Table of Contents

Go Back

Modeling innovation-based approaches to climate mitigation

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Abstract

Mitigation, decrease of greenhouse gases, is often regarded as expensive and as a major hurdle to innovation and economic development. Here we describe a systems model that allows assessment of integrated policies for mitigation and economic development. It is highly likely that such policies may yield gains instead of costs, up to a considerable decrease of present emission. This model, and this expectation, is based on accepted knowledge regarding the costs of mitigation. The model describes interrelationships between three complex realms that are at the heart of innovation: human knowledge, the economy, and new key people with knowledge of a basic innovation. The success of real policies normally depends on their appropriate, integrative, and simultaneous approach to all three realms. Development and assessment of such policies might help overcome the present deadlock in mitigation. Through them it should become possible to decrease risks in innovation and to learn to utilize innovation simultaneously for economic growth and for decreases of emissions of greenhouse gases. But appropriate integrated policies are complex to develop and assess. The regionalized global model on innovation and mitigation described here is a step toward facilitating this process.

Key Words

Mitigation, innovation, information society, ancillary benefits, regionalized global model

1. Innovation-based mitigation

Assuming the Kyoto Protocol is stalled in global politics, it is incumbent on science to explore methods that are suited to bring together the opposing factions. Obviously, no-regret policies, which decrease greenhouse gases and, simultaneously, bring economic gains, should be good candidates for fairly general acceptance. There is evidence that the building blocks of such win-win policies are waiting in the wings. According to a thorough overview by the International Panel on Climate Change (Metz et al. 2001), there is a large and growing reservoir of unexploited technologies, management methods, products, & production processes that could cut GHG emissions up to 50% with potential net gain or minimal net economic cost. But startup requires extensive investment in innovation, knowledge, specialized capital equipment and in key knowledge workers to guide the processes. As is so often the case, the costs and the benefits are not allocated equitably so as to provide incentives to undertake the necessary investments. Innovation normally involves high risks and high returns, with the risks and costs being quite certain and upfront and the returns being uncertain and accruing, if at all, only in the distant future. Furthermore, much of the benefit may accrue not to the firms that make the investments but to the population as a whole. On the other hand, investments in innovation can yield significant economic gain both to the investors and to the public. Similarly, recent overviews show that those economic sectors that innovate most, and have highest gains in profitability are those under the highest competitive pressure. Such pressure can be stronger than the inherent risks of innovation, whatever the noble promises of decreased GHGs may be. Missing is a tool enabling a more thorough assessment of innovation's complexities and potentials to guide markets toward both private and social/environmental objectives. Systems modeling is an ideal tool to support such endeavors.

If GHG abating innovation is promising, current US levels of real fixed investment, at $ 2.7 trillion per year, are encouraging. Of course the huge uncertainty regarding climate change, added to the enormity of these investments indicate that much research is needed as to how to piggyback GHG decreasing innovations on them. At present, some of these investments decrease emissions, others increase them, and still others are neutral. Overall, specific emissions have decreased in the last 20 years. But this gain has been more than offset by rapid economic development, in particular in China, India, and other Asian countries. Rising emissions from such large countries put them at odds with the developed world. Developing countries view new treaties as threats to their economic progress. Clearly, market based approaches that utilize innovation for mitigation and economic gain are opportune and necessary.

For the research we use a family of integrated socioeconomic models on economic and social innovation that describe the present transition to an information society. These models have been developed and used for policy development and assessment to support regional and urban development, e.g. Grossmann 2001, 2002.

Starting with these models, in principle we need to invoke coupling of climate and socio-economic models in systems that would be genuinely interactive. The idea of coupling socio-economic and climate models is not new. For example, Hasselmann (1990, 1999) or Hasselmann et al. (1997) introduce coupled models but, for lack of sufficient consideration of the innovations of the new economy, concentrate only on minimizing *costs* of adaptation and mitigation (abatement). We now concentrate on how to model large-scale innovation of the type that is behind the present emergence of an information society. There is not yet much research in this area (Weyant, 2000).

2. Major elements in innovation

During the last two centuries, at least, large-scale innovation ("basic innovations") came out of close interactions between three realms: economy, key people and knowledge. As the ISIS-model (Information Society Integrated Systems Model) describes the most important interactions between these three realms, this is a tool to explore, devise and assess policies not just for economic and social development – the original use of the ISIS-models – but also innovation that decreases emissions of GHGs.

Experience shows that successful policies address all three realms. Policy failure is frequently attributable to addressing just one realm or one of its aspects. In Systems Dynamics this result is well established, described already by Jay Forrester in his 1969 Urban Dynamics (counterintuitive behavior of complex systems). It was also established, in macroeconomics, in the Nobel Prize winning work of Robert Mundell which helped national economies emerge from the painful quagmire of stagflation. What often – not always – works well is bundles of policies for all three realms, bundles which are so well tuned that side effects of one policy are compensated by other policies. For example, policies that support economic development of modern industries create interesting jobs thus attracting key people. Their migration into well-developing regions, in turn, creates bottlenecks in housing. This phenomenon caught considerable attention in the recent bubble phase preceding the crash of the dotcoms. The time lag between the increase in demand for housing and its construction creates a bottleneck often of significant proportions. Furthermore, housing construction eats into the natural landscape, degrading possibilities for outdoor recreation, and thus decreasing regional quality of life. This example illustrates how policies have to be bundled to address all such issues simultaneously.

Innovation is risky and sensitive to obvious and subtle factors. Hence, innovation can be encouraged and supported. In the last 15 years research has made huge progress in how to provide incentives and frameworks to make innovation happen and how to make it succeed. One of the outstanding results of this research is in understanding the need for well-composed support groups that accompany the original inventor from invention to success in the final test, that is, in the markets. Regions could do much to vastly improve their success in benefiting from innovation. Some companies have recently learned to be exceptionally good in providing a "see-it-through until ultimate success-environment" for their most creative people. Other companies have learned how to make large groups of people much more creative. For example, Jürgen Fuchs, who was behind the turn-around of Lufthansa in the 1990s, created his concept of viable enterprises. Fuchs' writings (e.g. Fuchs 1994) are in German, unfortunately, and are not available in English.

3. Three-Landscape Approach to Innovation

New groups of basic innovations are nurtured through evolving sets of the three realms mentioned above, i.e. new key people, new knowledge, and new economy. We name these particular realms “landscapes”, because, like landscapes, they are complex and multifaceted, an image which is also implied in terms such as mindscape, knowledgescape, and so on.

Historically, one example of basic innovations centered on the first effective steam engine and brought the industrial revolution in the early 19^{th} century. Another group of basic innovations relied on electricity and carbochemistry and brought modern industrial society, starting at around the 1870s. A third group revolutionized mobility since the 1920s and 1930s, in particular cars and trucks, airplanes, radio, and TV. One result is globalization in tourism and trade, and global concern about grave human or environmental problems. At present a group of new basic innovations is driving development towards informatization of lifestyles, products and economy. These basic innovations utilize vastly extending capabilities coming from processing and transmitting large amounts of information, so that information now becomes an industrial raw material for thousands of revolutionary products. Examples are multimedia, the Internet, the use of the information in genomes, or the deciphering and utilization of proteins. This development has many names, e.g. information society, none of which is fully appropriate. We are at the beginning of a societal, economic, political and individual transformation on a global scale and can at present not well anticipate its major outcomes.

In the present socio-cultural economic transition, a set of three new landscapes – “new” key people, new knowledge and “new” economy – is cooperating and competing with the established set of three landscapes – i.e., “established” key people, “mature” knowledge and mature industry. Interactions between the old and the new sets of landscapes affect and transform the physical environment. The physical environment, ultimately, is the carrier of these interacting sets of landscapes. Some aspect of these interactions is our topic here, namely an innovation-based approach to mitigation.

The simplest model of these transforming processes, then, consists of two sets of three landscapes, embedded in their physical environment, with links to emissions of greenhouse gases. Some of the major components of such models are shown in the next figures and are explained below. These belong to the family of ISIS-models, used in co-operation between social and natural scientists. The names in the models have been chosen so that they are also suitable for mathematical equations, which are preferred by most natural scientists. The recent trend in variable names in modeling and programming has been long, self-explanatory names, which, however, would not be suited for equations. System models for use by both, social and natural scientists need to make a compromise in variable names.

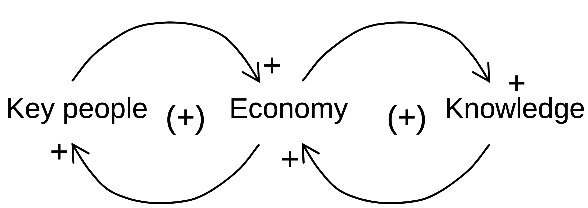


Figure 1: Causal loop diagram of feedback relationships between the three landscapes

Explanation of Figure 1: There are mutually positive effects of all three landscapes on each other. Mathematically it suffices to have these connections through just one landscape, here the economy. Naturally, more key people also produce more knowledge even without a connection through the economy; and vice versa, if there is more knowledge, more key people are needed to master this knowledge and to apply it.

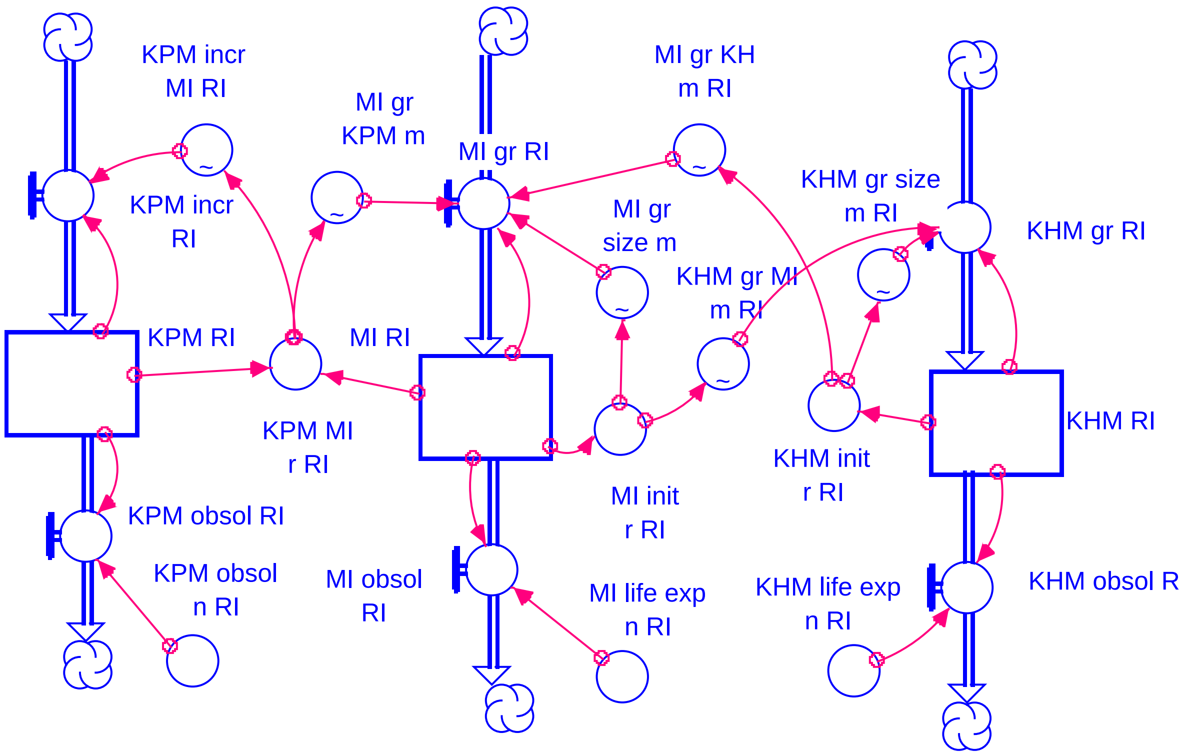


Figure 2: Relationship between the three realms for the mature sector

Explanation of Figure 2: Shown here is the mature sector of a 3-Region global model for mitigation through innovation (RGM, an ISIS-model). Shown is a part of Region I, which comprises the one billion people of the earth who live in highly developed regions. The three state variables are each modified by its own processes of creation and disappearance, or “obsolescence.” The left side of the figure depicts key people, the middle mature industry, and the right mature know-how. MI stands for mature industry, RI for Region I. KPM denotes key people in mature industry, KHM stands for know-how in mature industry, etc. With this nomenclature, KHM_RI is know-how in mature industry of Region I. The single letter “n” stands for “normal”, the normal value of a variable, i.e. a constant. Key people in mature industry increase in numbers (KPM_incr_RI) through training. The flow variable “KPM incr_RI,” therefore, is the increase in the number of key people for mature industry in Region I. Their knowledge has a limited lifetime (expressed by the constant “KPM obsolescence normal Region I”) and these people therefore leave the industrial system through the flow variable “KPM_obsol_RI,” unless they undergo continuous retraining. Likewise, the flow variables “MI gr RI” (mature industry growth, Region I) and “MI obsol_RI” (mature indstry obsolescence Region I) control the development of mature industry, and the flow variables “KHM_gr_RI” and “KHM_obsol_RI” control the development of know-how of the mature industry.

Several feedback loops of mutual influence link these subsystems. They are controlled in the well-known way of System Dynamics by multipliers so that these three subsystems can only develop well if in harmony with each other. The multipliers (functions) are of s-shaped form, as efficiency of any particular input is low for low values (beginning of s-shaped curve), and has a saturation (right side of s-shaped curve). Data for such systems are available from some standard and not so standard sources. For example, the unit cost per job or the fraction of leading people in the overall workforce, are standard from statistical offices. As an example of non-standard sources, see the research on innovation by Michael Porter and colleagues (e.g. Porter & Stern 2001) on the importance of innovation and how to measure it, using the number of patents. To avoid measurement problems and ambiguities, we divide the state variable for know-how by its initial value which eliminates dimension so that only the growth factor remains.

The sub model for new economy has the same structure as the sub model for mature industry, but the data are different. For example, in reality, the importance of key people for mature industry is considerable, but their training and curriculum have been well-established since the 1930s. Also, key people comprise only a small fraction of the overall workforce in mature industry, so that their availability is not so much a limiting factor. But in the new economy, new key people are a large fraction of the workforce and the most important bottleneck in slowing growth of new economy, a fact which is indicated by the stiff global competition for such people (Stern and Porter 2001, Florida 2002, Grossmann et al. 1997, findings by HUD 1997, or Schumpeter 1939). With the growing importance of knowledge, technology and information, a model on innovation policies needs to include these factors, and with them, the “creative class” (Richard Florida). In mature industry, due to rationalization and loss of jobs, there is usually a good supply of key people available to the new economy. This submodel of new economy, here and in reality, is not seriously limited by labor supply. Because of globalization, large numbers of workers are available in rapidly developing countries like China and India, a positive aspect of the outsourcing controversy. Like Stern and Porter, 2001, we have not included normal labor as a productive or limiting factor. Such a system of equations would have been without relevance for the economic reality of 15 years ago. With ongoing economic growth and maturity of the present new economy, amplified by aging populations in most countries, labor will again become a limiting productive factor.

To deal with implications of aging populations on economic change and emissions of GHGs, we have included a global population subsystem with 8 age groups which, in accordance to projections by UNESCO and other respected groups, shows a peak in population number in 2050 at about 9 billion people. This is in the upper third of projections, which anticipate peaks ranging from 7.5 billion to 9.5 billion people.

4. A Two-Sector Approach to Economic Transformation

Recent reviews of economic development in the past 15 years confirm that there is a vigorous, large-scale emergence of a new economy, and that this new economy is transforming established, mature, industry (Farrell, 2003, for background material see e.g. Enriquez and Goldberg 2000, Castells 2000, Margherio et al. 1998). From the viewpoint of economics, this is a two-sector situation of economic transformation. With this viewpoint, the economy furnishes ample knowledge on how to model these relationships. The present authors have described the process, in another paper as follows (Grossmann et al., under revision): "First, hitherto highly concentrated accumulations of economic assets and economic power, as well as geographic agglomerations and long established path dependencies, are "melting" under the influence of networks and information technologies (Jensen 2000). As derived incomes are redistributed, social systems can become, albeit imperfectly, more equitable and more democratic. Among the results are GDPs, particularly in the highly developed countries, that circulate more rapidly, that are significantly less heavy industry- and more information-intensive (Porter & Stern 2001). Physically and electronically integrated global markets are the productive origins of these GDPs. These often-observed trends may themselves be sources of mitigation of, and adaptation to, potentially negative impacts of climate change. Information, offsetting smokestack intensity, is an obvious case in point, which has driven down relative, but not so much absolute, energy use. Projections from the IPCC would imply that much more needs to be done. … An important tool here is an adaptation of New Economic Geography (NEG) studies to channel the dynamics to present and future locational trends (Fujita et al 2000). Other tools of importance include the results of decades of rich international business and economic analyses of corporate structure, competitive advantage, innovation & entrepreneurship, marine and ocean economics, and the like (Romer 1990). Enormous trade-offs prevail. The "melting" mentioned above and its concomitant "lightening" of GDPs through information inputs are only partial. Agglomerations, clusters, and heavy industries continue to exist, in part due to inertia and economic demands, but in larger part due to increasing returns to clusters. Goods production has globally grown considerably whereas the global number of jobs in manufacturing has declined by more than 20 million between 1997 and 2002, Colvin 2003." (End of citation).

The RGM-model therefore has, for each region, a new sector and a mature sector. ISIS-models for regional development (Grossmann 2002, and Grossmann et al, under revision), have manifold relationships between mature and new sectors, which allows an extension of the RGM-model.

5. A Three-Region Approach to Global Modeling

The speed and transformative power of innovation is very different for different parts of the globe. The developed, rich countries see, although they are highly developed, a massive transformation of their economies. This is Region I in the RGM-model; the number of inhabitants of Region I is at present 1 billion people. There is a second group of countries, those which are less developed but are developing more or less rapidly. This is Region II in our model, with 4 billion people. For some of them, development has recently accelerated. China is an obvious example, with its continued economic growth rates of 10% - 12%, or India with growth rates of 8% - 10%. For these rapidly developing countries the changes are even more pronounced and faster than for the rich countries. Unfortunately, not all countries belong to these two categories. There is a cumbersome third group, those, which are not really developing, constituting Region III, with 1 billion people. Any realistic modeling of innovation, therefore, needs at least these three regions. Each of the three regions in RGM has two sets of equations describing mature industry and new economy, with three landscapes each.

6. Policy Section of the RGM-Model

Before navigating the detailed and painstaking research path to realistic policies, RGM strategy entails realm specific master policies to test the efficacy of possible bundles of realistic or applied policies. RGM's master policies are simple, not realistic, with parameters not specified in advance. Nevertheless, they provide a transition to an analysis of the possible effects of realistic bundles of policies. If we find suitable master policies or combinations of master policies, defined in terms of the realms in which they are active, by their strength, beginning and duration of policy influence, then work can begin to devise realistic bundles of policies. This may include optimization of the model as done for policy development with one ISIS model by B. Grossmann 2002. These realistic bundles would induce the same effect with respect to strength of influence, but would have the added benefit of being capable of implementation. RGM has a proven record of devising bundles of realistic policies. Examples of policies that worked in actual applications appear in a sub-sector of RGM. The policy section of RGM shows typical policies for all three landscapes.

Figure 3 shows policies of major importance with respect to quality of life. There seem to be both, policies of almost global relevance and applicability and policies which are a must for specific regions but with little global appeal. That is why bundles of policies have to be composed individually for each region. Learning is possible, but not all lessons learned apply everywhere. Figure 3 gives examples which, in a suitable combination, hopefully allow to translate the master policy for quality of life for key people into reality. All issues in that figure have been carefully collected from applications by the authors as well as from successful development all over the world.

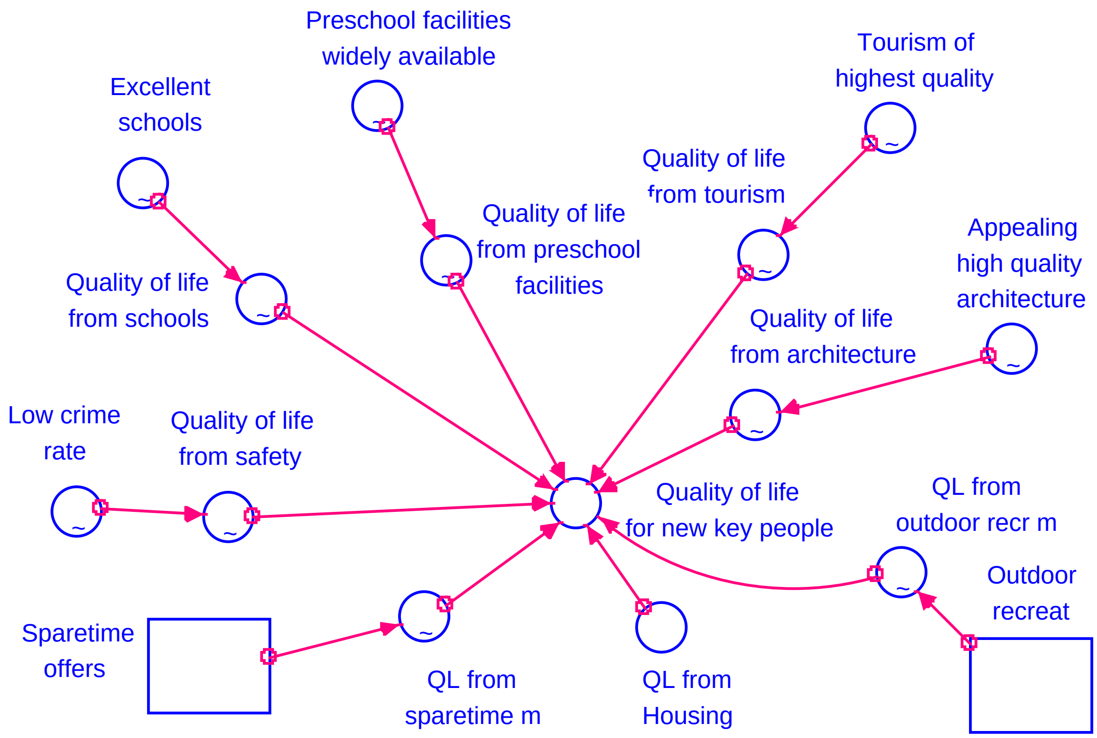


Figure 3: Example for realistic policies with additional input from Hamburg Chamber of Commerce 2003

Some issues, like quality of life from architecture, are indicators for other, more profound characteristics of a region. The potential attractiveness of outstanding architecture was learned just recently through striking examples such as the new, famous museum in Bilbao which has become a magnet for visitors from all over the world. What is appealing for key people is usually as well appealing for the rest of the population; only that key people with their economic relevance can serve as a more convincing reason to increase quality of life. And what is attractive for visitors is often also attractive for the local population.

A major focus of policies is to enhance the efficacy and power of the three legs on which desired outcomes depend: key people, knowledge and the economy. In each case, individuals, often highly skilled, do the work involved. We know from experience that people must not only be trained, they must be kept happy. They must be able to participate in and benefit from the information society as well as enjoy an invigorating and restorative life style. Quality of life is important to attract and keep key people, but it does not breed new key people.

Hence, policies for the development of key people involve, first & foremost, training with new skills, and for different levels of skills. Key people might be further encouraged through interactive special interest groups, which policies can encourage. It is now clear that educated people demand an improved quality of life, in particular through highly developed arts sectors, leisure & outdoor recreation, and ecological revitalization of natural environments (Levitt, 2002, Grossmann et al 1997). Leisure (or sparetime, everything created, built, offered by people such as restaurants, museums, arts, exhibitions) and outdoor recreation (everything related to nature) seem to be, may be globally, the two most important issues in quality of life for new key people. However, keep in mind that young key people get older, have family and children and care for more things than just their amusement. That is why the health sector, schools, safety and so on may not be mentioned prominently in questionnaires but turn out to be highly important in reality. Usually, a good group of local experts can rapidly agree on the relative importance of the factors of quality of life in relation to each other. Finally, policies must encourage creativity, innovation and the entrepreneurial spirit. This begins with such down to earth issues as good availability of venture capital, a regional administration that is fast and supportive, clever laws for bankruptcy which do not punish the entrepreneur after a first failure with ineffectiveness for the rest of his or her life and so on, see Figure 4 and Figure 5.

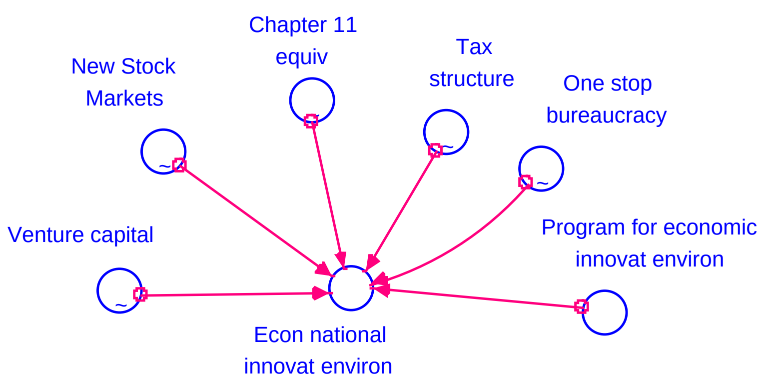


Figure 4. Factors that are important for new start-ups

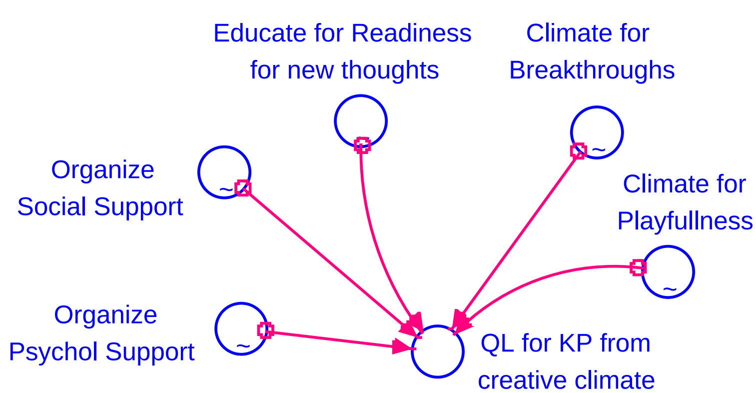


Figure 5. Factors that support creativeness

Policies must enable and facilitate the creation of knowledge, another of the three landscapes. Figure 5 addresses the creativity aspect of this landscape; the “support” in this figure is for creativeness. Institutionally, this involves the growth and nurturing of excellence in first class universities.

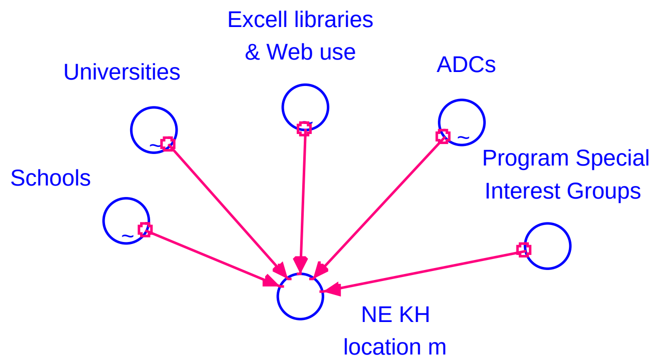


Figure 6. Factors that contribute to the generation of new knowledge, see text. ADC: Advanced development center. Web use: support people in advanced, sophisticated use of the Web.

We have been hesitant to provide Figure 6 because it may be misleading. We do not need the same old curricula all over again, and the same old research only now under a more fashionable heading. This is what seems to be done almost universally, when new curricula are called for; look just at the fate of System Dynamics with its difficulties in its very prolonged phase of fledgling. This figure looks pretty conventional and, to most people, reassuring. What is necessary is break-through knowledge how to do new things with "tons of information and light-years of networks" (Ruediger Warnke, a German consultant and leading thinker in management seminars). Additionally, a variety of enabling organizations, both government and private, would be needed to provide support for innovation, grants, official assistance. Equally important, however, is legislation which enables private, market oriented initiatives and disables excessive government interference and control.

Finally, policies to nurture the economy are vital. The government must provide a well-established rule of law, generally ensuring both economic and political freedom. Fewer laws are often better than more laws, thereby leaving creativeness to the intuition and decision of people and management of the economy mostly up to the market system. Nevertheless, the laws must be administered through a government judiciary. Furthermore, the tax code must be designed so as to minimize its discouraging and disrupting influences. Property rights, including intellectual property rights must be supported in the judicial system. There must be adequate and practical laws regarding bankruptcy. Policies should remove all impediments to the free flow of information and, in fact, help develop an information infrastructure which is cheap, good, fast, extended and evolving.

Another group of policies for the economy includes the locational factors of a region or city. Here again, for the new economy, attractive facilities for leisure, excellent universities, and a favorable natural environment are of highest importance. Also important is good access to specialized consulting, job training for the new economy, and market rents for office spaces. A regional intercontinental airport of high quality has also become a major support for high-tech companies.

7. Modeling policies

Policies for the economy increase or decrease the rate of investment by a factor, weighted by the importance of the policy. Policies for key people increase or decrease their training by a factor, and change the normal flux of key people moving to a region or leaving it, also by factors. Policies for knowledge creation accelerate learning and extend the scope of research. All of these factors are implemented in the model as multipliers, which increase the respective inflow into its state variable. The value of the multiplier depends on the power of the individual policy.

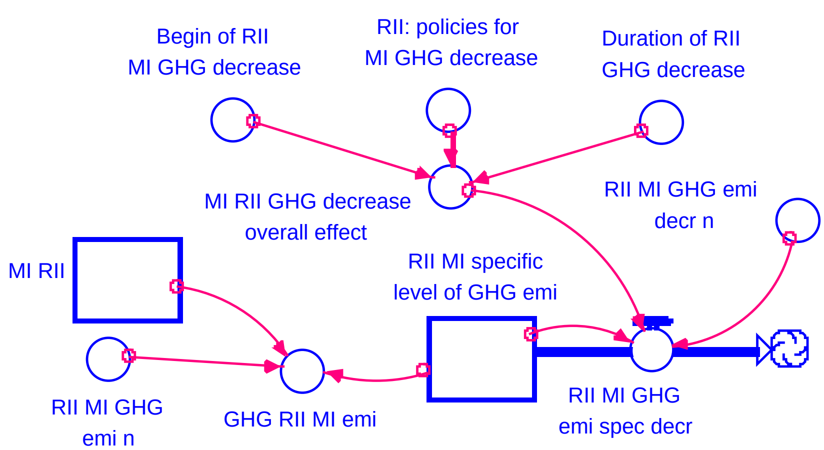
Almost all individual changes through a specific realistic policy are small (see e.g. Figure 9). Some policies are more powerful than others. The relative importance of policies is found through consultations with experts and from literature. The experts sort policies according to their relative importance and organize them by power. Amazingly, groups of experts from different fields often agree quite well on their ordering of policies.

This approach does not yet include costs of policies. Doing so might give a very different set.

8. Modelling of greenhouse gas emissions

Each emission rate is connected to an economic state variable, and is dependent on policies and technological progress. Figure 7 shows how policies, with a lag, decrease (or increase) emissions of GHGs, depending on the beginning, vigour and duration of the policy.

Figure 7: Emissions are caused by the economy in a region; here mature industries, Region II. Emissions are changed by investments in technology.



Explanation of Figure 7: Total emissions of mature industry in this region (here Region II) are the product of the size of the mature industry (MI RII) times the specific emissions per capital unit (RII MI specific level of GHG emissions). The specific emissions are subject to policies with the total effect given by the variable “MI RII GHG decrease overall effect”.

The model run shown in Figure 8 gives overall global economic development (curve 1), resulting from realistic, albeit different, economic growth rates for each of the three global regions, and the resulting emissions of GHGs in tons. Here, economy and emissions are closely related (no decoupling) as the assumption is that modernization does not much decrease specific emissions (which is too cautious and not realistic), and no policies are used. The assumptions underlying economic development are similar to those of the SRES A2 scenario and the resulting curve of emissions is also very similar to that of SRES A2. At a 3% average global economic growth rate, a 1% decrease in specific emissions in the model gives the typical upper range of SRES-scenarios, Figure 8 (compare with Metz et al. 2001, figure SPM.1, lower left, SPM-1d IPCC SRES A2 Scenarios – please note that they use gigatons C in their scaling instead of tons as in Figure 8). The group of ISIS-models might therefore become useful in exploring SRES-scenarios with the aim of benefiting from economic innovation.

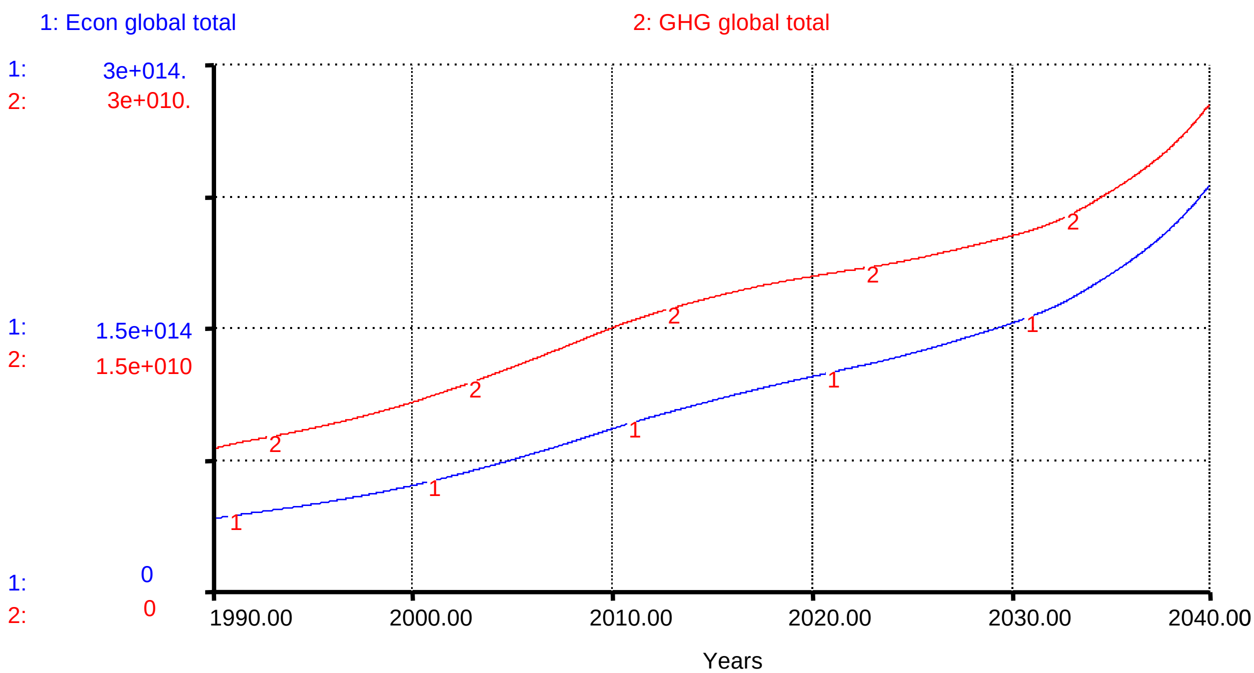


Figure 8: Economic global development and total emission of GHGs (in tons C-equivalent).

The model run in Figure 9 shows the rather low effect of isolated policies on economic development (curve 2 compared to curve 1 which is the development without such policies), and the remarkable effect of bundles of policies (curve 3). According to everything we have learned in our economic regional studies such a positive outcome should be possible, and we have seen it in a practical application. (However, rather systematic efforts by other, highly advanced, groups did not give comparable effects. We compare such policies with education of a young person: a good education puts him or her into a better position for a good career, but does not guarantee it.)

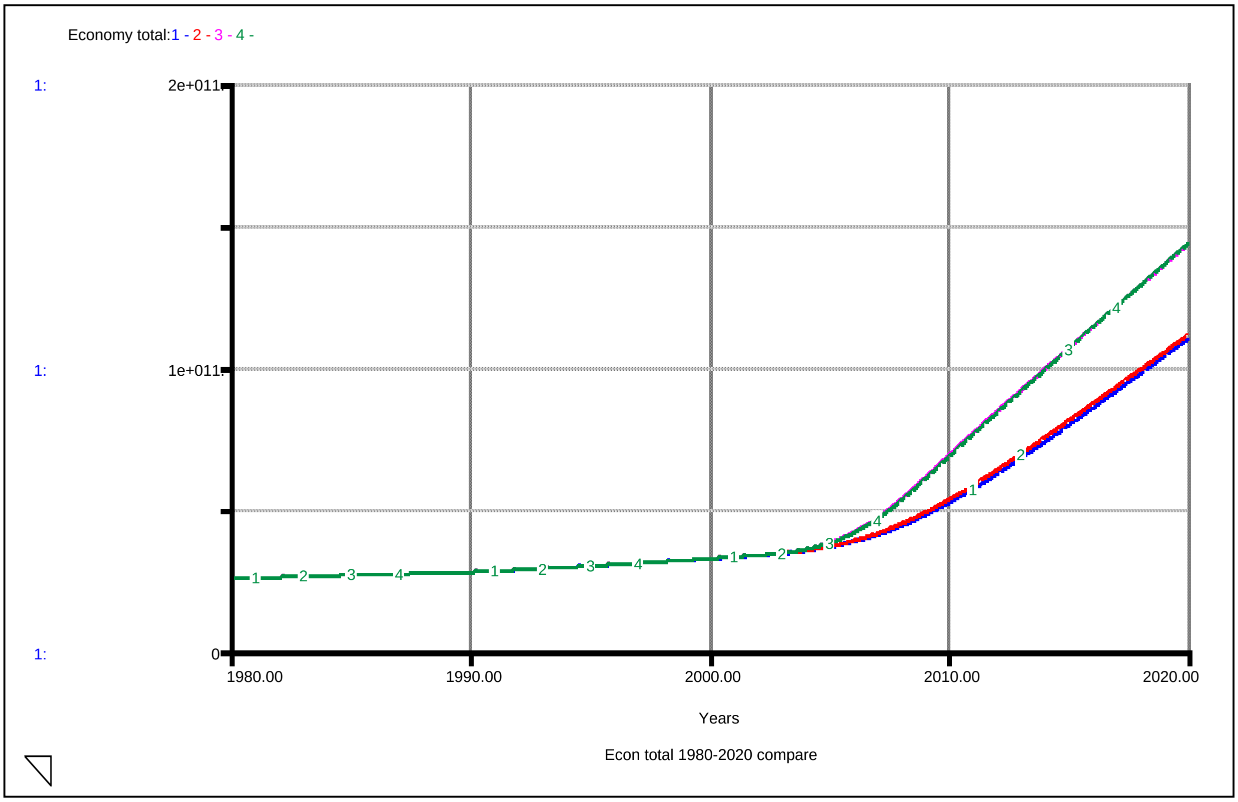


Figure 9: Visible effect of training of new key people on economic development

1: Base run – no policies
2: Isolated policy - little effect on growth
3: Bundle of policies from all four landscaped improves economic growth
4: Bundle as in 3 plus innovation policies against GHGs – no negative effect on growth

Curve 4 is most interesting, as it comes from a the same bundle of policies as in curve 3 plus **innovation** policies against GHGs which use ongoing investments. These policies have no visible negative effect on growth. Figure 10 shows the effect of these four innovation policies on emissions of GHGs. In curves 1 and 2 the emissions increase more or less in parallel with economic growth, because there is just the 1% specific decrease in emissions of GHGs, similar to the past development. Curve 3 shows a considerable increase in emissions, whereas curve 4 shows the impact on emissions of GHGs of an economic innovation that also aims at decrease of emissions. Much could be achieved in a short period of time with little additional costs, both for the economy and the issue of climate change.

In another study we could show that regional policies can simultaneously increase economic growth and achieve adaptation to climate change with the net result of an economic gain (Grossmann et al. 2003). Other authors report similar results, e.g. Metz et al. 2001, Lovins et al. 1997. Once we have more results on such policies we will use RGM to determine their effect on economic growth and emissions of GHGs in a global scale.

9. Integrated Policies for Implementable, Effective Solutions

In model runs for the city of Hamburg with an extended version of ISIS for regional analysis we analyzed the effect of training key people (or of acquiring more key people) on economic growth. This training accelerates economic growth in theory, but, unfortunately, not in the long run. As mentioned above, such increase of the number of new key people causes increased competition for housing, which, in turn, increases out-migration. We did not expect this result. In our model run, we proceeded assuming the received wisdom of regional economics that key people will be paid well enough to face increases in rents. This ability to pay, however, does not exist in the early phases of the development of a new basic innovation, because in those phases these new key people need a very large portion of their money to feed their new inventions and new businesses. Indeed, the city of Hamburg has seen a temporary increase in new key people, with an ensuing high loss of start-ups to other cities due to the high rents in Hamburg. This version of ISIS enabled us to shed perception blocking misinformation about events transpiring around us in Hamburg, things that actually did happen, and to read the newspaper accounts with greater critical skill. Models are good for such learning.

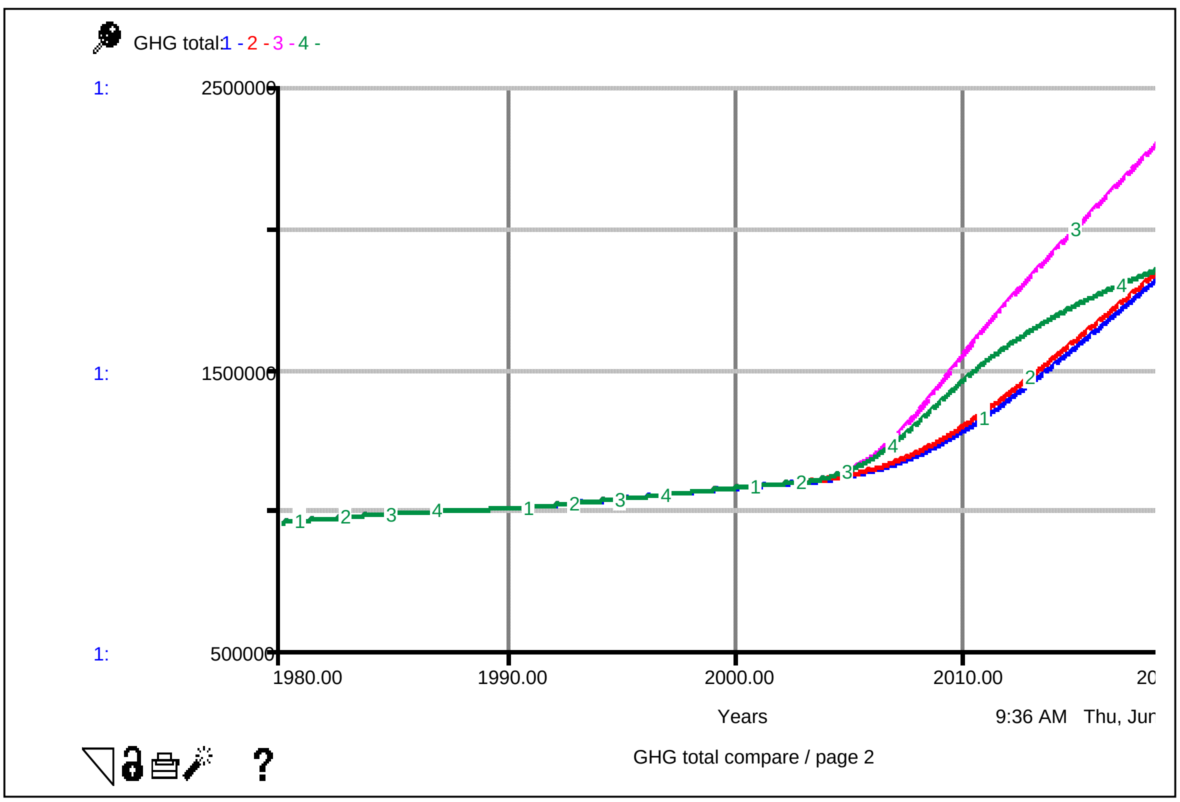


Figure 10: Shown are emissions of GHGs (index) for the policies shown in figure 9

1: Base run
2: Isolated policy - little effect
3: Bundle of policies for economic growth: Much higher emissions of GHGs
4: Bundle as in 3 plus policies against GHGs - decrease through ongoing innovation

As we want to use increased innovation for decreased emissions, by emphasis on a new economy with lower specific emission rates, we need a tool for integrated policy assessment. One reason for decrease of emissions could stem from an ongoing global competition between mature industries and the new economy for the purchasing power (or income) of regions. As the products of the information-intensive economy develop in sophistication and attractiveness, they, increasingly, outcompete products which are less information-rich. The production level of material goods declines, relatively, toward an unknown minimum, although it most likely will continue to increase in absolute terms. It is possible that material goods may end up like agriculture, which in many developed countries overfeeds the people yet accounts for little more than 1% of Gross Domestic Product. Even if the relative share of material goods drops to as little as 5% of GDP, this still may mean dramatic emissions. From a viewpoint of GHG-emissions, this relative share is considerably better than present levels of about 20%. Clearly, this competition between information products and material goods, is highly relevant for mitigation.

As mentioned above, economic development is very sensitive to the availability of key people. This is shown for three different rates of availability in Figure 11. The model's sensitivity is highly welcome as it corresponds to reality.

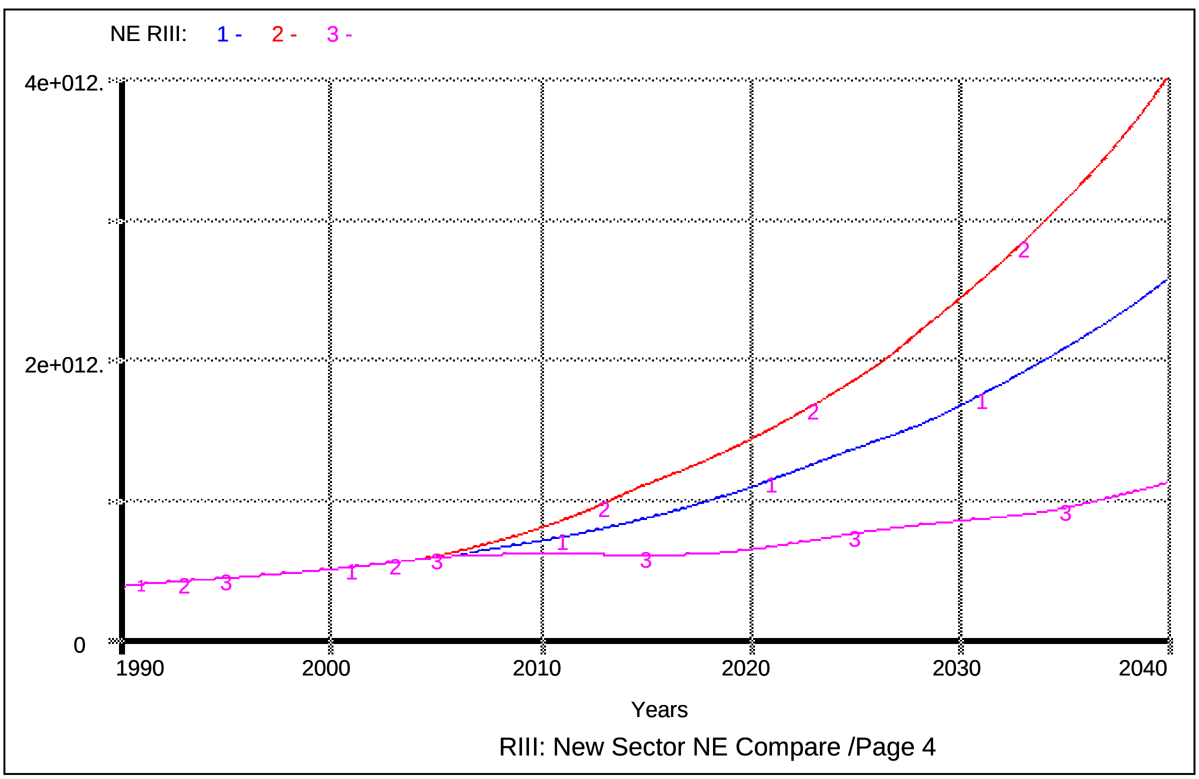


Figure 11: Economic development of Region III with different availability of new key people. Curve 1: standard run; no policies. Curve 2: additional extensive training. Curve 3 might be closest to reality as many key people migrate from Region III to Region I.

10. Outlook

We have embarked on an ambitious project to build a tool for integrated policy development for mitigation through innovation. This involves a family of fairly complex simulation models, actual applications and consulting, and is bringing together an interdisciplinary group of researchers from the US, Asia and Europe.

We use the present prototype for testing the importance of different hypotheses. The prototype serves as a reference model to see what various refinements in elaborated models will bring. If refinements are simply cosmetic and make little difference, we keep the models simple by not including them in final versions, of course with appropriate documentation.

Some model runs were disappointing in that the most well-intended sets of policies for mitigation were, in the long run, overrun by economic growth. This occurred in spite of our use of the most environmentally benign technology, with almost total dematerialization and resulting low specific, but not absolute, emissions of GHGs.

Model development for realistic estimates of costs will be done with the final model. We expect, as in an application of ISIS-models to the problem area of adaptation (Grossmann et al. under revision), that effective innovation policies will be possible which provide considerable economic gains and, simultaneously, curb emissions.

The development of these effective innovation policies would help to overcome the present political battle, a highly detrimental struggle given grave risks due to climate change. Effective policies must integrate very different sectors, which complicates the elaboration and assessment of such policies. Assessment needs an effective tool set, which then can help in integration over disciplines and administrative courts. The systems model RGM is a piece in this emerging tool set.

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