and therefore possibly making the challenge surrounding the food supply even more difficult. Decisions in the next decade or so thus determine whether the 2 °C target can still be reached without negative emissions, or not. It is the exploration of the scenarios with negative emissions that Geden in his article described before as dubious and potentially misleading (Geden, 2015). But, given what we now know about the honest broker, would it not be more misleading if our scientific assessment would not indicate these scenarios and their potential strengths and weaknesses? Would it not be strange if scientists decide whether or not societal goals are feasible, based on a subjective assessment of what can and cannot be achieved?

Instead, we can use our models to make a selection from the mix of options, based on different assumptions – as you can see here – and show what it would take to achieve an emission reduction consistent with achieving the 2 °C target. Accepting the option of some negative emissions, the 2 °C target is often equated with a 50% emission reduction by 2050 (Van Vuuren et al., 2007). On the left, you see again the scenario without policy and with 2 degrees and, next to it, how with a combination of various measures we

Global greenhouse gas emissions and options to reduce emissions

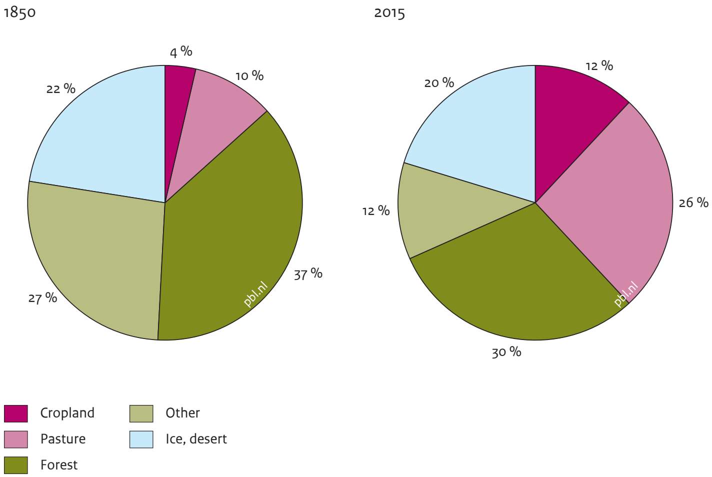



Source: PBL

Figure 9: *Alternative scenarios to reduce global greenhouse gas emissions by 50% by 2050, compared to 2010 (PBL, 2012).*

could achieve the 2 °C scenario, according to our model. In this case we have considered three possible scenarios based on certain preferences for solutions; one based on large-scale technology; one more on local solutions; and one on lifestyle changes. We can now compare the results of these options. The results actually show that, in reality, the goal of 2 °C is so strict that it would require using just about the entire arsenal of options. You can also see that, in addition to energy-efficiency, also other options contribute significantly to mitigation, including reduction of non-$CO_2$ greenhouse gases, Decarbonisation of the electricity system always play a fairly large part in the solution. In general, calculations also show that cost does not appear to be the biggest problem, with 1% of GDP in 2050 being

**Global land cover**




Bron: Klein Goldewijk et al. 2010

Figure 10: *Change in global land cover between 1850 and 2010 (Klein Goldewijk et al., 2010).*

a reasonable estimate. But that does not mean that other barriers – such as the interests of coal or oil producers – should be overlooked.

We have also started to use these results to provide more insights into the types of policies that would be needed to implement these technologies. This includes, for instance, ensuring a credible long-term target, identifying important co-benefits (e.g. for local air pollution), and using a wide portfolio of policy instruments that, in addition to ensuring the correct pricing of activities that cause greenhouse gas emissions, would also include other instruments. Our analysis has shown that early action tends to be cheaper than a more delayed response (van Vliet et al., 2012; Riahi et al., 2013).

*Providing food to 9 billion people in 2050 while halting biodiversity loss*
In a similar way, we can also take on another major challenge; the question how to achieve access to food for 9 billion people while protecting biodiversity. Figure 10 shows the land surface of the world divided up into the categories of cropland, pasture, forests, other green nature, and ice and desert. Since 1850, the world population has grown from less

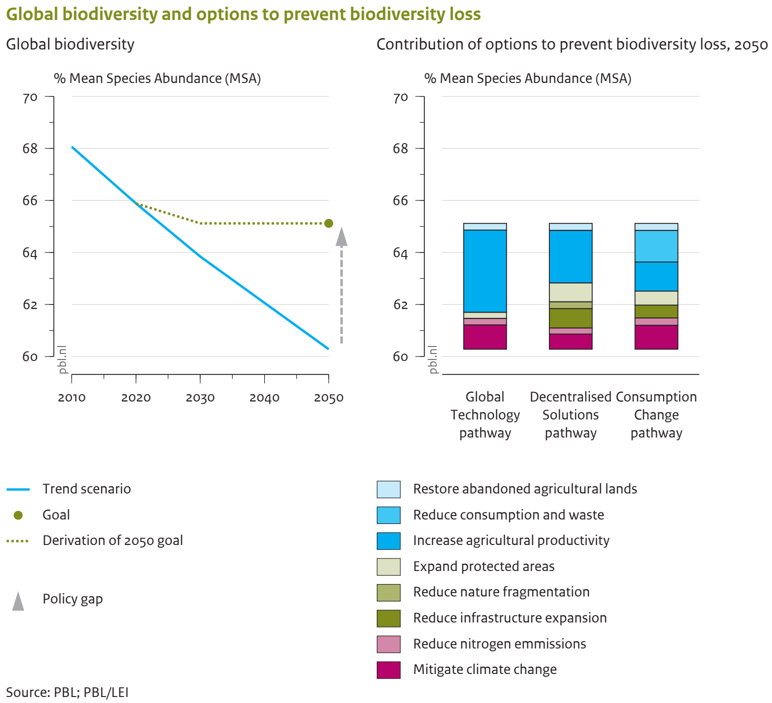



Figure 11: *Alternative scenarios that provide food for 9 billion people in 2050, while halting biodiversity loss (PBL, 2012).*

than 1 billion to 7 billion people, while food consumption per person has also risen. Food production, therefore, has increased by more than a factor of 10, in total. The largest part of this increase has been brought about through higher yields per hectare – also mainly due to the use of artificial fertilizer. During this same period, croplands and pastures have also been greatly expanded at the expense of nature. At the moment, about half the fertile land is being used for food production.

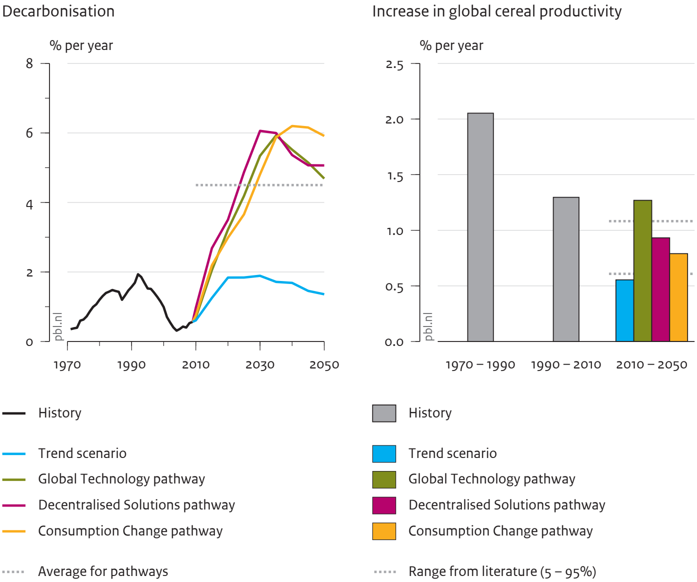
For the next 35 years, the world population is expected to further increase to around 9 billion people and a shift in diet will again contribute to a greater demand for food. It is expected that about 60% extra production will be needed (PBL, 2012). Greater productivity will be a vital factor in the coming decades, too. But further loss of nature is expected, in order to meet part of the increased demand. Here too, we have promised to do better; the biodiversity treaty wishes to halt the further loss of nature, while all sorts of other development treaties are aimed at combatting hunger.

Again, using the approach of model-based scenarios, we have looked at what pathways will enable us to achieve such goals – using the same three scenarios as described above for climate (global technology, local solutions and lifestyle-change) (Figure 11). The option here intends to reduce biodiversity loss. Here, I would like to highlight three options from the portfolio shown in the Figure. First of all, we see that greater productivity improvement takes on an important role in all three scenarios. Secondly, what can also be seen is that under the lifestyle-change scenario, the assumed dietary change would make us less dependent on improved productivity. Dietary change here refers to *less* meat consumption rather than *no* meat consumption. In fact, we only assumed a reduction in meat consumption which is consistent with the internationally recommended level for a healthy diet. The last factor I would like to mention is the role of mitigating climate change, which is also shown to have an important contribution to halting biodiversity loss. As some measures to mitigate climate change themselves could lead to use of land and thus biodiversity loss, this needs to be carefully balanced.

All in all, the calculations lead to a picture which suggests that it would be technically and economically possible to get quite some way towards the goals set out in the international treaties. There are also several routes available for this. At the same time, it is important to realise that this is not just a slight adjustment to the present course. I will try to illustrate this in Figure 12, which shows the annual improvement in the relationship between greenhouse gas emissions and income, also referred to as the carbon intensity on the left, and the annual improvement in global grain yields on the right. Both panels compare the ‘trend scenario’ (without additional policy) to the scenarios needed in order to achieve the climate and biodiversity goals while ensuring access to food and modern energy.

In the past, carbon intensity has improved by about 2% per year simply as a result of technology progress and shifts towards a more service-based society. For reaching the 2 °C target, however, this needs to be 6% per year. It is possible – but requires a huge trend break. Historically, such high intensity improvements have only been achieved for short periods of time, on a country level (e.g. in France, during the period it embarked on its nuclear programme). The same applies to yield improvement. While historically yield improvements have been slowly declining, they would need to increase again, to achieve

**Global decarbonisation rate and yield increase**




Source: PBL; LEI

Figure 12: *Indication of the level of transformative change (PBL, 2012).*

the goals related to food and biodiversity. This could be compared, historically, to the situation of the green revolution in Asia.

Various people, in the past, have compared changes of this sort with the American project to put a man on the moon. In 1961, Kennedy announced that within 10 years an American would walk on the moon, and through a dedicated research programme this did indeed happen 10 years later. The comparison, however, is unfair – the scale of the process here is much bigger in terms of research and certainly in terms of gaining public support and involvement. Much more useful perhaps is to see this as a range of smaller projects per sector in which a goal must be achieved within a certain period of time. For example, the goal to reduce $CO_2$ emissions in transport in OECD countries over the next 10 years – or to design a car from which emissions are reduced by half. Model calculations could be used to help identify the most appropriate goals.

## 5 Further research

My last topic is that of the need for further research. There are four topics that I particularly want to touch on here. These are:
1. specific model improvements,
2. more work on model validation,
3. cooperation on the matter of how to bring about transitions, and
4. finally, expressing model results differently, in order to make them relevant for specific sectors and target groups.

*Specific model improvements*
I previously compared the IMAGE model with the 'Back to the Future' car travelling through time. People have told me, however, that the 'DeLorean' car used in the movie is uncomfortable and also usually runs on petrol. If there would be a sequel to the movie, they might want to update it to a similarly fancy, but a little bit more modern: comfortable and full electric. So let us assume that, as with this car, we can also make our computer models a lot better. I see three priorities here.

- First of all, defining concrete measures more clearly. To keep our models transparent and thus simple, we regularly use abstract factors to represent an activity. Air pollution, for example, is set with emission factors, and yield improvement with an aggregated factor which we call the management factor. If we want to be more policy-relevant then we should be able to indicate, for example, whether an improvement in yield will be achieved with different crops, possibly also through genetic manipulation, more fertilizer or, through mechanisation, i.e. tractors. This then gives us the opportunity to really examine the consequences of such measures. The motto for this model improvement therefore would be 'from factor to tractor'.
- The second priority in model improvement is to improve the links between the model components. For both scientists and integrated assessment modellers it is often most interesting to further elaborate and refine a specific model component; this offers the best chance of publishing scientific papers in disciplinary journals. However we need to know more about integrating themes – certainly in IAM models. This may, for instance, involve the nexus between water, energy and food – the themes

related to bio-energy – but also the the links between energy use, air pollution and environmental and human health impacts (Chuwah et al., 2015).

- The third category of model improvements concerns heterogeneity, which means how we take into account differences between groups in society. An important priority here is to include the role of urban and rural populations on a much more systematic basis. For the last five years, most of the world's population has been living in cities – and numbers are expected to continue to grow. This is something which also affects the sustainability issue because of its relationship with consumption patterns, infrastructure, transport and innovation opportunities.

*More work on model validation*

The second area for further research concerns model validation. Once again, we can make a nice link with the film Back to the Future. This is because 'Back to the Future 2' takes place in 2015 – and on the internet we can already compare all sorts of things predicted in the film with today's reality to see whether these actually happened or not. Scientists refer to this process as validation.

Model validation and the credibility of our research is becoming an increasingly important topic for us as (environmental) scientists. This is so because, first and foremost, the changing role of science and experts in society in general has set new standards for transparency. As scientists, we can no longer justify what we do in terms of our white lab coats or black academic gowns and barely accessible peer-reviewed literature. This is partly related to the scandals of recent years, but even more so by the ability of the public-at-large to gain access to information and engage in debate via the internet. On top of this, in the run up to the Paris conference, the interest in climate research is only growing given the importance of the topic – which makes it all the more likely that various parties will be taking an even more critical look at the evidence presented.

Nevertheless, proper model validation is a major challenge in integrated assessment work. It is clear that, historically there have been frequent surprises that could not have been described by models, such as the rapid rise of ICT and its consequences, the implications of the fall of the Soviet Union, or the impact of reactor accidents on the future of nuclear power. It is even more complicated for the type of model calculations discussed here, where we are also looking for scenarios that actually break with the past.

However, this does not mean that validation is completely impossible. There are a few things that we really must do. First of all, we need to pay particular attention to providing transparency by ensuring that the best possible documentation is provided on both the models and their application. This should include the input data and assumptions, as well as the results. But we should also continue to search for more interactive forms of communicating results – ways that go far beyond articles and reports.

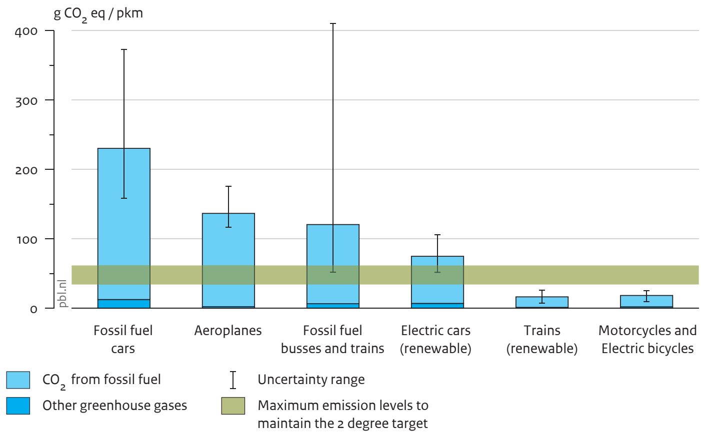
In addition, in my view, there is still a great deal to be gained from a smart comparison with past trends. Perhaps not so much for direct validation, but rather to gain a clearer picture of the degree to which our model calculations deviate from historical trends – for example, by comparing the growth in renewables with the rapid adoption of gas in the past. We are working on this, for example, in the framework of the LIMITS and PATHWAYS projects (Van Sluisveld et al., 2015). It is also possible to make comparisons in a more qualitative sense, using the type of dynamics as a starting point (van Ruijven et al., 2008).

**Cooperation on the matter of how to bring about transitions**
The third area is the academic question of how the pathways predicted in the models could actually be brought about.

As I previously tried to explain, models are mostly good at predicting scientific, technological and economic processes. The power of modelling therefore also lies in the support for policy processes and future focus, but also requires simplification in other areas. An important simplification (and thus limitation) is that IAM models do not typically address the role of individual actors (i.e. those who take decisions) and their interactions. These elements are very difficult to capture in models. We are talking here about the interests of power companies; for example, regarding whether or not there is a shift to a more sustainable power supply, the role of innovative processes in this, as well as the question of how these interests can be influenced. There are many other, better scientific methods for investigating this, including the tools used in the field of transition and innovation studies. What strikes me is that many of the methods in these fields may well provide good insight into the real complexity, but are often rather case-study-oriented and provide explanations for historical transitions. In my view, there is therefore a great deal to be gained from integrated assessment and institutional and actor-oriented researchers working together more closely, so that IA researchers can learn from innovation studies on the limitations posed by societal process related to transformation, while innovation researchers will also be more inclined to think in terms of the future. It is therefore about building suitable bridges, which is what we are trying to do now, not in the least in the PATHWAYS project.

*Make model results more relevant for specific sectors and target groups*
The final area also touches on the previous one. It is about finding ways to make the IAM results more interesting to other actors than just the government. Figure 13 provides an

Greenhouse gas emissions from travel, 2050




Source: Girod 2014

Figure 13: *Comparison of the emission intensity in transport consistent with the 2 °C target in 2050 for different transport options. The data includes both direct and indirect emissions and is based on data on current technologies.*

example based on the work of Bastien Girod (2014). He used the results of IMAGE to look at the most important activities per sector projected for 2050 and the emission levels that may be permitted per activity if we are to aim for the 2 °C goal. For transport, he first derived a target for the maximum emissions from the entire sector and, subsequently, calculated the level of emissions which may be permitted per kilometre travelled, shown here by the orange band (the band reflects uncertainty). He then looked at how this compared with the emissions from various forms of transport, based on current data from life-cycle analysis. It is clear that, if all our transport would be done in current cars running on petrol, then we would exceed our goal, considerably. Fossil-fuel based cars are likely to become more efficient in the future, but this, on its own, would not close the gap with 2 °C level. But the goal can easily be achieved by using other forms of transport, such as bicycles, electric bicycles, or trains that run on renewable energy. From the various options, it is would now be possible to select a mix of technology improvements and lifestyle changes that could lead to a sustainable and realistic contribution by every sector.

## 6 Final thoughts

Having identified some of the key research questions, how will my position at Utrecht University be related to answering them? Over the past four years, I have seen that there is a great deal of knowledge available at this university, specifically in the areas I have referred to here. This includes knowledge on the scientific aspects of the environmental system, innovation processes, technologies and policy. Over the past few years, the IMAGE team at PBL has acquired a wealth of knowledge on the subject of integrated assessment, as I have also shown – and we are capable of applying this in a wide range of policy processes. Based on my experience over the last few years, in the coming period I intend to continue making connections to the benefit of both institutes. How? I think that both institutes have an interest in integrated research and the possibilities offered by the IMAGE projections. It is also clear that we can work together on the themes I just mentioned. This could be through joint projects – possibly externally funded – but also by giving young PBL staff the opportunity to obtain their PhD at Utrecht University, or by exchanging staff in other ways, of which there already are several examples. In any event, I am looking forward to it.

This then brings me to my last point – and that is a word of thanks. I have been advised to keep this brief, because there will always be people who you forget to mention, anyway. Thus, first I must thank my family: my father, mother, brother and sister, and, of course, Petra and the children. Petra, besides our relationship at home, we now also have a further relationship of sharing a single academic gown at work. This gown has the unique ability to be able to change the colour of the sleeve and, thus, be a natural-science for you as well as a geo-science gown for me. Mette and Sanne, my two daughters, please let me know in due course, maybe using a time travelling car, how our projections turned out in the end. I cannot complete this inaugural lecture without expressing my thanks to those who made this appointment possible, including Bert de Vries, Klaas van Egmond, Maarten Hajer, Martin Wassen, Wim Turkenburg, Pieter Boot and Bert van der Zwaan. And, last but not least, all my colleagues at PBL and Utrecht University. I look forward to working with you in this field for many years to come.

Thank you.

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Professor Detlef P. van Vuuren (1970) has been appointed as professor of ‘integrated assessment of global environmental change’ at Utrecht University, Faculty of Geosciences (since 2011). He graduated in Environmental Sciences and Chemistry from Utrecht University, and attained his PhD in 2007 from the same university, for his research on scenarios to explore the future development of energy systems and climate policy.

Detlef van Vuuren is interested in applying integrated assessment models to study the complex interactions between drivers of global environmental change, various environmental issues and their relationship with human development goals. The main objective is to integrate information from various scientifc disciplines and place that in the context of decision-making processes, in order to formulate effective response strategies. He works at PBL Netherlands Environmental Assessment Agency as project leader of the IMAGE integrated assessment modelling team. In his work, he plays an active role in the international research community, among other things as (coordinating) lead author in the Millennium Ecosystem Assessment and the assessment of IPCC, and as member (of the steering board) of several research organisations such as the Integrated Assessment Modelling Consortium, the Working Group of Coupled Models of the World Climate Research Programme and the Global Carbon Project.