Industrial transformation towards sustainability of the energy system

Pier Vellinga

Institute for Environmental Studies (IVM)/Vrije Universiteit, De Boelelaan 1115, 1081 HV Amsterdam, The Netherlands
E-mail: pier.vellinga@ivm.vu.nl

Human induced climate change is one of the single most significant indicators that human society is not pursuing a sustainable trajectory. Managing the risks requires a major transformation of the way energy needs are met. Such a transformation includes changes in the production and consumption system and the incentive structure that shapes this system. The major driving force for transformation is the public concern about the environmental impact of the present fossil fuel based energy system. We may expect that energy producers, encouraged by governments, NGOs and consumer preferences will be responding to these concerns and expectations sooner or later. In fact a number of major international energy companies are presently adjusting their strategies to the needs and concerns of the public. A mix of measures including energy efficiency, a switch to natural gas, major investments in low carbon and renewable energy technologies and underground storage of carbon are elements of such new strategies. Consumers in a number of OECD countries have expressed their willingness to pay more for energy, provided it is green and clean. NGOs continue to put pressure on governments to deal with the climate problem. The challenge for governments is to develop an institutional framework that helps the producers and consumers to go through a transformation of the energy system. As different groups in society are likely to support different strategies, this paper suggests that a pluralistic policy approach including efficiency standards, renewable energy portfolio standards, carbon taxes, and the introduction of a system of tradable emission permits is the most promising approach for a transformation towards a low carbon energy economy. Research can support a transformation of the energy system by exploring the various transformation scenarios. Such research should take a multi-disciplinary approach, it should focus on the energy system as a whole, including production, consumption and the incentive structure that shapes the interaction between the two and it should be international in scope.

Keywords: industrial transformation, energy sector, climate change policies, carbon dioxide, energy efficiency, carbon sequestration, renewable energy, incentive structure, production, consumption

1. Economic development and resource use

The relation between economic growth and pressures on the environment is often illustrated as in figure 1. As a country develops from a mainly agricultural economy to an industrialised economy its GDP grows, while simultaneously the use of environmental resources and pollution increases as indicated in the left hand side of the bell-shaped graph of figure 1.

Industrialised countries have followed the upward path of the graph of figure 1 until about 1970. At that time the signals of environmental degradation became very visible, such as the pollution of water (fish kills), air (visibility and effects on human health) and soils (pesticides and dumping of toxic wastes). Meanwhile, the primary societal needs such as water, food, infrastructure and housing had been met and, even more important, human, financial and technical resources were available to redesign industrial processes and to clean up some of the most polluted industrial sites. The idea that the developed countries will continue to move downward along the right hand side of the bell shaped graph in figure 1 (de-coupling of economic growth and environmental resource use) is based on the hypothesis that a services and information economy will use fewer environmental resources and will consume fewer materials.

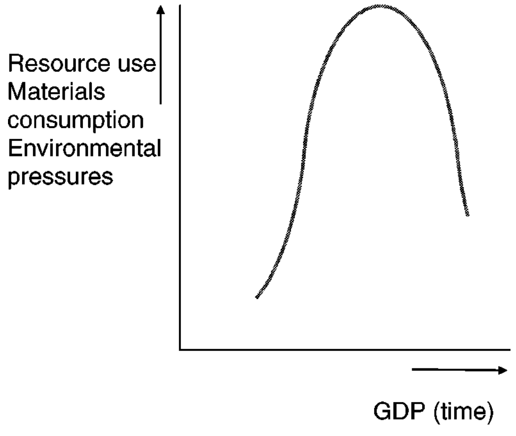

Figure 1. Environmental Kuznets-curve hypothesis.

However, recent economic analysis indicates that such a de-coupling is not a generic feature of present day economic development in OECD countries. It may become true for a number of environmental problems such as heavy metals, pesticides and toxic wastes that can be solved with end-of-pipe and process technology. For some of the other environmental problems, especially the global environmental problems, the hypothesis of growing economies with decreasing resource use is not confirmed by the data of the OECD countries (De Bruyn [1] and Cleveland and Ruth [3]). In fact, the OECD countries data of the 1990s suggest a tendency towards a re-coupling after some de-coupling in the 1970s, as illustrated in figure 2.

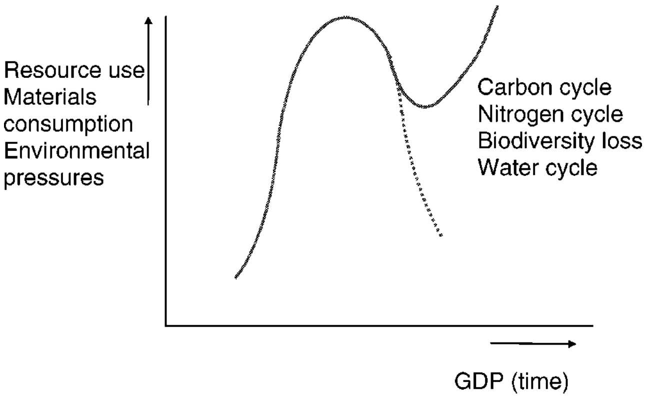

Figure 2. De-coupling (downward curve) and re-coupling (upward curve) between economic growth and resource use in OECD countries, in particular for those resources leading to global environmental change.

The re-coupling suggests that eco-efficiency increases do not keep up with economic growth. An important explanation may be the fact that cost of mining, producing and using (natural) resources has decreased over the last few decades as a result of technological and institutional development. The historically low prices of fossil fuels, iron ore and fertiliser in the 1990s as compared to the 1970s, may be responsible for a slowdown of "autonomous" efficiency increases. Another important factor is the geographic relocation of resource intensive industrial activities to developing countries. The re-coupling tendency would become more visible when resource use would be accounted for on the basis of consumption (including resources embedded in imported products).

The re-coupling (or continued coupling) between resource use and economic growth is particularly apparent for those environmental problems that are related to the major bio-geochemical cycles that operate on global and continental scales, such as the carbon cycle and the related problem of climate change and the nitrogen cycle and the related problems of land degradation and eutrofication of lakes and coastal seas. Similar challenges are faced with the use of water and space. Stopping human induced loss of biodiversity presents an unprecedented challenge, because growing economies show a very strong tendency to use more water and more space for economic activities at home as well as abroad at the expense of habitats for wildlife.

From a natural sciences point of view, these global environmental problems can be described in terms of the challenge to understand and manage flows of carbon, nitrogen and water, and the challenge to use biodiversity and land in a sustainable manner. From a social sciences perspective, global environmental issues can be seen as problems directly related to society through the ways in which human needs and preferences are met in the following four domains: energy, food, land and water. These domains can also be grouped as nutrition (food and water), habitation (energy, housing, working), health (human and ecosystem) and communication and transport (people, resources and materials).

The challenge for society in the early part of the 21st century is to de-couple the ways in which the growing societal needs and aspirations are met from their environmental impact, i.e., de-linking economic growth from environmental degradation (or at least significantly loosen the historic coupling between the two). This cannot be fixed with add-on technology measures. A re-examination of needs and social preferences is a necessary starting point. In parallel the technical and institutional setting should be reconsidered. Before entering this field it is useful to take a historical perspective on the evolution of ways in which society has addressed environmental problems. This requires a major transformation of the ways in which societal needs and preferences, such as energy and food are met.

2. Evolution of society–environment interaction

Human history can be characterised as an evolution marked by changes in the interaction of people and their environment. On the time-scale of centuries one recognises the hunter and gatherers, the agricultural, the industrial and the upcoming information age.

Considering the industrial age and the societal response to the problems of the environment on the time-scale of decades one can recognise a number of overlapping stages. As a response to the rapid industrialisation after World War 2, the environmental issues became quite visible in the 1960s. Since that time we can distinguish a series of societal responses that can be characterised as end-of-pipe, process oriented, product oriented and system oriented (see figure 3).

When we consider the way in which energy needs are met, we can recognise the end-of-pipe mode with scrubbers and catalytic converters; the process mode emphasising energy efficiency such as lean burn motors and co-generation; the constructive mode focusing on new products using much less energy (e.g., the hybrid car and membrane technology in chemical industry and refineries) and ultimately the pro-active approach focusing on ways to meet energy needs with "zero emissions", such as renewable energies and hydrogen-based fuel cells.

The latter phases with focus on products and systems (see figure 3) involve more than producers and governments. Actually consumers and society as a whole are likely to become the major players in guiding producers and governments.

The stage model presented in figure 3 should not be seen as a static approach; the stage model is dynamic and the phases have no strict borders. It is difficult to say that a company, community or a country is in a specific phase of development, but only that it shows signs of a development phase (Winsemius and Guntram [8]).

Two other examples of the response phases can further help to illustrate the difference in response phases to environmental problems (Vellinga [7]). The first is about the way port authorities address the environmental aspects of

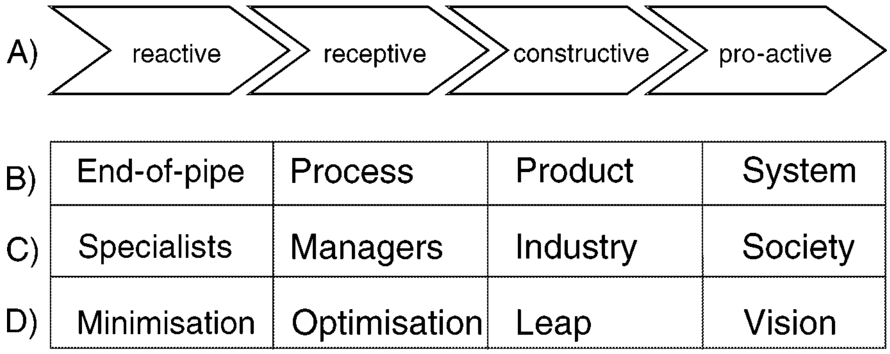

Figure 3. Development stages in environmental policy planning (Winsemius and Guntram [8]). (A) response phase, (B) focus of attention, (C) main actors and (D) driving philosophy.

dredging. In the *reactive phase*, the general attitude is: "it is not really contaminated", or "...the pollutants are not really hazardous to our health or to our ecosystems, but if required we will take some measures".

In the *receptive phase*, the reaction is: "OK, if we have to do it, let's be smart about it: we will optimise dredging and define several classes of pollution. Let's use screens in the water during dredging activities to avoid leakage. Dig a hole for storage or create special storage basins". All are rather costly solutions. In the *constructive phase*, the aim is recycling and re-use of dredged spoil for brick making or a similar industrial activity, and separating the contaminants from the sediments. New techniques for dredging of contaminated material are developed and regulations tend to encourage the industrial approaches such as "burn it or clean it". Finally, in the *pro-active phase*, the attitude has changed into: "Reduce at source and make the producers of the contamination liable (let them pay for your problems – they are their problems); join the environmental movement in the London Convention".[1] In this phase new coalitions develop, such as a coalition of Port Authorities and Environmental NGOs.

A second example is about the insurance sector's response to environmental issues. Insurance companies initially responded to the environmental issues in a reactive mode. Denial, followed by important losses such as with the asbestos cases, and the fights between the insurance industry and oil companies about the costs of cleaning the oil spills caused by the tanker accidents made the insurance companies move into the next phase. In the *receptive phase*, arguments about liability come forward: is it negligence by the company, or is it covered by the insurance policy? In this stage the company managers feel responsible for the environmental aspects of insurance contracts. Some companies have recently entered the *constructive phase*: they develop insurance concepts, and reconsider the whole arrangement of accident insurance, life insurance and re-insurance. In the years to come insurance companies are likely to enter the *pro-active phase*: instead of selling cover for damage, they will sell risk management and security. In co-operation with industrial sectors they will analyse vulnerability and will propose measures to reduce vulnerability. Insurance cover is then much stronger related to other measures to manage the risks.

The development stage model and the examples presented above illustrate that environmental policy is moving from policy driven by constraints to policy driven by opportunities, moving from technical add-on measures to a development driven by visions about the future. Attention is moving from end-of-pipe and process towards products and systems. In fact environmental issues are about transformation of the way societal needs are met.

2.1. Industrial transformation, time scale and geographic scales

Industrial transformation goes beyond the notion of "green" products and beyond the domain of single sectors. It is about system innovation (see figure 3). Different sectors are likely to get involved simultaneously. Moreover, industrial transformation cannot be planned by a single actor, it requires the engagement of society as a whole.

Moreover, transformation takes time, in the order of decades, and involves geographic scales that go beyond a single country or a single continent. In figure 4 the relation between the various response modes and the time-scale and geographic scale involved is tentatively illustrated.

The food, energy, and information systems are globalised, yet they are also deeply embedded in local cultures and legislation. Consequently, transformation of such systems will take time. Transformation may well start at the local level triggered by local initiatives. However, to succeed in the long run as a new way of meeting primary needs and preferences, it will have to be accepted and adopted at larger geographic scales.

[1] The London Convention: Convention on the prevention of marine pollution by dumping of wastes and other matter (London, 29 December 1972).

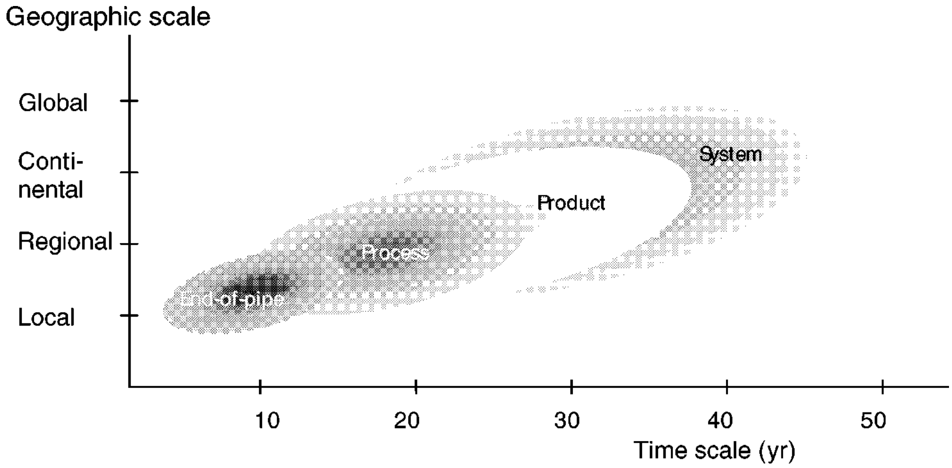

Figure 4. Societal responses to the issue of environment, scales in time and space.

3. Multi-disciplinary approaches to industrial transformation

The preceding sections illustrate the evolution of the relation between economic development and environmental resource use. Since the environmental effects of economic growth became increasingly visible in the 1970s, significant progress in environmental resource use efficiency has been made. First through end-of-pipe measures followed by process efficiency measures. Both these types of measures could be introduced through government regulations and producers actions. The next step, adjusting the product and seeking new market opportunities, requires the involvement of the sector and the buyers of the product, the consumers. When adjusting the product (for example the car) it is not enough to meet the longer-term environmental goals: the (transport) system as a whole (infrastructure, fuels and vehicles) needs to be reconsidered. This takes longer and it requires a vision (or competing visions and competing systems) about the future. This implies that society as a whole is taking part in the shaping of a new system. When the goal of research is exploration of different transformation scenarios towards a future with a significantly smaller burden on the environment, then such research should include the consumers, the producers and the institutional perspective. As such it should take a system approach and it should be multi-disciplinary in scope.

To illustrate that a single disciplinary approach is inadequate, a number of traditional disciplinary approaches are described below. In a slightly caricatured way a number of different approaches can be described as the “economist approach”, the “technologist approach”, and the “behaviour approach”.

The *economists* tend to consider environmental overexploitation as a problem of an inefficient allocation of (common) goods and ecosystem services and/or as a matter of imperfect markets in which the prices do not reflect the value of the goods and services provided by nature. The solution according to this frame of analysis is to get the prices right (internalisation of external cost) and to get the ownership/liability right. The market mechanisms will subsequently ensure an efficient allocation of the use of environmental resources. Major challenges for this approach are how to deal with equity issues (intergenerational and intra-generational) and how to deal with the relevance of institutional arrangements and technology dynamics.

The *technologists* tend to view the environmental problems as a challenge and a trigger for technological innovation. Underutilization of scientific, technological and managerial knowledge and irrational societal perceptions regarding promising technologies are seen as the main reason why environmental problems are not adequately addressed. According to this view, more investment is required in research and development. Government regulations should subsequently help to get the best technologies in the market. Major conceptual challenges for this approach are threefold. One is the fact that earlier technological innovations have paved the way for present day over-utilisation of environmental resources. The second challenge is how to overcome the rebound effect: technological innovations and related price reductions per unit of service encourage the consumer to use more. The third challenge is the role of the market, consumer preferences and societal acceptance as a hurdle for the introduction of more efficient technologies.

Behaviour-oriented approaches toward the issue of global environmental change cannot be easily captured in a single paradigm. Some approaches focus on individual responsibility and choice and refer to the commons dilemma. “Sufficiency” and the “irrationality of consumerism” are value concepts introduced in the societal debate. More recent approaches focus on the interdependency between producers and consumers and the cultural, institutional and infrastructural setting as determinants for consumer choice. Important challenges for the behaviour-oriented approach are the differences between people as consumers, as producers and as citizens (civil society).

The approaches described above are for illustrative purposes only. They may be slightly caricatured, they are certainly not meant to be comprehensive. Besides the approaches mentioned, one could add a political sciences perspective and historians' and geographers' approaches. Completeness, however, is not the goal of these descriptions. They are presented to illustrate the need to bring the disciplinary approaches together when it comes to the exploration of transformation scenarios.

An example of why the different approaches need to be explored simultaneously is the development and broad scale introduction of renewable energies: a number of energy technology firms and a number of energy producers have started to invest in the development of renewable energies. However, renewable energies will not be able to compete in the existing market characterised by a technological, infrastructural and institutional (fossil fuel) lock-in and an abundance of low cost fossil fuel energy (fossil fuel reserves are estimated to be much larger than ever before, see Nakicenovic et al. [9]). Consumer preferences and adjustments of incentives such as taxes and/or environmental costing systems are crucial factors for the development of a long-term market for renewable energies. Thus research in consumer preferences, exploration of and experimentation with incentive structures and (international) institutions are as important as technological research and development. International co-operation across the different research, policy, and private sector communities and mutual inspiration are equally important factors for useful research. As indicated in figure 3, transformation research is research about system change, and system changes require an understanding of the interaction between technological change and societal change.

3.1. Multi-disciplinary co-operation in a system approach

To provide a framework for the co-operation required between various disciplines, a matrix was developed as indicated below. The horizontal rows reflect the more or less disciplinary research fields that each have a certain tradition (outlined in the Industrial Transformation Science Plan [4]), while the vertical columns describe the systems considered relevant for global environmental change.

Systems in the framework of industrial transformation research are defined as a chain of interrelated economic activities aimed at providing a specific need for society (e.g., energy and food). Such a system includes: the actors (government, producers and consumers), the flow of goods and/or services they deal with (including the metabolism along the chain) and the overall physical and institutional setting in which they operate.

In transformation research, the column representing the system should be the object of research while this system should be explored from the three horizontally listed perspectives simultaneously.

System changes in the past have occurred as a result of scientific and technological developments that, through their progressive adoption, came to replace existing systems (for example, the steam engine and in a later stage information technology). System changes have also occurred as a result of technical and institutional innovation inspired by societal problems (for example, the green revolution driven by the concern about food shortages), or as a result of colonisation processes. Usually system changes are driven by a combination of specific societal aspirations and/or concerns and economic/technological opportunities. System changes come about quickly when such aspirations, concerns and opportunities are mutually reinforcing.

4. Transformation of the energy system

4.1. Introduction

To explore the ways in which energy needs can be met in a way that does not cause serious and/or irreversible environmental degradation it is important to consider the three perspectives as indicated in the matrix of figure 5. This section first addresses the consumer's perspective, followed by the producer's perspective and the government's perspective (incentives).

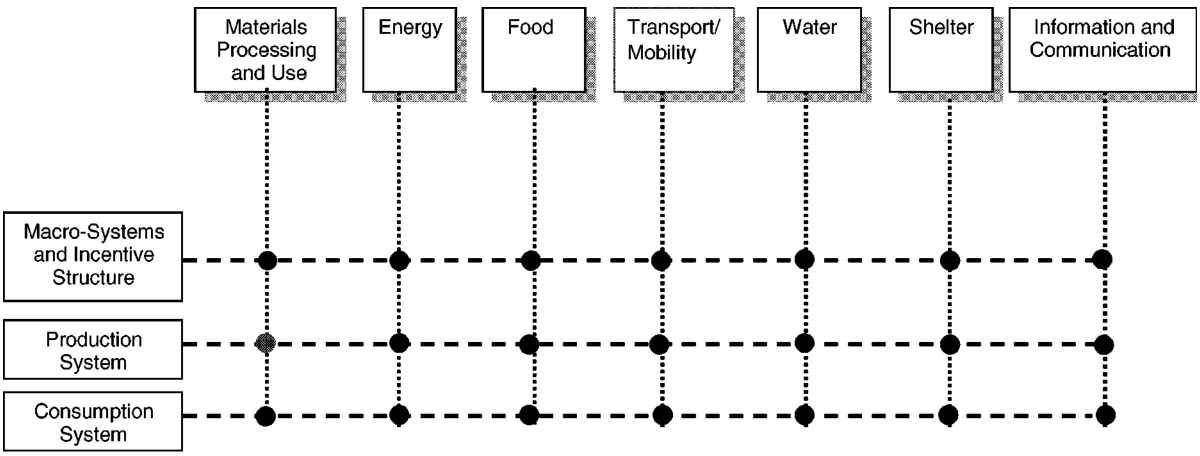

Figure 5. Tentative framework for industrial transformation research with research fields/disciplinary approaches on the horizontal rows and human needs/activities in the vertical columns. The "needs" (verticals) should simultaneously be explored from all three perspectives (horizontals).

4.2. Consumers

With growing economic prosperity and increasing access to information, individualism and consumerism have become important characteristics of present day societies in the OECD countries. For environmentalists this has raised concern as they expect consumerism to generate an ever-increasing exploitation of environmental resources. However, economic prosperity has also generated awareness and concern about the environment. Surveys indicate that the general public considers sustainability as an overarching condition for production (Steg [6]). The survey results also indicate that the general public is not really willing to make sacrifices in terms of lifestyle changes. They expect producers and government to assure that the products and services introduced in the market do not cause serious and/or irreversible damage to the planet. There are also clear demonstrations that people are willing to pay more when there is assurance that the products or energy purchased is environment friendly. Especially in Northwestern Europe consumers are supporting NGOs and political parties that advocate the introduction of more sustainable energy systems even if this is more costly. Relative cost increase in turn will affect lifestyles.

The response of energy consuming companies depends on the intensity of energy use. The companies that have energy cost below 5% of sales are not demonstrating a significant response. However, energy intensive companies with higher energy cost percentages, such as the chemical and steel industry, do respond more readily. They systematically explore and exploit opportunities for energy efficiency increases. However, in view of the rebound effect (as mentioned in section 3 under the "technology approach") efficiency measures will not be enough to meet long-term sustainability criteria.

4.3. Producers

A number of energy production companies (including oil companies) do respond to the public concerns about the environment. Their response is not only driven by short-term profit considerations: employers' and customers' satisfaction, and considerations such as "licence to produce" are becoming equally important factors.

The ways in which companies respond depend on their position in the energy chain and their capacities to respond to changing societal concerns and preferences. Below, the options for the energy demand and supply side are listed as indicated in the IPCC Second Assessment Report, Climate Change [5].

4.3.1. Energy demand

According to the energy experts as reflected in the IPCC [5] report: "Numerous studies have indicated that 10–30% energy efficiency gains above present levels are feasible at negative to zero cost in each of the sectors in many parts of the world through technical conservation measures and improved management practices over the next two to three decades. Using technologies that presently yield the highest output of energy services for a given input of energy, efficiency gains of 50–60% would be technically feasible in many countries over the same time period. Achieving these potentials will depend on future cost reductions, the rate of development and implementation of new technologies, financing and technology transfer, as well as measures to overcome a variety of non-technical barriers". (IPCC [5]; Synthesis reports and underlying documents.)

4.3.2. Energy supply

This IPCC report also indicates that: "It is technically possible to realise deep emission reductions in the energy supply sector within 50–100 years using alternative strategies, in step with the normal timing of investments to replace infrastructure and equipment as it wears out or becomes obsolete. Promising approaches, not ordered according to priority, include:

(a) Greenhouse gas reductions in the use of fossil fuels:

- more-efficient conversion of fossil fuels (e.g., combined heat and power production and more-efficient generation of electricity);
- switching to low-carbon fossil fuels and suppressing emissions (switching from coal to oil or natural gas, and from oil to natural gas);
- decarbonization of flue gases and fuels and carbon dioxide storage (e.g., removal and storage of CO_2 from the use of fossil fuel feedstocks to make hydrogen-rich fuels);
- reducing fugitive emissions, especially of methane, in fuel extraction and distribution.

(b) Switching to non-fossil fuel sources of energy:

- switching to renewable sources of energy (e.g., solar, biomass, wind, hydro and geothermal);
- switching to nuclear energy (if generally acceptable responses can be found to concerns such as about reactor safety, radioactive-waste transport and disposal, and nuclear proliferation)."

4.4. Incentive structure

The most appropriate approach to manage and reduce the flow of carbon to the atmosphere would be a global system of tradable CO_2 emission permits. This way the environmental resource (air as a sink for CO_2) could be introduced in the market system just like other commodities (see, for example, Chichilnisky and Heal (1995) and also Bromley [2]). The challenge, however, is to set up such a pseudo-market and get agreement about the allocation of rights. Trading between countries as envisaged under the Kyoto Protocol could be a start. The next step would be liberalisation and privatisation of emission permits and open market tradings. However, the need to consider the international trade implications for energy intensive materials will make the introduction of an international private sector trading scheme rather complicated. It is likely to take another 10–20 years before agreement about and introduction at a global scale of such a system can be achieved.

Introduction of a tradable permit system will take time and it is not certain whether a CO_2-trading system is the best in all cases. Green taxes as a way to reduce income taxes may also be a promising approach as there are fiscal policy benefits that go beyond CO_2 management that may well be attractive. Moreover, a fiscal system can be introduced in incremental steps.

Renewable energy portfolio standards is an effective way to create a market for renewable energy generation. Energy distributors or energy producers could be regulated to bring a certain minimum, but over time increasing, percentage of energy to the market in the form of renewable energy. Flexibility and efficiency could be introduced by trading. A number of governments in Europe are presently exploring this system.

For some sectors pricing will not have much effect on the efficiency of energy use. Appliances, buildings, cars, trucks, and aeroplanes, for example, could probably best be made more efficient through the introduction of energy efficiency standards and/or fleet requirements. For some of these products there are only a limited number of producers that operate on a global scale. It may be relatively efficient to reach agreement at a global level by putting pressure on these key producers.

5. Pluralistic approach

The preceding text illustrates that there are many options within an overall transformation process. As the different options are driven by different concerns and opportunities, the most promising strategy is to develop a portfolio of measures each with its own set of players and its own constituency. Some consumers and producers will favour energy efficiency. Others will favour a switch to natural gas, while still others will have an interest in renewable energies. None of them may be primarily driven by CO_2. Efficiency can be a technical and economic goal in itself. Natural gas is cleaner than any other fossil fuel and easier to handle. Renewables are intuitively attractive to many consumers apart from the CO_2 issue. Carbon storage/injection in existing oil and gas fields helps to recover oil and gas, more than would otherwise be the case. Injection in deep coalfields could help to release methane (as a source of energy) from these fields.

Because of the range of opportunities available, the best strategy for transformation is likely to be the introduction of a broad set of options that is mutually reinforcing or at least not mutually exclusive for the long term. In fact, all the mentioned options satisfy this criterion. A transformation scenario with interesting potential is the following. Over the long term, energy could be generated through solar PV with hydrogen as an energy carrier/buffer. Fossil fuel derived hydrogen with CO_2 underground storage could be a transitional technology, while increasing the share of natural gas in combination with energy efficiency increases could be the most promising short-term strategy. These three steps together would form a consistent and cost effective transformation scenario.

To exploit all opportunities and to respond to the broad range of views the most promising strategy is to shape/develop the incentive structure in such a way that as many options as possible are encouraged. Each will have its specific benefits apart from CO_2 emission limitation. It is expected that over time systems convergence will occur. The direction should be towards a significantly lower CO_2 intensity. The driving forces would be the generic societal drive towards efficient and environmentally compatible energy systems and not just CO_2.

In fact, industrial transformation towards a new way of meeting energy needs will only be successful when societal concerns and technological and economic opportunities are mutually reinforcing.

Research can support a transformation of the energy system by exploring the various transformation scenarios. Such research should take a multi-disciplinary approach, it should focus on the energy system as a whole, including production, consumption and the incentive structure that shapes the interaction between the two and it should be international in scope.

References

[1] S. de Bruyn, Dematerialisation and rematerialisation; Two sides of the same coin, in: *Managing a Material World: Perspectives in Industrial Ecology*, Environment & Policy, Vol. 13, eds. P. Vellinga, F. Berkhout and J. Gupta (Kluwer Academic, Dordrecht, 1998).

[2] D.W. Bromley, *Environment and Economy: Property Rights and Public Policy* (Oxford, Cambridge, 1991).

[3] C.J. Cleveland and M. Ruth, Indicators of dematerialization and the materials intensity of use, J. of Industrial Ecology 2 (1997) 15–51.

[4] Industrial Transformation Scientific Planing Committee, *Industrial Transformation Science Plan*, eds. P. Vellinga and N. Herb, IHDP Report no. 12, IHDP Secretariat Bonn (2000) (website: httm://www.vu.nl/ivm/hdp/hdp.htm).

[5] Intergovernmental Panel on Climate Change, *IPCC Second Assessment*, Climate Change, WMO/UNEP (1995) p. 12.

[6] L. Steg, *Verspilde Energie? Wat doen en laten Nederlanders voor het Milieu*, Sociaal Cultureel Planbureau, Den Haag, Cahier 156 (1999) p. 144.

[7] P. Vellinga, ed., *The Environment – a Multidisciplinary Concern* (Institute for Environmental Studies, Vrije Universiteit, Amsterdam, 1996) p. 531.

[8] P. Winsemius and U. Guntram, Responding to the Environmental Challenge, Bussiness Horizons, Vol. 35(2), Indiana University Graduate School of Business (March–April 1992) pp. 12–20.

[9] N. Nakicenovic, A. Grübler and A. McDonald, Global Energy Perspectives (1998).