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Sustainability-oriented Innovation Systems

Towards Decoupling Economic Growth from Environmental Pressures?

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Preface

This paper was written by a research team of the German Development Institute / Deutsches Institut für Entwicklungspolitik (DIE). It was developed in the in the context of a project called "Sustainable Solutions through Research" and financed by the German Federal Ministry of Education and Research (BMBF). Without this funding, the conceptual work would not have been carried out and first empirical evidence on important aspects would not have been collected.

The paper sketches a research agenda linking innovation system research, environmental sustainability research, and development research. The authors are convinced that significant research needs to be done at this interface, research that is academically challenging and may at the same time help to adequately inform policy makers in a field essential to reconciling the economic, social and environmental dimensions of development. The paper will be followed by a series of publications that go deeper into a series of cases related to sustainability-oriented innovations in Brazil, China, India and South Africa.

The research group at the DIE is looking forward to receiving comments on the paper and is very interested in linking up with researchers and research groups working in the same or related fields.

Bonn, October 2009 Andreas Stamm

Contents

Boxes

Abbreviations

BMBF	Bundesministerium für Bildung und Forschung (German Federal Ministry of Education and Research)
DIE	Deutsches Institut für Entwicklungspolitik (German Development Institute)
EKC	Environmental Kuznets Curve
EU	European Union
FDI	Foreign Direct Investment
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GNI	Gross National Income
GWp	Gigawatt Peak
ICT	Information and Communication Technology / Technologies
IPR	Intellectual Property Rights
IS	Innovation System(s)
MA	Millennium Ecosystem Assessment
MDG(s)	Millennium Development Goal(s)
NIS	National Innovation System
ODA	Official Development Assistance
OECD	Organisation for Economic Cooperation and Development
PV	Photovoltaic
R&D	Research and Development
RIS	Regional Innovation System
Sasol	South African Synthetic Oil Ltd.
STI	Science, Technology and Innovation
SoIS	Sustainability oriented Innovation System(s)
UN	United Nations
UK	United Kingdom
UNFCCC	United Nations Framework Convention on Climate Change
WTO	World Trade Organization

Summary

At the beginning of the new Millennium, the world is faced with a normative dilemma: While the goal of a fast poverty reduction would call for higher economic growth rates in most of the developing world, more dynamic growth would increase pressure on the natural environment if growth patterns are not significantly altered. The paper argues that to reconcile various development goals, ways have to be found to effectively decouple economic growth from environmental pressure, in ways that allow for high value addition and welfare creation, while at the same time minimising the impact on the resource base and sink capacities of the environment.

There is no empirical evidence that this decoupling might occur automatically as economies and societies mature, as postulated by the environmental Kuznets curve. The transition from an economy based mainly on industrial activities towards a service economy might reduce resource consumption and emissions in one country, but this will most often mean simply externalising environmental costs, with manufactured goods being imported from other countries or world regions. Nor is it possible to identify any generalised transition towards post-materialist values that could mitigate the pressures on the environment, and there is no reason to expect this, either, as long as many human beings continue to struggle to escape absolute poverty.

Policy is needed to achieve effective decoupling, and technology development and deployment will have to play a crucial role. Innovations are often directly related to improved environmental performance, e.g. in connection with increased energy efficiency of processes and reduced product material requirements. However, technology-driven improvements in resource productivity have thus far been outpaced by economic growth, even in world regions with strong innovation systems and relatively low growth rates, such as the European Union (EU). What this means is that overall resource and energy consumption has not decreased. Thus, technological innovations need to be developed at a higher rate and translated into practice at a quicker pace. And their impact on resource efficiency needs to be enhanced significantly.

What is called for to achieve this is determined efforts that involve not only the traditional technological powerhouses in the North but also the developing countries. A special role will have to be played by a number of large anchor countries, first of all Brazil, China, India and South Africa. On the one hand, they have developed a rather large ecological footprint, e.g. due to large-scale and coal-based energy production or extensive deforestation. On the other hand, they have built up relatively high levels of technological capability.

While technology transfer will have to play an important role in innovation-driven decoupling efforts, this instrument must be embedded in more comprehensive strategies. These will have to involve efforts to strengthen technological capabilities in the anchor countries as well as joint Research and Development (R&D) efforts between industrialised and developing countries. There are three main factors that explain why technology transfer is only part of the solution:

– First, technology transfer can only be effective where a reasonable degree of technological capability is already in place.

- Second, a number of technologies crucial for an effective decoupling are still not ready to be rolled out on a large scale.
- Third, anchor countries are less and less willing to accept traditional modes of transfer that imply continued dependence on international technology providers.

What is called for to come up with adequate policy conclusions and approaches for international cooperation is a thorough understanding of where the anchor countries stand regarding their technological and innovation capabilities and capacities, especially those related to sustainability-oriented technologies.

The innovation system approach as a research tool with gaps that still need to be filled

The concept most widely adopted to analyse these capabilities and capacities, and to identify possible entry points for policy intervention, is the innovation system approach, which has been developed since the end of the 1980s. For many years, the focus has been on national innovation systems, understood as the aggregate of public and private organisations that contribute to the generation and application of new technological knowledge as well as the policies and incentives adopted in a national economy to support this process. Further developments of the concept have led to a focus on sub-national geographic entities as the unit of analysis (regional innovation systems) or on the complex interactions between local/regional, national and international actors (sectoral innovation systems). Whether focused on the national, regional or sectoral level, IS research has thus far mainly viewed innovation performance as the chief factor contributing to economic competitiveness, **largely neglecting sustainability dimensions**.

The most ambitious and visible attempt to link innovation and sustainability must be seen in the **transition or system innovation discourse**. During the late 1990s and early 2000s, the focus of the debate started to move away from micro-level dynamics related to the introduction of clean process and product technologies. It became concerned with the ways in which broadly defined socio-technical systems evolve towards greater sustainability. This shift has been driven by the recognition that a narrow focus on innovation at the firm level could neglect important changes at the institutional and policy level. Consequently, this new analytical focus accords increased attention to changes in broad socio-technical practices and technical and institutional systems that contribute to sustainable development.

One significant deficit of the approach that emerges when it is tested as a helpful tool for research on the connections between technological innovation and sustainability is the fact that the empirical base for ex-post transition studies – even in the industrialised countries – is still very limited.

One approach that explicitly takes up the Innovation System (IS) approach and links it with the challenges posed by environmental sustainability is the concept of the sustainable innovation policy regime. The studies underlying the concept have compared sustainable innovation promotion in the United Kingdom (UK) and EU and analysed the dynamics in industries related to the provision of low carbon energy in Great Britain and technologies for new fuels in vehicles in Europe.

The approach derives the need for policy intervention from the concept of system failure. In order to identify system failures and to derive feasible policy options, the authors look at the chain of innovation processes from R&D, through the demonstration, pre-commercial and supported commercial stages to the fully commercial stage. The two stages most likely to suffer from system failures are the transition between the demonstration stage and the pre-commercialisation stage and between the pre-commercialisation stage and the supported commercialisation stage. The authors derive sets of policies adequate to push forward sustainability innovations, namely promotion of basic R&D, market-creating policies and fiscal incentives. These should be seen as complementary, and not substitution-oriented, environmental policies in the stricter sense.

For developing countries with restricted public budgets, market-creating policies appear to be of special significance, as they do not necessarily call for increased government spending or lower revenues. Public procurement is an opportunity to increase the diversity of technologies available and give cleaner technologies the opportunity to mature through learning-by-doing and learning-by-interacting (strategic niche management). Other options discussed to create markets for environmental technologies include: awarding prizes for high-performance sustainable solutions and setting long-term, outcome-based targets or obligations for cleaner technologies to gain a certain share of the market.

Towards a research agenda

Having identified the gaps in the available literature, we can now conclude that **the issue of how best to build effective sustainability-oriented innovation systems (SoIS) in anchor countries is still a rather unexplored research field**. We propose that further research be clustered around three main and interlinked topics:

1. What are the specificities of sustainability-oriented IS?
2. Are sustainability-oriented innovation systems emerging specifically in the anchor countries?
3. Are we observing a shift towards global innovation systems for sustainability?

1. Specificities of SoIS

There is at present no comprehensive approach to explain what makes sustainability-oriented innovation systems (SoIS) different from commercial IS, and thus what feasible policy options there may be to shape SoIS. Some specific features of SoIS may, however, be derived from the fact that the main concern is to generate innovations that reduce pressures on the environment, and thus on (global) public goods. This implies that SoIS suffer from a two-fold market failure:

– a private company will usually not reap all of the benefits from investment in innovation activities (non-appropriability);
– environmental costs continue to be largely externalised.

Where markets fail in such a systematic manner, the role and responsibility of policy making are especially important. This gives rise to the question: **How can policy contribute specifically to the formation and strengthening of sustainability-oriented innovation systems?**

In view of the problem of market failure, it can be assumed that demand-side measures and market-creating policies will play an especially important role in shaping SoIS. In recent years, industrialised countries have introduced a series of demand-side policy measures, and some empirical knowledge about their effects has been built up. **What still needs to be done is to explore how and to what degree these (and possibly other) measures need to be adapted to the specificities of developing and anchor countries in order to make them effective.**

On the supply side, public intervention will be focused on the same elements as in the case of commercial IS, namely building human resources and R&D, two areas where markets failure is evident. Beyond providing quantitatively sufficient support, it will, in the case of SoIS, be of special importance to assure sufficient variety in the training profiles and technologies developed in order to overcome, or to avoid, path dependency.

In view of the urgency of the need to develop ready-to-deploy decoupling technologies, the “Valley of Death” problem is of high relevance. Technologies may remain stuck between the R&D and commercial stages, as neither public research funding nor private sources are willing or able to provide the substantive funding needed for demonstration and pre-commercial projects. This raises the question **whether large-scale funding to bridge the “Valley of Death” in sustainability-oriented technologies can be expected to be mobilised at the national level and how international, and especially multilateral, efforts might possibly serve to flank these efforts.**

What is needed to form SoIS is implementation of a coherent set of different policy measures on the supply and the demand side, often with high levels of ex-ante uncertainty. This raises the question whether **the governance and implementation capacities in anchor countries are sufficient to establish effective SoIS and how, possibly, international co-operation may contribute to achieving effective policy making and implementation**.

2. Sustainability-oriented innovation systems in anchor countries?

Little is known regarding the existence or emergence of SoIS in anchor countries. There are some case studies that shed light on the processes behind identified success stories. **It is important to enlarge the empirical base through additional in-depth case studies and to feed the findings back into the IS and SoIS discourse.**

Patterns of technological expertise in anchor countries

Anchor countries, including Brazil, China, India and South Africa, have in the past sought to spur high-technology development on the basis of large government-sponsored programmes, often organised in the form of technology missions. This implies that the technological knowledge base should be greater in these countries than in other parts of the developing world. Anecdotal evidence indicates that this may be relevant for sustainability-oriented technology fields like wind energy or hydrogen technology.

One research task lying ahead is to gain a deeper understanding of the role of past or ongoing technology missions for today’s knowledge landscapes in anchor countries:

- How significant (in terms of capabilities and capacities) is the technological knowledge built up through these policies?
- What has happened with embodied and disembodied knowledge in cases where technology missions have been discontinued or political ruptures have occurred?
- To what extent are knowledge clusters contributing to the formation or strengthening of SoIS in the anchor countries, as indicated in the examples above?
- Can they be made functional through policy intervention?

Building technological capabilities under conditions of globalisation

Early industrialisation in today's most advanced countries and the related build-up of technological expertise was accompanied by rather strong government intervention, including tariff protection for domestic markets. Today's catching-up processes are taking place under conditions of a regulated globalisation, and this implies a different and narrowed scope for policy making. Some aspects have clearly to be seen as disadvantages for current technological catching-up processes:

- Local efforts geared to technological upgrading and innovation encounter fierce competition in global markets, affecting international as well as local markets.
- Market liberalisation today restricts policies designed for selective infant industry protection or market reservation.
- International regulations affect the ways in which technological knowledge can be accessed, e.g. stricter Intellectual Property Rights (IPR) protection regimes severely restrict options for reverse engineering.
- Instruments of industrial policy, common in many countries in the past, have today largely been ruled out, including measures designed to link local companies to FDI on the basis of local content requirements.

On the other hand, globalisation is also opening up new opportunities for catching-up countries, which were available for early movers:

- Technology development and innovation can fall back on huge stocks of available information and knowledge, partly in the public domain and accessible through Information and Communication Technology / Technologies (ICT).
- Technology corporations are increasingly relocating knowledge-intensive activities to some developing countries.
- Organisations and companies in developing countries have the opportunity to use global research networks to access international know-how and merge it with local knowledge.
- Developing countries can learn from the Organisation for Economic Co-operation and Development (OECD) countries regarding effective innovation policies and efforts to abbreviate learning processes and minimise the risks of costly policy failures.

When we weight these two sets of arguments, some important research questions arise. **Does globalisation make the formation of IS easier or more difficult? Do pathways exist to short-cut learning processes and the related build-up of technological capabilities? Do the changes in framework conditions impact on the specific features of IS in anchor countries, e.g. in the mix of national and international access to specific knowledge?**

SoIS formation in anchor countries: a promising avenue to catching up technologically?

It is furthermore important to understand whether sustainability-oriented innovations may be a promising field for anchor countries to close the technological gap. We may conclude from the innovation system literature that the possibilities for technological catching up may be greater than they are for more commercial technologies:

- In sustainability-oriented innovations, core technologies are either still in flux or rather simple, lowering the barriers of entry for latecomers, compared to older industries, where the technological lead of the industrialised countries is very significant.
- Sustainability-oriented innovations often imply a rather radical deviation from established trajectories, giving developing countries an advantage, as technological lock-ins may be less severe there than in the industrialised world.
- Geographical conditions in developing countries may prove especially favourable for the development and implementation of sustainable solutions. This could in the end transform them into lead markets for sustainability innovations.
- Sustainability-oriented innovations developed in the industrialised countries may not be adequate for quick deployment in developing countries, as such innovations do not correspond to their factor endowments. Anchor countries could become providers of sustainable solutions for countries with similar factor endowments.

On the other hand, specific setbacks and potential barriers can be identified that could hinder the development of SoIS, specifically in developing countries. As these are still poor countries, the (financial and governance) resources dedicated to the environmental dimension of sustainable development could be competing directly with other efforts that may be given higher political priority in many countries.

It would thus seem to be an open research question whether the balance of advantages and disadvantages is positive or negative when it comes to assessing whether sustainability-oriented innovations are a viable opportunity for anchor countries to reach a technological par with the OECD world.

3. Towards global innovation systems for sustainability?

Globalisation is affecting the generation of knowledge and the deployment of technologies, including disciplines of relevance for more sustainable development paths. This applies for publicly funded scientific research, but also for private sector R&D. Making the development of decoupling technologies more dynamic will require an intelligent combination of national efforts designed to strengthen innovative capabilities with significant international cooperation.

This requires a deeper understanding of how processes on the national level relate to increasing efforts in international cooperation. Some of the questions that would have to be addressed include:

– Does international cooperation in sustainability-oriented disciplines and topics have an impact on innovation policies, one leading to higher priority for the environmental dimension of sustainability?
– To what extent and under what conditions does international cooperation contribute to domestic learning processes and increasing levels of "technological mastery"?
– To what extent can international dialogues and cooperation lead to improvements in the institutional settings required for a quick deployment of environmentally sound technologies?
– Which are the most successful or promising formats for bilateral and multilateral cooperation in science, technology and innovation, especially for the development and deployment of environmentally sound technologies?
– To what extent can technology-based private companies be integrated in international cooperation networks that are primarily geared towards addressing global public goods?

The need to bring different research and discourse communities together

How global sustainability challenges can be addressed by national and multilateral innovation policies is still a largely open question. This can partly be explained by a failure of the research community to adequately inform policy makers. This, in turn, is largely due to a division of the research community into those researchers who deal with technological innovation and innovation systems on the one hand and those that deal with environmental challenges and the effectiveness of environmental policies on the other:

– Innovation (system) research has largely neglected the pressing challenges of sustainable development, limiting the scope of research to the features of innovation systems that contribute to economic competitiveness.
– Researchers concerned with the environment have largely ignored the potential power of technological innovations for sustainable development, often focussing on possible threats that specific technologies pose for ecosystems.

In order to adequately inform policy makers, it will be crucial to bring three research communities together, namely IS researchers with researchers dealing with the mitigation of environmental problems and, finally, the development research community.

– IS research can explain how technological and innovation capabilities within a sector or country are shaped through the interplay of actors from the private and the public sector, governed by rules and regulations largely influenced by policies.
– Environment-related research can shed light on what the most pressing challenges are in terms of the environmental dimension of sustainability, and thus also on the question of what areas are most in need of technological solutions to mitigate them.

Development research can contribute knowledge regarding the level of complexity at which the development and deployment of environmentally sound technologies needs to be conceptualised.

1 The challenge of reconciling social and environmental dimensions of sustainable development

At the beginning of the new Millennium the world is faced with a normative dilemma that is reflected in the Millennium Development Goals (MDGs). Most likely it will continue to be a key element of the development discourse beyond 2015, the benchmark year for meeting the Millennium Promise laid down in the Millennium Declaration of 2000.

– On the one hand, there is a commitment to reduce poverty at a much quicker pace than in the past (MDG 1). Empirical evidence indicates that as long as distribution patterns for productive assets and incomes are not altered, high growth rates are crucial for reducing poverty. In many parts of the developing world this implies significantly *higher* growth rates than in past decades, as average growth rates had been insufficient to lead to dynamic poverty reduction.

– On the other hand, the world community has also committed to a development that will not further destroy the natural resource base that allows future generations to meet their own needs (MDG 7). Empirical evidence shows a general correlation between rates of economic growth and the speed of depletion of natural capital. This means that, from an environmental point of view, *reduced economic growth* would be desirable.

The present paper argues that there is no easy answer to how this dilemma may be resolved, noting that using the set of technologies currently available, it will prove possible neither to achieve a transition towards environmentally and socially sustainable development paths nor to find an answer to the urgent resource and emission crisis. Thus, technological innovations will be key, and taking into account the dimensions of the challenges, both the frequency of innovations and their impact on resource productivity will have to be increased. We argue that this cannot be achieved on the basis of concepts involving horizontal technology transfer alone1 but will require joint Research and Development (R&D) programmes between actors from the North and the South and considerable technological efforts in developing countries. A special role will have to be played by a group of so-called anchor countries,[2] namely China, India, Brazil and South Africa, due to their increasing environmental impact on the one hand and considerable technological achievements on the other.

How innovation systems in these countries can contribute to environmental sustainability in a systematic manner is the overarching theme guiding this paper. Its purpose is not to give definite answers. Rather, the intention is to outline a research agenda that delineates the knowledge that will have to be created to conceptualise sustainability-oriented innovation systems (SoIS), especially in anchor countries, and to guide policy makers and international cooperation.

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1 What we understand in this paper under horizontal technology transfer is the passing of technology-related knowledge from one (industrialised) country to another (developing) country. Vertical transfer may be understood as transfer of technologies from the R&D stage through to commercialisation; see also the definition of technology transfer on page 29.

2 Anchor countries are those countries that play a key role both in their particular regions and in coming to terms with global challenges and shaping global governance structures (Stamm / Altenburg 2005).

1.1 Recognising the challenge – a historical perspective

The challenge of how to reconcile socio-economic needs and environmental requirements has by no means just recently been recognised. Already in the early 1970s, the publication (in 1972) of the first *Club of Rome Report* ("The Limits to Growth") and the first oil crisis of 1973 triggered an international scientific and public debate on how to deal with the fact that a growing world population with increasing levels of per capita material consumption cannot easily be harmonised with the limited resource base and sink capacities of the globe. The *Global 2000 Report to the President*, commissioned by US-President Jimmy Carter in 1977, had a similar jolting effect, at least within a global community of people open to information and knowledge, challenging conventional thinking and *business as usual* concepts of life.[3]

Interestingly, the environmental debate and the development debate were thrust simultaneously into the global discourse. In 1970, the first formal international commitment was made to undertake efforts to commit at least 0.7% of the rich countries' gross domestic product (GDP) to official development assistance (ODA).[4]

In the 1970s, development issues and the harsh realities in developing countries were increasingly realised and discussed by concerned observers in the industrialised countries, triggered e.g. by the 1973 coup d'état in Chile, the 1979 revolution in Nicaragua and the cruelty of apartheid in South Africa. In 1980 – and practically at the same time the *Global 2000 Report was issued* - the report of the "Independent Commission on International Development Issues" ("Brandt Report" - commissioned by World Bank President McNamara) appeared, calling for urgent action to overcome poverty.

Thus, the message that the perspectives for continued quantitative growth of material consumption will be limited and the awareness of the unacceptable ethical implications of the existing global welfare divide reached the critical parts of the global public simultaneously, and without advocating positions inimical to one another. However, they have since then not been brought together in any particularly systematic way. The challenge of how to meet the ethical dilemma between the need for global social equity on the one hand and the need to preserve natural resources for future generations (also on a global scale) on the other has still not really been resolved.

There have been attempts to conceptually de-link *development* from economic *growth*, e.g. based on the approach of *satisfaction of basic needs*, prominent especially during the 1970s. However, the growth target for that decade, the Second UN Development Decade (1971-1980), was an average of 6% for all developing countries, a figure then thought to be required for a per capita GDP growth of 3.5% (UN 1970, para 13 and 14). Part of the frustration with this (and other) Development Decades was related precisely to the fact that the growth rates of developing countries clearly failed to achieve these envisaged high averages, and this in turn has lowered the potential for achieving increases in needs satisfaction.

3 One indicator that this community was not too small is that the print version of "Global 2000" sold more than 1.5 million copies.

4 UN General Assembly (1970, Resolution, Paragraph 43).

Another approach to reconciling the environmental and development agendas might be seen in an equity-oriented burden sharing between the different parts of the world. Ethically motivated discourses have suggested that people in the wealthy countries of the North should abstain from consumption of resources and energy in order to allow poorer strata of world society to catch up in their appropriation of material prosperity. This change in consumer behaviour could, it was thought, be supported by a shift of values towards *post-materialism* (Inglehart 1977).

So far, empirical evidence shows no indication that this kind of voluntary burden sharing may already have materialised or that a voluntary reduction of consumption might be anticipated in the near future. This is not to say that the educated and informed consumer might not be willing to adjust his or her consumption patterns and behaviour towards higher levels of sustainability, even if this implied additional efforts (e.g. voluntary recycling) or paying a price mark-up (organic food, Fairtrade products). However, the *absolute level* of material consumption is not decreasing, not even in the most affluent societies.

Quite the contrary, younger generations in the OECD countries are taking advantage of falling unit prices to increase their levels of consumption of goods and services, such as tourism, and the frequency with which they acquire artefacts, e.g. in the consumer electronics sector. Mobility has increased significantly, and it has typically failed to pay heed to the environmental externalities bound up with different modes of transport. The number of motor vehicles in OECD countries more than doubled between 1970 and 2001 and the distance travelled by road vehicles increased, e.g. in Canada, by 33% between 1980 and 1997 (Boyd 2001). The same is true for the UK for the years between 1970–2000. Here the *growth rates* of car trip distance (measured in passenger-km) and car driving distance (measured in vehicle-km) were reduced between 1990 and 2000 compared to the two previous decades, but still individual car transport continued to increase (Kwon / Preston 2005). The frequency of long-distance airline travel – a form of mobility with high external costs for the global environment – tends to increase with high elasticity when per capita incomes grow (BCG 2006).

Unfortunately, even if consumers in OECD countries shifted broadly towards less resource-intensive lifestyles, the economic implications and the impact on poverty reduction in the South would most likely be *negative*. Empirical evidence from the past decades indicates that success in poverty reduction and improvement of social welfare in developing countries has been based on sustained and high economic growth and the related creation of employment in the formal sector as well as through multiplier effects extending to agricultural producers and the informal sector. Sustained economic growth, in turn, depends on the existence of markets with sufficiently high absorptive capacities. Especially for smaller developing economies, this means to a large extent *export* markets. International trade encourages specialisation in the use of productive assets, resulting in productivity growth and rising factor remuneration. Finally, delivering products and services to demanding markets also provides important opportunities for learning and thus accumulation of capabilities.

As transport is directly associated with consumption of fossil transport fuels and related emissions of greenhouse gases, the option for consumers to deliberately abstain from consumption of goods shipped across borders and over long distances seems rather convincing, at first glance. However, the argument oversimplifies the environmental impact of different production and transport systems. Due, for instance, to favourable climate conditions or higher inputs of human labour compared to machinery or chemical inputs, specific internationally traded goods may indeed have a smaller ecological *rucksack* than goods produced at a short distance from consumers in the wealthier countries. A study conducted by Cranfield University concluded that flowers produced in Dutch greenhouses produce six times higher amounts of greenhouse gases than flowers produced in Kenya and transported to the UK by airfreight. These findings, at first glance surprising, can be traced back to high energy consumption in Dutch greenhouses (Williams 2007). Similar findings have been made for apples and wine grapes produced in Germany and overseas. Here an important reason for a lower energy footprint of internationally traded fruits can be found in the relevance of an "ecology of scale", implying that production on larger farms is much more energy-efficient per unit than small-scale production (e.g. Schröder 2007).

Additionally, empirical evidence indicates that limiting drastically imports from developing countries would obstruct their efforts to close the socio-economic gap on the industrialised countries. Massive reduction of poverty in China has to a large extent been based on the build-up of export-oriented manufacturing capacities. Smaller economies like, for example, Chile and Costa Rica have achieved important socio-economic progress based to a large extent on the delivery of high-value agribusiness products to consumers in North America and Europe. International tourism is an important economic activity in many developing countries, providing access to foreign currency and generating large numbers of jobs, and often accessible for poor strata of the societies concerned.

Changes in consumption patterns in the wealthier countries can indeed contribute to making growth patterns in developing countries more "pro-sustainable", e.g. by giving preference to goods produced in low-impact agricultural systems or by industries complying with the most stringent environmental standards.[5] But this does not go hand in hand with any reduction of overall levels of material consumption.

1.2 Roadmap for the following sections

To sum up this section, the challenge of how to reconcile the social and environmental dimensions of global sustainable development has still not been resolved. The number of people populating the globe will continue to rise during the coming decades (mainly in the South) and a voluntary reduction of material consumption in the North is neither in sight nor necessarily desirable. The only feasible option seems to be to find ways to provide increasing levels of welfare with decreasing levels of resource degradation and emissions. How this might be done, or more precisely, what we will need to know to be able to do it, is the overall concern of this paper.

In **section two** we will argue that to achieve this **decoupling of growth from environmental pressures,** technological innovations are a condition necessary (though probably not sufficient) to enabling sustainable development globally. The frequency and depth of innovations need to be increased in an effort that involves not only the traditional techno-

5 Mobilising more effectively these demand-side incentives would require further development of standard-setting, certification and labelling to capture the complex interrelations between production systems and the different dimensions of sustainability.

logical powerhouses in the North but also the developing and anchor countries striving to develop their own scientific, technological and innovation capabilities. In this context a special role will have to be played by anchor countries, which have a rather large ecological footprint on the one hand (due to e.g. large-scale and coal-based energy production or high levels deforestation) and increasing levels of technological achievement on the other, namely Brazil, China, India and South Africa.

It might be thought that introduction of cleaner technologies in these anchor countries could be achieved via traditional modes of North-South technology transfer. However, in **section three** we argue that technology transfer will have to be embedded in more comprehensive strategies that involve the strengthening of technological capabilities in the anchor countries and joint R&D efforts between industrialised and developing countries. On the one hand, technology transfer can never be seen as an easy relocation of technological knowledge from one place to another. Perhaps more importantly, a number of technologies that are crucial for an effective decoupling have still not reached the commercial stage. And last but not least, the anchor countries are less and less willing to accept traditional modes of transfer that imply continued dependence on international technology providers.

How policies designed to promote technological innovations on the one hand and environmental sustainability on the other can be brought systematically together, is still a largely unexplored field of research. Even in the most advanced countries, innovation and sustainability have until recently been the object of separate intervention schemes - and of different research and discourse communities. **Section four** explores the current state of research at the interface between these two policy fields, using the innovation system approach as the conceptual anchor. The main argument is that, due to pervasive market failure, sustainability-oriented innovation systems are necessarily characterised by features significantly different from those typical of innovation systems in many fields of commercial technology, and this in turn gives policy intervention an essential role. However, what policy makers can do to shape sustainability-oriented innovation systems is still a rather open research question.

Starting from the gaps identified in the scholarly literature, **section five** outlines a research agenda assumed to be specifically conducive to the development of a deeper understanding of the formation of sustainability-oriented innovation systems in anchor countries. Putting these countries into the focus is justified by the fact that decoupling economic growth from environmental pressure is essential in them because of their swiftly growing ecological footprint. At the same time, countries like China, India, Brazil and South Africa have developed, over the past decades, scientific and technological capabilities that constitute an important potential for developing essential decoupling technologies. Three interlinked research areas have been identified: First, gaining a better understanding of the specificities of sustainability-oriented innovation systems; second, whether sustainability-oriented innovation systems are evolving in anchor countries; and third, how the formation of domestic technological capabilities relates to the ongoing internationalisation of research and innovation.

The concluding **section six** identifies the need to bring together three still largely separate research and discourse communities in order to pool knowledge and utilise synergies, namely innovation (system) research, environmental research and, finally, development research.

2 The role of technology and innovation in decoupling economic growth from environmental pressures

Two approaches can be distinguished in analysing the interrelations between socio-economic development and related damage to the natural environment:

— To a certain extent, an already degraded resource base or ecosystem may be restored, e.g. by reforestation or soil decontamination.

— Considering the limits of this first approach, efforts have to be made to effectively decouple economic growth from depletion of natural resources.

Once an ecosystem is severely damaged, its **rehabilitation** is usually a long-term issue. In detail, that process requires very different time frames, depending on the nature of the environmental damage. For instance, while river water may return to reasonably sound quality levels within a rather short time once the contamination source has been removed, forests need many years to grow and decades to return to levels of biodiversity at least close to natural conditions. Severely eroded or degraded soils will not recover in time frames within the planning horizons of human beings. And of course there is damage to ecosystems that can never be reversed, such as the extinction of species.

According to the Millennium Ecosystems Assessment, which has been described as *"the largest global effort ever undertaken to catalog the state of the world's ecosystems and the human effects on them"* (Sachs 2008, 145), many ecosystems have already been degraded to such an extent that their ability to provide services for human beings (food, timber, water etc., but also regulatory, support and cultural services) has been severely reduced.

Box 1: The Millennium Ecosystem Assessment

The Millennium Ecosystem Assessment (MA) was called for by the United Nations Secretary-General Kofi Annan in 2000. Initiated in 2001, the objective of the MA was to provide an integrated assessment of the consequences of ecosystem change for human well-being and to analyse options available to en-hance the conservation of ecosystems and their contributions to meeting human needs. The main find-ings of this exercise may be summarised as follows:

Over the past five decades, humans have changed ecosystems more rapidly and extensively than in any comparable period of time in human history, largely to meet rapidly growing demands for food, fresh-water, timber, fibre and fuel. This has resulted in a substantial and largely irreversible loss in the diver-sity of life on Earth.

The changes that have been made to ecosystems have contributed to substantial net gains in human well-being and economic development, but these gains have been achieved at growing costs in the form of degradation of many ecosystem services, increased risks of nonlinear changes, and exacerbation of poverty for some groups of people. These problems, unless addressed, will substantially diminish the benefits that future generations obtain from ecosystems.

The degradation of ecosystem services could grow significantly worse during the first half of this century, and it constitutes a barrier to achieving the Millennium Development Goals.

The challenge of reversing the degradation of ecosystems while satisfying increasing demands for services can be partially met under some scenarios considered by the MA, but will involve significant changes in policies, institutions and practices that are not currently under way. Many options exist to conserve or enhance specific ecosystem services in ways that reduce negative trade-offs or that provide positive synergies with other ecosystem services.

Source: www.millenniumassessment.org

This implies that efforts need to be undertaken to restore damaged ecosystems in order to guarantee an adequate provision of ecosystem services to a growing world population (see Box 1).

In some cases, these efforts are directly related to technological innovation, e.g. when it comes to restoring contaminated or saline soils through methods of modern bio-remediation. In other cases, the link is more indirect. For instance, restoring fish stocks heavily depleted by overfishing can be achieved primarily by reducing the quantities of fish taken, or by a complete moratorium on fishing activities. Considering that fish is an important source of protein, fishing needs to be substituted by aquaculture, a knowledge- and technology-intensive activity, if it is to be carried out without imposing any additional burdens on the environment.

2.1 Decoupling economic growth from environmental pressures: What can we learn from the environmental Kuznets curve?

In view of the fact that there are no easy "fix-and-repair" options for ecosystems and their elements, the growing resource crisis is best addressed strategically by preventing damage and resource depletion. The objective has to be **to decouple,** as far as possible, economic growth from degradation of the environment and depletion of natural resources.

In its 2001 publication "Environmental Strategy for the First Decade of the 21st Century", the OECD lists decoupling environmental pressures from economic growth as one of its five inter-linked objectives for enhancing cost-effective and operational environmental policies in the context of sustainable development (OECD 2001, 6). The OECD defines decoupling as "breaking the link between "environmental bads" and "economic goods."

Decoupling occurs when the growth rate of an environmental pressure is less than that of its driving economic force (e.g. measured in GDP) over a given period. Decoupling can be either absolute or relative. **Absolute decoupling** occurs when the environmentally relevant variable is stable or decreasing while the driving economic force is growing. **Relative decoupling** occurs when the growth rate of the environmentally relevant variable is positive, but less than the growth rate of the economic variable (OECD 2002).

Since the 1990s, an intense discussion has taken place around the hypothesis of the **environmental Kuznets curve (EKC).** In analogy to the hypothesis developed by Simon Kuznets that during economic growth income inequality first rises, then levels out and finally decreases, a similar "inverted-U" relationship was postulated for the link between socio-economic development and depletion of natural resources. This would imply that once a turning point has been reached (certain level of per capita income) further increase in social welfare is decoupled from additional burdens on the environment. Decoupling could thus be seen as automatic, or as *"a "natural" process that takes place as economies mature"* (Azar / Holmberg / Karlsson (2002, 11).

A series of studies has sought to empirically test the EKC for a series of pollutants and other indicators of environmental degradation. Many of them have corroborated the existence of an inverted U-curve for local air pollutants like SO_2 or NO_2, but not for other indicators, such as total energy use, traffic volumes etc. (Stern 2004, 1435).

In the context of the pressing problem of climate change, one essential question is whether an inverted U-shape can also be found for CO_2 emissions. Various studies come to different conclusions, either implying that no turning point can be found or identifying very high per capita incomes as turning points (ranging from $ 11500 to $ 35000, Panayotou 2003, 80f).

Possible arguments supporting the "inverted U-curve" may be found at different system levels:

- **Values** within a population tend to shift from a purely quantitative satisfaction of material needs towards higher preferences for environmental quality. Better-educated consumers are more likely to take environmental externalities into account when taking buying decisions, thus giving incentives to the business community to adapt their production (Inglehart 1977).
- Increasing per capita income is directly related to changes in the **structural composition of value addition** within an economy, from agriculture to industry and, finally, the service sector, implying very different patterns of appropriation of natural resources and of related emissions (Pasinetti 1981).
- More advanced societies tend to have **stronger institutions** in place. These are required to identify environmental externalities and internalise them by setting adequate prices, to ensure that the population is well informed and to enforce environmental regulations.
- Finally, businesses in more advanced economies tend to apply increasingly higher levels of **knowledge and technology** in their production processes. Technological innovations, even those mainly introduced to enhance a company's competitiveness, often include features of importance for more sustainable development patterns (energy efficiency and material productivity).

There are two very important arguments that make clear that a mere "waiting for the turning point of the EKC" is clearly not a feasible option, at least for greenhouse gas (GHG) emissions:

- Even taking the lowest income levels at which the downwards slope of the EKC was found to be reached for CO_2 emissions ($ 11500 per capita, see above), this would imply that, looking at the main GHG emitters among the anchor countries, decoupling would begin only once per capita income had risen by a factor of 2 in the case of South Africa (2007: GNI/cap. $ 5720), 4.9 in China (GNI/cap. $ 2370) and 12 in India (GNI/cap. $ 950).[6] This is clearly not a feasible option considering the urgency of climate change mitigation and the increasing role that some anchor countries play in this context.
- *"International trade obscures the link between income and environment in a given country by delinking consumption from production within the country."* (Panayotou 2003, 53). The EKC was mainly developed and tested at the level of individual *nation* states or societies. To reflect decoupling on a *global* scale, the model would have to be far more complex and consider the effects of economic globalisation. For instance, reductions in emissions of e.g. SO_2 or NO_2 in socially and economically advancing countries may in part be related to the re-location of pollution-intensive industries to poorer countries. Structural change towards a "dematerialised" service society to

6 World Bank, Key Development Data & Statistics, www.worldbank.org, last accessed 2009-05-15.

some extent "buys in" energy consumption and resource degradation if the required material goods are increasingly imported to advancing countries.

If waiting for a natural "decoupling" of economic growth from environmental pressure is definitely not an answer to the grand challenges facing the world, policy is required. If we look at the above-mentioned four factors that may lead to the inversion point of the EKC (values, sector composition of the economy, institutions, technology), the two entry points that seem most promising for the required rapid advances towards relative and absolute decoupling relevant for fast developing countries are institutions and technology.

- A society's **value systems** are clearly a variable of slow change and do not lend themselves to simple policy interventions. To expect people barely emerging from absolute poverty to *leap-frog* to post-materialistic values would imply, additionally, a sort of moral colonialism by the richer segments of the world's population.

- **Structural change** towards a service society, while feasible for a national economy with high levels of satisfaction of material needs and in the context of an international division of labour, finds its limits at the global level. The idea of people who were the absolute poor catching up in consumption implies first of all acquisition of increasing volumes of material goods and – less - of services. De-linking production from the consumption of material goods, while feasible on the level of individual societies, is definitely not feasible on a global scale.

Institutional change and **technological innovations** often go hand in hand. As we will see below, this is especially the case regarding sustainability-oriented innovations the emergence of which is hampered by market failure and calls for politically shaped rules and incentive systems designed to trigger dynamism and to guide it in the right direction.

2.2 Technological innovation and resource productivity

Technological innovations are essential for decoupling economic growth from burdens on the environment, mainly on the basis of rising **resource productivity** (Cropper 2008). This concept expresses the efficiency with which an economy generates value from the use of natural resources.[7] Bearing in mind the complex impacts that economic activities have on environmental *systems,* and not on *singular elements* of them, a wide definition of natural resources is required. In addition to (non-renewable) energy resources and non-energy primary products, it is important to take into account natural *sinks*, i.e. the capacity of the biosphere to absorb solid waste, liquid effluents and air pollution (Gross / Foxon 2003, 119 f.). Thus, resource productivity measures the amount of resources used *and* the stress on natural systems generated by an economic activity.

Increases in resource productivity have to be very substantive in order to actually decrease the ecological footprint of a growing economy. For instance, within the EU15 region the energy intensity of the *economy* as a whole dropped by 5.1% between 1995 and 2005.[8] The energy intensity of *industry* was reduced from an index value of 100 (1995) to 95.6 in

7 It can also be understood as the reciprocal of the material input per unit of product or service, see Ritthoff / Rohn / Liedtke (2002, 9).

8 Measured in kilogrammes of oil equivalent per 1000€ of value addition.

2003. However, technology-driven increases in resource productivity have until now been outpaced by economic growth. As a consequence, total energy consumption in EU15 industry *increased* by 5.4%. between 1995 and 2005[9] At the same time, energy consumption in the EU 15 transport sector rose by more than 15%, notwithstanding the introduction of more fuel-efficient vehicles.[10]

Due to this so-called 'rebound effect' (Sorrel / Dimitropoulos, 2007), even in a world region characterised by limited economic growth,[11] and among the best performers on technology and innovation, innovation systems have thus far not delivered the solutions required for an effective decoupling of economic growth from rising resource consumption and increasing stress on natural systems. Consequently, the situation appears to be even more dramatic in countries with much higher growth rates and less effective innovation systems, such as China, India and South Africa.

What would be required to reconcile social and environmental development targets is a qualitative leap in resource productivity (Rennings 2005; Frondel / Horbach / Rennings 2006). This also implies qualitatively new dynamics in innovation that would increase the **frequency** of technological innovations and their **depth and outreach**, triggering much higher impacts on resource productivity.

Already in 1995, a vision of this kind was formulated, by the Wuppertal Institute for Climate, Environment and Energy, as the *"Factor 4 Strategy: Doubling Wealth, Halving Resource Use"*. This vision implies that the industrialised countries would need to achieve a fourfold increase in resource productivity within a timeframe of 30 to 50 years (see Weizsäcker / Lovins / Lovins 1995).

One and a half decades later, the *'Factor 10 Manifesto'* was published. In order to make environmental space available for emerging nations, the 'Manifesto' proposed that industrialised countries would need to increase their resource productivity at least tenfold, mainly on the basis of improvements in the production processes for food, machinery, vehicles and infrastructure as well as of dematerialisation of value addition, such as substitution of service provision for heavy industry and manufacturing (Schmidt-Bleek 2000). The proponents of the manifesto saw an increase in resource productivity by a factor of ten as feasible within one generation if – and only if – resolute measures were taken immediately. The manifesto also had a normative element: Reducing resource consumption and the environmental space occupied by the rich of the world would provide the poor with more opportunities to satisfy their needs.

Both concepts (Factor 4, Factor 10) were taken up within a small community of environmental researchers - and virtually ignored by policy makers in developed and in developing countries. However, there is reason to expect that in the near future the question of how to effectively decouple economic growth from energy, resource consumption, emissions of harmful gases, effluents and waste will range high on the agenda. For the **private sector**, the

9 From 260 879 ktoe (kilotons oil equivalent) to 271 879 ktoe, http://epp.eurostat.ec.europa.eu, accessed Dec. 27, 2008.

10 Among the reasons for this trend are increasing numbers of households that possess a car; e.g. in the European catch-up countries (Ireland, Spain etc.), consumer preferences for heavier cars etc.

11 In the last ten years, real GDP growth in the EU 15 peaked in 2000 (3.9% annual growth) and was below 3% in all subsequent years, http://epp.eurostat.ec.europa.eu, accessed 12 Aug., 2009.

projected long-term increase in prices for energy and raw materials makes resource efficiency an urgent business case. **Policy makers** in many countries are implementing programmes designed to respond to internationally agreed environment targets and to the increasing pressure of the international scientific community, civil society and the media.

The *'Factor 10 Manifesto'* to some extent sketches a dichotomy between the rich (countries) that inevitably will have to reduce their resource consumption and the poor (countries) that will be enabled to grow economically in order to satisfy their pressing social needs. However, developments in recent years have made quite clear that this "give and take" strategy cannot lead to the intended preservation of the global environment. Continuously high growth rates and dynamic industrialisation have turned some of the dynamic anchor countries into major consumers of natural resources and occupants of environmental space. China and India are today among the five major emitters of carbon dioxide worldwide. It is becoming increasingly clear that if they do not achieve significantly higher levels of resource productivity, the inevitable result will be severe overexploitation of natural resources, including sink capacities of the biosphere. This raises the question of whether anchor countries could achieve a technology-driven leap in resource productivity that would lead to more sustainable growth patterns in the near future.

3 Technology transfer versus domestic innovation capabilities: Which way forward?

Technology plays an important role both in the global environmental discourse and in the context of related multinational agreements. The main debates of the past decades have concentrated on the modalities of technology transfer and intellectual property rights and thus also on the question of costs of access to technology in developing countries. In the context of climate change and rapid resource degradation, these issues are very high on the agenda.

Technology transfer can be defined as *"... a process by which expertise or knowledge related to some aspects of technology is passed from one user to another for the purpose of economic gain"* (Schnepp et al. 1990). In the case of the transfer of sustainability-oriented technologies, the economic benefit includes the mitigation of future costs related to damage to the environment (see Ockwell et al. 2008, 4105).

In fact, the transfer of technology from the industrialised to developing countries will have to play an important role if the target of climate change mitigation is to be reached, and this will most likely go hand in hand with revisions of existing IPR regulations (ICTSD 2008). There are a number of technological artefacts for the transition towards more sustainable development patterns, and these are available "off the shelf" and at continuously declining costs due to international competition (e.g. Zahedi 2005 for the case of solar photovoltaics). In most of these cases, overcoming the sustainability challenge requires a quick diffusion of clean technologies across the developed and the developing world. This has to do mainly with institutional and financial issues and less with further technology development. However, for a couple of reasons, technology transfer is but one element in the transition towards increases in resource productivity and decoupling in developing countries and will have to be accompanied by other measures:

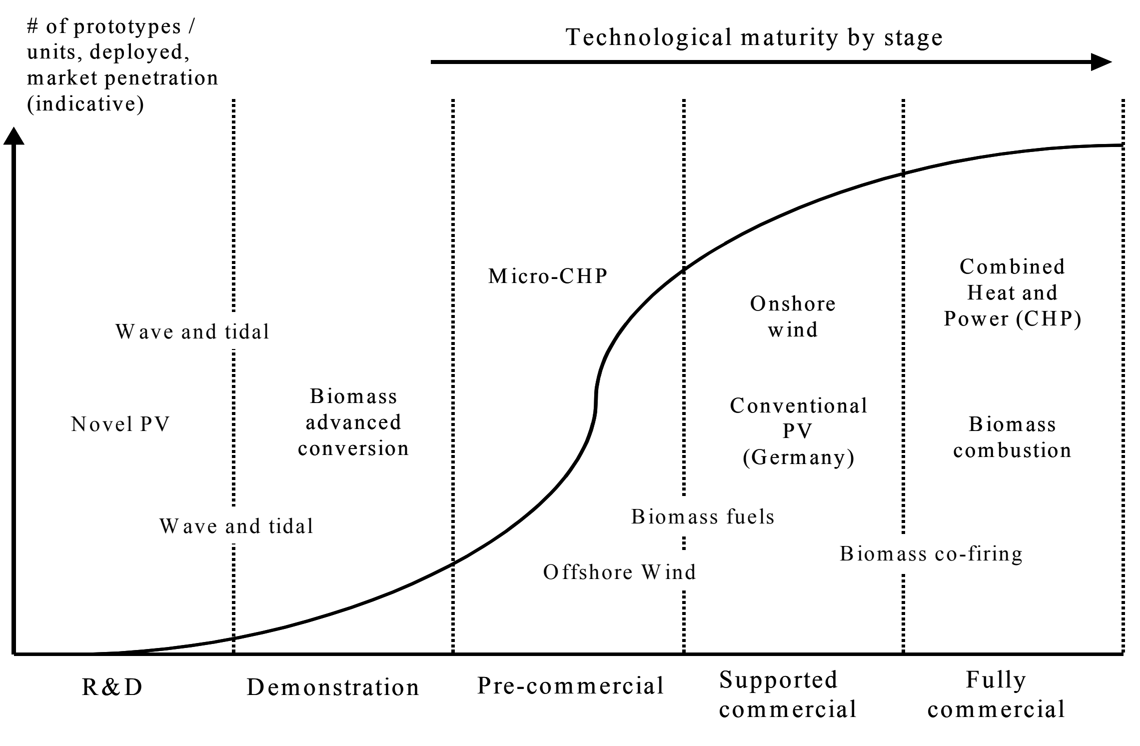
— Many technological options for providing sustainable solutions are still in the R&D, demonstration or pre-commercial phase, even on a global level (see Box 2), and this implies high technology risks for any country wishing to roll them out on a large scale. It calls for internationally coordinated R&D activities in order to shorten the time required to make these technologies ready for quick deployment. These efforts should include all countries with advanced scientific and technological capabilities.

— Even where technologies are relatively mature, a multitude of factors may explain why technology transfer – assuming willingness on both the side of technology provider and technology taker – is a complex task, especially when this transfer is to be managed across distance (without face-to-face contact) and in an intercultural setting. The transfer of technologies that go beyond simple-to-use artefacts (e.g. mobile phones) can be successful only where a certain level of *technological mastery* (Dahlman / Westphal 1982; Katz 1987; Lall 1987) is found. For instance, the already-mentioned solar photovoltaic (PV) panels, even though they can increasingly been seen as a globally available industrial commodity, will only reach significant levels of roll-out if they are integrated into more complex systems (solar home systems, hybrid mini-grids) that require certain levels of capability in system integration, monitoring and maintenance.

— Technological artefacts generated in the North, especially in areas like agriculture or health, are often not ready to be applied in the South but need first *"to be translated to the ecological specificities of a different part of the world"* (Sachs 2002, 8).

— Finally, technological knowledge has important tacit components, elements that are difficult to codify and thus "sticky" and difficult to transfer to other locations. Especially

Box 2: Technological maturity of selected clean energy technologies



This graph can only illustrate the overall situation, that may vary between countries and change within few years. Foxon et al (2005) classify conventional PV as belonging to the "pre-commercial" stage in the case of UK. In Germany, however, due to a very attractive feed-in tariff, solar PV may clearly be classified as a "supported commercial" technology.

Source: Foxon et al. (2005b), slightly modified in a cross-cultural context, this calls for local experts able to translate the requirements of technologies into the local context.

The fact that horizontal technology transfer can be only part of the solution is increasingly recognised in multilateral dialogues and agreements. Thus, the Bali Action Plan (December 2007), within the UNFCCC (United Nations Framework Convention on Climate Change) process, goes beyond technology transfer issues; the agreement includes the *"Promotion of endogenous development of technology through provision of financial resources and joint research and development"* and *"Promotion of collaborative research and development on technologies"* as important elements of the agenda.

In many cases, mainly in most small low- and middle-income countries, domestic technological capabilities will be limited, for the foreseeable future, to search, selection and adaptive capabilities. In a couple of anchor countries, however, the situation is quite different and their potential contribution to the generation of innovations required for the transition towards more sustainable development patterns is much higher. They look back on decades of efforts to develop own technological capabilities. The amounts of resources they are able to invest in infrastructure, education and incentives related to technological achievement are likewise much higher. They are higher in *absolute* terms, due to the size of the economy, and often also in *relative* terms, due to the higher political priorities given to technology development. Larger territories, economies and societies offer the possibility of greater economies of scale and scope for innovators. Anchor countries like Brazil, China, India and South Africa have recently initiated targeted efforts aimed at reaching a scientific and technologic par with the OECD world, quickly expanding national spending on R&D and developing ambitious long-term strategies.

To the extent that sustainability-oriented technologies are considered key for future economic growth and employment creation, there is reason to expect the anchor countries to strive to gain a relevant share of their development and production, even for regional and global markets. That this is a feasible option I shown by the case of Suzlon, the Indian manufacturer of wind turbines (see Box 3).

Box 3: A global player in the international wind energy sector: The Indian company "Suzlon"

Established in 1995, the Indian company Suzlon is today Asia's leading manufacturer of wind turbines, covering around half of the wind energy market in India. It ranks fifth at the global level and today has operations in 21 countries and R&D labs in India, Denmark, Germany and the Netherlands.

Suzlon has adopted a diversified strategy to acquire the technological know-how it needs. It collaborated with the German Company Sudwind Energiesysteme GmbH (Sudwind) in 1996 to acquire technical know-how relating to wind turbines of various capacities, ranging from 270 kW to 750 kW. In return it made royalty payments for each wind turbine sold over five consecutive years. Subsequently it entered into a licensing agreement with another company, Enron Wind Rotor Production B.V., for production of a different model of rotor blades in India. The company adopted a manufacturing strategy based on a combination of in-house R&D and acquisition of technology through licensing agreements. To gain a greater control over the supply chain, reduce cost and make product delivery faster and more efficient, it strengthened its manufacturing capabilities and went for maximum in-house manufacturing of wind turbine components. In 2006 Suzlon acquired Hansen Transmissions, the world's second largest turbine gearbox maker. This backward-integrated supply strategy was aimed at establishing a presence along the supply chain. Besides reducing its external dependence on components, it also enabled Suzlon to sell components, such as gearboxes, to third parties. In 2007, Suzlon further opted to acquire a German wind turbine manufacturer - REpower - to gain a foothold in the European market and become an integrated global player.

Sources: Red Herring (2005); Kristinsson / Rao (2007)

Box 4: Internationalisation of innovation systems in anchor countries

Science, technology and innovation (STI) policy, a traditionally inward-oriented policy field, is increasingly becoming part of global politics. Over decades, governments in Western European countries, the US and Japan pursued explicit strategies to enhance their performance in research-based innovation and science. They delegated responsibility to intergovernmental organisations (IO) such as the Organisation for Economic Co-operation and Development (OECD) and special entities at the United Nations (UN) to refine the formation of science- and innovation-related policies and their impact on economic development. Since the end of the Second World War, a fragmented architecture of 'global governance' in STI has come into existence. Beyond the regulation of intellectual property rights (IPR), several global governance institutions have begun to provide models and policy guidelines elaborated on the basis of their own research or in collaboration with social scientists with the objective of promoting STI in the developing world.

Anchor countries play a threefold role in this setting: **First**, anchor countries pursue explicit science and innovation policies to increase their international competitiveness and raise the welfare of their societies. Their governments are experienced in STI policy making in different development contexts, often in close contact with intergovernmental organisations. They now also provide models for STI policy for less developed countries.

Second, following decades of inward-oriented science and technology policy, their strategies have shifted towards outward and systemic innovation policy. Some governments in anchor countries assume the role of driving forces in voicing the interests of the developing countries in international organisations. Brazil and Argentina initiated a development agenda for World Intellectual Property Organization (WIPO) to ensure that the institution aligns its activities to the UN Millennium Development Goals. 2003 saw the emergence of the India-Brazil-South Africa (IBSA) Dialogue Forum, which has a programme on science and technology cooperation. Furthermore, the G8 invites the governments of selected anchor countries, the so called O5, Mexico, China, India, Brazil and South Africa, to join its annual summits. The OECD also initiated 'outreach programmes' with selected anchor countries that allow them to participate in and observe the committee meetings.

Third, as global problems grow, these countries are indispensable partners for collective action to promote, quickly and efficiently, research and infrastructure for technological innovation - although there is as yet no common understanding as regards how to best to organise multilateral research cooperation.

There are, thus, good reasons to consider anchor countries as **strategic partners** in internationally coordinated efforts to quickly bring about the innovations required for the transition towards a sustainable development path. This is mainly due to three reasons:

- due to their large and quickly growing environmental footprint, technological change is essential in these countries;
- they have significant technological capabilities that enable them to contribute to the development of sustainable solutions;
- technologies developed under the ecological conditions and factor endowments of the anchor countries could prove to be more adequate to be rolled out in less advanced developing countries in their world region than those developed in industrialised countries.

Setting up R&D cooperation networks between industrialised and anchor countries might, however, see itself faced with some specific challenges. Private companies in OECD countries that are owners of technologies may be very reluctant to share specific knowledge with anchor countries, as they fear increasing competition in high-end markets from non-traditional actors that, while catching up technologically, benefit from considerably lower production costs. It is thus not surprising that the question of how to deal with IPR issues still remains highly contentious in international negotiations, and is especially prominent in the context of climate change mitigation (Ockwell 2008, 4104).

4 Innovation systems in anchor countries and sustainability – A literature review

In Section 3 we concluded that a dynamic deployment of sustainability-oriented technologies in anchor countries cannot be reached exclusively through the transfer of technologies developed in the North but that both local technological capabilities and joint innovation efforts are needed for the purpose. How effective policy regimes can specifically foster the swift development and diffusion of clean technologies and how this can be assisted by adequate international cooperation agreements is still a largely open question. What is required is a deeper understanding of *"technological systems of sustainability innovation"* (Walz / Meyer-Krahmer 2003, 16).

In this section we will argue that the innovation system (IS) approach developed since the early 1990s is an adequate heuristic concept to analyse the institutional setting in which innovations are generated. However, we will highlight two deficits in the available IS literature. First, most IS research to date has concentrated on the advanced industrialised countries, and possible specificities of IS formation in developing and anchor countries are not captured in a systematic way. Second, IS research is mostly concerned with the development of technologies that enhance the competitiveness of companies, sectors or national economies. Little can be said, at present, about the emergence and dynamics of IS that contribute significantly to the preservation of global public goods and thus need to be driven much more by forces that are not directly market-based. Two strands of the literature are discussed that explicitly link innovation with sustainability: 1) the **transition or system innovation** approach, which focuses mainly on the framework conditions under which socio-technical systems may shift towards higher levels of sustainability, and 2) a body of literature that takes up the IS approach in order to derive conclusions for **sustainable innovation policy regimes**. From gaps identified in the IS literature, we derive, in section 5, conclusions for a research agenda.

4.1 Development of the innovation system approach

Two groundbreaking books published in the early 1990s (Lundvall 1992; Nelson 1993) have triggered a large body of literature dealing with innovation systems (IS). While the first publication deals with IS from different angles (learning in institutions, user-producer relations, the role of the public sector and of finance in IS etc.) the latter is basically a compendium of 14 national case studies. The scope of the two books has clearly shaped the subsequent international debate on **national innovation systems (NIS)**, understood as the aggregate of public and private organisations (universities, research centres, and companies) that contribute to the generation and application of new technological knowledge as well as the policies and incentive systems in place within a national economy to support this process.

The comparative country studies in the book by Nelson (ed.) mentioned above and subsequent studies by other authors conclude that there is no such thing as a single mode of NIS, even in today's highly industrialised countries, which implies that they have a certain level of idiosyncrasy. Despite this, the concept has gained great acceptance among economic and social science researchers interested in understanding variations in the technological achievements of different countries. It has also received attention by policy makers, as it helps to map out actors involved in innovation generation, identifying the linkages among them as well as gaps and missing links that lower technological capabilities.[12] The majority of the early studies following the NIS approach remained relatively descriptive. In 1994, Nelson outlined the concept of "co-evolution of technology, industrial structure, and supporting institutions", stressing the cumulative character of technological learning and the possible path dependency of technological trajectories. This may be seen as an important step towards a common understanding of NIS evolution.

In a parallel scholarly development, regional economists and economic geographers stressed the empirical fact that in many cases specific innovative capabilities arise not at the nation-state level but within geographically limited spaces. They analysed and highlighted the importance of specific and often locally or regionally bound resources and of complementarities among private and public actors within clusters, such as Silicon Valley or "Third Italy". Especially with regard to high-tech regions in developed countries, the focus was on the important role of actors sharing common social and cultural values ("creative milieus") (Fromhold-Eisebith 1999), to some extent reviving the much older concept of industrial districts.[13] This line of research led to the concept of **regional innovation systems (RIS)**. Even though the term was coined already at the beginning of the 1990s (Cooke 1992), the concept became really popular only at the beginning of the new millennium (Doloreux / Parto 2005).

Finally, in recent years the **sectoral innovation system** concept has started to gain importance. This reflects the growing awareness that, in many cases, technological capabilities and innovation potential have to be analysed at the level of distinct sectors in order to achieve a thorough understanding of them. Especially in high-technology sectors, such as pharmaceuticals or information and communication technology (ICT), innovative dynamics have to be conceptualised as the outcome of complex interaction between local/regional, national and international actors (Malerba 2004). Sectoral systems of innovation have a lot of variability since they emerge and develop in continuously changing environments, are characterised by path-dependent processes and are embedded in different socio-economic contexts (Kristinsson / Rao 2007, 6).

With very few exceptions, IS research focuses on the **developed market economies**. The book edited by Lundvall, while basically issue-centred, refers exclusively to concrete cases bearing on historical or recent experiences of Europe, the US and Japan. The selection of NIS studies edited by Nelson, as well as the compendium edited by Malerba on sectoral innovation systems, also comprise mainly EU countries (Germany, UK, France Italy), the US, Canada, Japan. Argentina, Brazil, Israel, Korea and Taiwan are included as examples for less advanced countries. Only recently have a number of other countries been included in this strand of the research, e.g. Uruguay (Arocena / Sutz 2000), some African countries (Muchie / Gammeltoft / Lundvall 2003) or India, Indonesia and Thailand in the book on Asia's Innovation System edited by Lundvall / Patarapong / Vang (2006). The attention of an increasing number of researchers is drawn to China, triggered by the high dynamics of its development (Guangzhou 2007; Altenburg / Schmitz / Stamm 2008). In Section 5.2 we will outline some basic assumptions on what may make IS formation different in countries that today are striving to catch up technologically with the OECD world.

12 Actually, South Africa, in a White Paper on R&D from 1996, has adopted the innovation system approach as the concept for policy making in this field, one of the first countries worldwide to do so.

13 This term was coined by the British economist Alfred Marshall (1842–1924).

4.2 How innovation system research links with sustainability – A first look into the debate and political practice

Until recently, IS research did not systematically take into consideration aspects of ecological sustainability.[14] Only since around the end of the 1990s has this gradually begun to change. This change seems first of all to have been triggered by growing environmental concerns in the industrialised countries that have either induced (market differentiation) or forced (regulations, technical norms) companies to introduce cleaner production processes and made ecological product features a competitive asset. The observation that some sustainability-oriented industries have become boom sectors, such as wind energy in Denmark or solar energy in Germany triggered a series of specific sectoral studies, e.g. in the field of renewable energies (see Box 5). Despite these new research fields, there is still no *systematic* integration of sustainability dimensions into innovation systems research, and it still needs to be clarified whether sustainability-oriented innovation systems have features qualitatively different from more commercial systems - and then, what these features are.

Box 5: Sectoral innovation systems related to renewable energies in Europe and India
One important line of research on innovation systems is concerned with the emergence of new technological systems and system functions. The empirical focus of this line of research has been the forma-tion of renewable energy innovation systems in industrialised countries, addressing specifically how the functions of such systems are established and how they interact as the system develops. As Jacobsson and Bergek (2004) argue, "for a transformation of the energy system to take place, new technological systems with powerful functions need to emerge around a range of new energy technologies" (p. 819). A number of case studies on solar, wind, biofuels/biomass have been carried out in Germany, Sweden and the Netherlands. Some of the findings that have emerged from this research highlight that govern-ment policy has been one of the central influencing factors in the development of new renewable energy systems. Such influence has been both positive - creation of incentives for market formation and knowledge development - and negative - erratic policy initiatives that have hindered the creation of diversity in the development of technological solutions and increased uncertainties about market and technological development. Recent work has also examined the development of renewable energy innovation systems in a late-comer context. This research indicates that the development of the Indian wind energy innovation sys-tem drew on interactive learning involving Danish and Indian actors rather than simple technology transfer.
Sources: Bergek / Jacobsson 2003; Jacobsson / Bergek 2004; Negro / Hekkert 2007; Suurs / Hekkert, 2007, Bergek / Jacobsson 2008; Hekkert / Suuvs 2007; Kristinsson / Rao 2007

4.2.1 The "transition" or "system-innovation" discourse

The approach with probably the most ambitious and visible aim of linking innovation and sustainability issues is the transition or system-innovation discourse. During the late 1990s and early 2000s, the focus of the debate started to move away from the micro-level dynamics involved in the introduction of clean process and product technologies. The debate has become concerned with the ways in which broadly defined encompassing **socio-**

14 Some authors mention the sustainability challenge as leading to or requiring a new paradigm for the handling of knowledge creation in research and policy: *"The development of environmentally friendly technologies and their universal diffusion may impose a more cooperative civilisation and an entirely new pattern of institutional change and of knowledge accumulation"* (Freeman 2002, 209).

technical systems evolve towards greater sustainability (Berkhout 2002; Smith 2003; Geels / Elzen 2004). This shift has been driven by the recognition that a narrow focus on innovation of single technologies at the firm level neglects important changes at the institutional and policy level that are intrinsically associated with environmental innovation and a path towards sustainability. Consequently, in the context of this new analytical focus, increased attention is given to changes in broad socio-technical practices and technical and institutional systems that contribute to sustainable development.

A socio-technical system has been defined as *"a cluster of elements, including technology, regulations, user practices and markets, cultural meanings, infrastructure, maintenance networks and supply networks"* (Geels / Elzen 2004, 3). These socio-technical systems involve a multitude of elements that are responsible for or involved in fulfilling specific societal functions such as transportation, energy provision, housing, health care and so on (Geels 2004a). The concept is broader than sectoral innovation system concepts, because it includes the user environment and consumption patterns as central dimensions of the system (Geels 2004b).

System innovation refers to the transition from one socio-technical system to another, qualitatively different one, for instance, from horse-driven to automobile transport systems (Geels / Elzen 2004, 3). According to the proposed model, system transition has the following characteristics. It is:

- multi-level, with changes occurring simultaneously at the level of 'socio-technical landscapes' (macro-level, encompassing broad political, economical, etc. trends), 'socio-technical regimes' (meso-level) and 'niches' (micro-level);
- multi-actor, involving multiple stakeholders; and
- multi-factor, with changes driven not by a single factor such as technological change but by several interacting factors, such as behavioural, institutional and technological drivers (Elzen / Wieczorek 2005).

System innovations are conceived as subjects of social experiments that can be promoted through sustainability *niches* that subsequently develop into new *systems*.

> *"Finally, transitions require learning processes and policy pressure upon incumbents in order to transmit improved niche practices into the mainstream (socio-technical change.)"* (Smith / Kern 2007, 6 f.).

The transition discourse has received significant attention in sustainability science and also in policy making. For instance, the fourth Dutch environmental plan explicitly adopts this approach as the guiding principle to define, basically, future development trajectories in energy supply. However, as Kern (2006) points out, five years after its adoption the "energy transition" approach has not managed to significantly alter Dutch energy policy. Smith / Kern (2007, 18) come to a very sceptical conclusion regarding the impact that transition discourse has thus far had in practice:

> *"The transitions discourse is failing to reinvigorate and radicalise ecological modernisation. As before, structural components diminish the storyline. Overriding imperatives around economic performance and international competitiveness, embodied within the more powerful policy-making institutions of government, continue to trim ecological modernisation into a series of incremental reforms".*

When the approach is tested as a useful tool for research on the inter-linkages between technological innovation and sustainability, one significant deficit found is the fact that the empirical base for ex-post transition studies – even in the industrialised countries - seems to be very limited. In this respect the two "transitions" analysed in the book edited by Elzen / Geels / Green (2004) are not wholly convincing:

- Belz (2004) analyses how the Swiss agri-food chain has moved towards higher levels of sustainability during the last decades. However, there is some doubt as to whether transition from industrialised agriculture to standard integrated production within a timeframe of 30 years can really be labelled a radical innovation, or even a system innovation. It does not really imply a complete shift from one complex socio-technical system to another but rather the introduction of a set of better (more sustainable but also cost-saving) technologies in agriculture.
- Correljé / Verbong (2004) analyse the shift in the Dutch energy system from coal-based to gas-based supply. Here the scale and scope of change is indeed very significant, but it was triggered by a very specific event, the detection of massive amounts of natural gas in the north of the Netherlands. Also it may be questioned whether the substitution of oil by gas can effectively be labelled a sustainable system innovation.[15]

4.2.2 The sustainable innovation policy regime approach

A research project at the Imperial College in London[16] took up the innovation system approach to develop "guiding principles" and concrete policy recommendations for the development of a **sustainable innovation policy regime.** The authors stress the fact that even in Europe this is a rather new policy field:

> *"Historically, SI has not generally been seen as a subject for deliberate policy delivery, with separate policy regimes addressing innovation and environmental sustainability. The challenge of bringing these two policy areas together is now coming under active consideration at both the EC level, through the Environmental Technologies Action Plan, and at the UK level, including in the government's Energy White Paper and Innovation Report"* (Foxon et al. 2004, 4).

Thus, the first "guiding principle" mentioned for the development of a sustainable innovation policy regime is to bring the two policy regimes together by promoting sustainable innovation as an explicit goal of policy making, facilitating systemic changes in technological and institutional systems, creating a long-term, stable and consistent strategic framework and formulating clear, long-term sustainability goals (Foxon et al. 2005b, 12).

The study compared sustainable innovation promotion in the UK and EU and analysed the dynamics (or lack of dynamics) in six industries related to the provision of low carbon energy (onshore and offshore wind, wave and tidal, photovoltaic, biomass hydrogen from renewables and combined heat and power) in the case of the UK and technologies for new fuels in vehicles (Europe). It derives the need for policy intervention (dedicated govern-

15 It may be conceded that coal is a far higher-pollution fossil fuel than gas, so the outlined transition may indeed have led to a certain decoupling of energy from CO_2 in the Netherlands.

16 *"Policy Drivers and Barriers for Sustainable Innovation"*, see Foxon et al. (2005b).

ment support and financial incentives) from the concept of "system failure" initially developed by Edquist (2001).

With a view to identifying system failures and deriving feasible policy options, the authors look at the chain of the innovation processes from R&D through the demonstration, pre-commercial, and supported commercial stages to the fully commercial stage. The two stages most likely to suffer from system failures are the transition between the demonstration stage and the pre-commercialisation stage and between the pre-commercialisation stage and supported commercialisation stage (Foxon et al. 2005b, see also Box 2).

Gross and Foxon (2003) derive sets of policies that push sustainability innovations forward and should be seen as complementary to environmental policies in the stricter sense, such as regulations and efforts to internalise environmental costs:

- basic R&D,
- market-creating policies,
- fiscal incentives.

All three policies are relevant for policy makers in developing and anchor countries. However, even if countries manage to raise public R&D spending, as announced in some ambitious plans, the absolute financial resources available for the promotion of innovation systems will probably be limited in the near future (especially under the conditions of the financial crisis and the economic downturn). Only market-creating policies are not directly related to increased spending and thus seem most interesting for countries with constrained public budgets.[17] The authors see here three main options for government action that are also relevant for developing countries.

- The aim of **strategic niche management** is to increase the diversity of available technologies and give cleaner technologies opportunities to mature through learning-by-doing and learning-by-interacting. One important tool in this respect is public procurement. By linking public procurement to specific product and process specifications, governments can contribute to the creation of geographical and/or sectoral niches.
- Sustainable innovations can also be promoted by what has been referred to as **back-loading support**, e.g. by awarding prizes for the development of technological solutions that pursue particular environmental objectives.
- A complementary approach consists in setting **long-term, outcome-based targets** or obligations designed to allow cleaner technologies to gain a certain share of the market. One example is the Zero Emission Vehicle Program in place in California since 1990. The regulation requires automakers to make available a certain percentage of different types of emission-free vehicles for sale or in demonstration programmes in California.[18]

17 This does not imply that these measures cost nothing at all. Linking public procurement with high environmental standards will usually imply not buying the cheapest artefact on the market. Feed-in tariffs for renewable energies usually imply higher electricity costs that have to be paid by consumers. Enforcing high environmental standards for products may result in higher production costs that may be passed on to the consumer.

18 http://www.ucsusa.org/clean_vehicles/solutions/advanced_vehicles_and_fuels/californias-zero-emission-2.html, last accessed Oct.15, 2009.

5 The formation of sustainability-oriented innovation systems in anchor countries – Towards a research agenda

We have argued that what is required to reconcile socio-economic and environmental development goals are high levels of technological and innovation capabilities not only in OECD countries but also in developing countries. This is first of all the case with regard to those countries that, due to their size and rapid growth, have ascended into the group of heavy emitters with high levels of resource consumption. How technological capabilities in these countries can be strengthened by building effective sustainability-oriented innovation systems (SoIS) is still a rather unexplored research field. Having analysed the literature, we propose that further research be clustered around three main and interlinked topics:

- What are the specificities of sustainability-oriented IS? For too long, innovation and environmental policy have been treated as separate policy regimes and addressed by different research communities. Bringing them together requires a deeper understanding of the functioning of innovation systems oriented towards sustainability.
- Are sustainability-oriented innovation systems emerging in the anchor countries, and especially those with a high impact on the global environment, namely Brazil, China, India and South Africa? What policies could assist in their formation and what role can international cooperation play in this respect?
- Are we observing a shift towards global innovation systems for sustainability? International cooperation and network building in science, technology and innovation are rapidly increasing, including disciplines related to sustainability. Knowledge needs to be generated regarding these emerging patterns of global knowledge creation and the possibilities available to promote it with a view to better addressing global sustainability challenges.

In Sections 5.1 through 5.3 we outline some guiding questions and preliminary assumptions related to these three thematic issue clusters. We propose that these should be taken as the starting point for in-depth research, empirical validation and further concept development.

5.1 Sustainability oriented innovation systems: What makes them special?

As noted above, the idea of gearing innovation systems especially to providing solutions for the overarching challenges of sustainable development poses a serious challenge to both research and policy making. Innovation systems are usually driven by private interests, with public actors filling the gaps, mainly in training and basic research, where markets do not function properly. SoIS operate in science and technology fields, where market and system failures are pervasive, due to the fact that environmental costs are still largely externalised.[19] This implies that SoIS need to be shaped under the conditions of a *twofold market failure* (non-appropriability of the returns on investment in innovation *and* externalised environmental costs). Where markets fail in such a systematic manner, the role and

19 This is in especially the case with regard to sink capacities of the atmosphere, water bodies and soils, where pricing has only recently been discussed and implemented, e.g. through emission-trading arrangements.

responsibility of *policy making* are especially important. This brings up the question: **How can policy contribute specifically to the formation and strengthening of sustainability-oriented innovation systems?**

Proceeding from the transition literature (4.2.1) and the research on sustainability innovation policy regimes (4.2.2), it is possible to derive some provisional considerations on how SoIS can be conceptualised. On the **supply side** of the innovation system, government action is needed to ensure the provision of training for a sufficient number of people able to develop, deploy and master clean technologies. As regards the qualitative orientation of human resource formation, it will be important that a sufficient *variety* of training profiles is achieved in order to break out of (or avoid) path-dependent development and ensure that a set of technology options will have the opportunity to mature, first in specific niches, with the possibility to challenge less sustainable development paths. Traditional engineer-type technology experts will have to represent important components of the human resources base. However, the complexity of sustainability challenges also requires non-traditional and interdisciplinary approaches, including linking "hard" sciences with social sciences, which can provide knowledge on how new solutions may be adopted swiftly by societies.

As in the case of human resource development, funding and governance of research and development will also need to assure sufficient variety in technological options, especially as long as levels of uncertainty about potentially successful trajectories remain high. Under the conditions of limited public R&D budgets, this implies developing funding schemes with high leverage effects – regarding the scale of R&D undertakings, but also regarding the creativity induced by the programmes.

The term *Valley of Death* denotes the gap arising between public funding of basic research and private funding of close-to-commercial technologies, i.e. mobilising funding for demonstration projects and pre-commercial undertakings (Etzkowitz 2006, 314). It does not come as a surprise that this problem in technology development has also been identified in the case of SoIS (see Foxon et al. 2005a). As regards sustainability-oriented innovation, viewed from a public goods perspective, the risk that potentially feasible innovations may "die" in the Valley of Death or that their maturation process may be significantly delayed should clearly be avoided. Bridging the Valley of Death requires significant funding, as technological demonstration projects tend to require high upfront investment. In the context of anchor countries, as large and powerful but still relatively poor developing countries, this raises the question **whether large-scale funding for bridging the Valley of Death in sustainability oriented technologies can be expected to be mobilised at the national level and how international and especially multilateral efforts might possibly serve to flank these efforts.**

Due to market failure in sustainability technologies, **demand-side measures** and **market-creating policies** may be seen as especially important features of SoIS. Here government regulations and incentive schemes are crucial. In the case of renewable energy technologies, feed-in tariffs have proven to be a very powerful instrument in a number of industrialised countries (Medonça 2007, 76-86). A number of developing countries, such as South Africa, have adopted feed-in tariffs to promote renewable energies. However, in this case and with regard to other incentive and regulation schemes, it would be important to explore **whether and what adaptations to the technical and socio-economic conditions of the specific countries will be required when it comes to designing effective promotion schemes**.[20]

As has been shown e.g. for the case of the renewable energy innovation system in place in the UK (Foxon et al. 2005a), the formation of SoIS requires the implementation of a coherent set of different policy measures on both the supply and the demand side. In many cases, the outcome of policy measures is, ex-ante, highly uncertain, implying the need for continuous monitoring and readjustment of instruments. This raises the question whether the **governance capacities and implementation capabilities in place in anchor countries are sufficient to establish effective SoIS and how, possibly, international cooperation could contribute to achieving effective policy making and implementation.**

Box 6: Catching up in sustainability-oriented innovations: The case of solar energy in China

The origins of Chinese solar energy research date back to the 1950s, but industrial production took off only in the late 1970s/ early 1980s with the establishment of five state-owned enterprises, one of which was a spin-off of a research institute. The government's interest in the sector was originally driven by the strategic potential seen for both space and terrestrial applications. Following the reform process and market liberalisation, sector development relied more and more on private firms, which concentrated their activities on crystalline silicon technology and the production of solar wafers, cells and modules. Annually installed photovoltaic (PV) capacity in China developed slowly at a rather low level, although the industry soon concentrated on export-oriented production and the more labour-intensive stages of the production chain. Special government programmes designed to spur rural and township electrification led to a brief boom in national installation of off-grid systems around 2002.

Chinese firms are active at all stages of the silicon-based solar energy production chain, and the capability to produce solar grade silicon has been developed quite recently. Technology development is based both on in-house R&D of major producers and in collaboration with universities and specialised research institutes. Although China's solar energy industry is very competitive in the global market, it is often noted that the industry is technologically weak for the following reasons: 1) some core technologies needed in the production chain, such as solar inverters, still have to be imported; 2) production is concentrated on silicon-based solar technologies, and other technologies (thin-layers, membranes etc.) are still in the R&D stage; 3) the national market for PV is rather weak, mainly due to a considerable price advantage for coal; 4) there are still both technological problems and institutional challenges that serve to impede efforts to feed solar energy into China's grid.

While the government adopted a rather low profile in the industry's development during the 1990s, a change in government policies occurred in 2006, when the development of renewable energies became part of the strategy to embark on a sustainable development path. Government programmes to support renewable energies have been accompanied by announcements of intent to actively foster solar energy research capacities. Many provinces and municipalities have accordingly created support plans. Most recently, the government has announced that the ambitious targets set in 2006 to reach an annual PV installed capacity of 1.8 Gigawatt peak (GWp) by 2020 will be upgraded to 10 GWp, in the framework of the soon-to-be-published 'Sectoral programme for new energies', as part of a strategy to seize the opportunity of the financial crisis to launch a 'technological revolution' in new and renewable energies

Sources: Marigo / Foxon / Pearson (2007); Li / Wang (2007)

20 In the case of feed-in tariffs, for instance, these work on the basis of a cross-subsidisation, by consumers, of the production of electricity from renewable sources. A dynamic increase in renewable energies would thus quickly lead to burdens, especially for poorer consumer strata.

5.2 Emerging sustainability-oriented innovation systems in anchor countries?

Relatively little is known regarding the existence or emergence of SoIS in anchor countries. There is some anecdotal evidence that in fact countries like India, China and Brazil (Boxes 5, 6, 8) have developed internationally competitive technologies in some niches within the broader field of sustainability technologies. There are some case studies that shed light on the processes behind these success stories. **It seems, however, important to enlarge the empirical base through additional in-depth case studies and to feed the findings back into the IS and SoIS discourse.**

In general terms, innovation systems have to be understood as the outcome of historical developments that are specific to each and every country. However, it is possible to identify some common determinants that may well contribute to common features of emerging innovation systems in anchor countries, and specifically in those countries that are of special interest for the topic of our paper:

We can, first, assume that past efforts to achieve high levels of technological mastery, often through mission-type undertakings and large-scale public investments, have a significant impact on today's knowledge landscapes. Second, the international framework conditions for catching up technologically are different from what today's most advanced countries experienced in past decades and centuries. **Both aspects need to be further explored and validated through empirical research.**

Box 7: Sasol (South Africa): Global player in coal-to-liquid technologies
Sasol (South African Synthetic Oil Limited) is a South Africa-based global player in the fuels sector. Its establishment goes back to a White Paper from 1927 which investigated the establishment of a South African oil-from-coal industry. The background of this approach is the fact that South Africa lacked crude oil reserves, and the government's aim was to protect the country's balance of payments from increasing imports. After years of research, the South African Coal, Oil, and Gas Corporation was formed in 1950. Since then, the company has developed world-leading technology for the con-version of low-grade coal into value-added synfuels and chemicals (Sasol 2009) and has specialised in using the Fischer-Tropsch method, originally developed in Germany. Sasol is a company that has been described by experts as innovation-seeking. Major milestones of the company's history include its first automotive fuel (1955), the establishment of the National Petroleum Refiners of South Africa (1967), and the establishment of a first international marketing company, Sasol Chemicals Europe, in 1990, which paved the way for the company's globalisation program.
Source: Stamm et al. (s. a.)

The role of technology missions for today's knowledge landscapes

Anchor countries, including Brazil, China, India and South Africa, have in the past tried to spur high-technology development with large government-sponsored projects, often organised in the form of technology missions driven by nationalistic and sometimes military motives. These technology missions were related to fields like space technology (India), the aerospace industry (Brazil) and nuclear technology (both of the former countries plus South Africa).

Most of these technology missions have been discontinued in the meantime. In most cases, they have failed – at the latest in the commercialisation stage, e.g. the intentions of Brazil and India to create a domestic computer hardware industry. However, in other cases technological clusters have successfully been built up, e.g. in the aircraft industry in Brazil (Embraer). In South Africa the parastatal company Sasol (*South African Synthetic Oil Limited*) emerged in the 1950s as a provider of liquid fuels from coal, and this entity is today considered a world leader in the Fischer-Tropsch coal-to-liquid (and gas-to-liquid) technology (see Box 7).

Little is known about the legacy of such technology missions for today's technological achievements in these countries. There is some anecdotal evidence that it may have a rather significant impact. For instance, Anand (2009) indicates that the Wind Energy Division of India's NAL (National Aeronautics Limited) is involved in the design and development of small and medium-scale wind turbines and has facilities for wind monitoring, wind resource assessment and micro-siting. Stamm et al. (s. a.) found that the technological capabilities and capacities built up in South Africa through the long-term coal-to-liquid projects conducted by Sasol (see Box 7) are today an important asset in the country's hydrogen and fuel cell strategy.

There is very little literature available that provides more systematic "longitudinal insights" into the emergence and development of technological learning in anchor countries and the relevance of technology missions in this context. This might at least partially be explained by the fact that most technology missions have been carried out under more or less autocratic governments that invested extraordinarily high amounts of financial resources in these projects, without always being obliged to consider the opportunity costs and the (lack of) broad-based benefits arising from this spending. Additionally, technology missions were considered strategic, and information related to them was not disclosed.[21]

Thus, one challenging research task is to gain a deeper understanding of the role of past (and sometimes ongoing) technology missions for today's knowledge landscapes in anchor countries. **How significant (in terms of capabilities and capacities) is the technological knowledge built up under these missions? What has happened with the embodied and disembodied knowledge in cases where technology missions have been discontinued or political ruptures occurred? To what extent do knowledge clusters contribute to the formation or strengthening of SoIS in the anchor countries, as indicated in the examples above? Can they be made functional through policy intervention?**

IS formation under conditions of a regulated globalisation

Early industrialisation in today's most advanced countries and the related build-up of technological expertise was accompanied by rather strong government intervention, including tariff protection for domestic markets. Today's catching-up processes are taking place under conditions of a **regulated globalisation**, implying a significantly different and narrowed scope for policy making. Some aspects have clearly to be seen as **disadvantages** for current technological catching-up processes:

— Local efforts aimed at technological upgrading and innovation encounter fierce competition on global markets for technology-based products and services, affecting in-

21 See Hofmänner (2003) for the case of energy research in South Africa.

ternational as well as local markets. Contrary to what has happened in the case of earlier success stories (Korea, Taiwan), market liberalisation today does restrict selective infant industry protection policies or market reservation policies.

- International regulations also affect the possible ways and forms in which technologically relevant knowledge is appropriated. For instance, stricter IPR protection regimes severely restrict the options for reverse engineering and copycat strategies.
- The scope for technology and innovation policy is also affected by other new "rules of the game" established within the World Trade Organization (WTO) framework. Instruments of industrial policy, common in many developing countries in the past, have largely been ruled out, including efforts to link local companies to Foreign Direct Investment (FDI) by imposing local content requirements.

On the other hand, the shift towards a globalising knowledge economy also opens up **new opportunities** for countries in the process of catching up, and these were not equally available for early movers:

- Technology development and innovation can fall back on huge stocks of available information and knowledge, in part in the public domain and accessible through ICT.
- Technology corporations are increasingly relocating knowledge-intensive activities to some developing countries, either in order to access human resources or to be present where demand for technology-based products is growing at a rapid pace.
- Research organisations and companies in developing countries have the opportunity to tap into global networks (e.g. in the context of EU Framework Programmes) and/or to contract specialised human resources, allowing them to access high-end know-how and merge it with locally generated knowledge.
- Developing countries can learn from experiences in OECD countries regarding effective technology policy and instruments, thus shortening learning processes and minimising the risks of costly innovation policy failures.

Comparison of these two bodies of argument, gives rise to some important research questions. **Does globalisation make the formation of IS easier or more difficult? Do pathways exist to short-cut learning processes and the related build-up of technological capabilities? Do the changes in framework conditions impact on the specific features of IS in anchor countries, e.g. in terms of the mix of national and international access to specific knowledge?**

SoIS formation in anchor countries: a promising approach to catching technologically?

We may conclude from the innovation system literature that anchor countries may enjoy **some advantages** in the development of sustainability-oriented innovations, or at least that the possibility for technological catching-up may be greater here than in more commercial technologies:

- Technological learning is a cumulative process. This implies that the lead of industrialised countries is very significant in old industries, especially where different fields of expertise need to be combined in developing a new artefact (e.g. in the automotive industry). In sustainability innovations, the underlying core technologies are often still in flux (e.g. non-silicon-based photovoltaics) or rather simple (wind turbines), lowering the entry barriers for latecomers.

- Sustainability-oriented innovations often imply a rather radical deviation from established trajectories. As Walz / Meyer-Krahmer (2003, 15) point out, high fixed investment in established (e.g. water and energy) infrastructures can lead to technological lock-ins in the industrialised countries of the North. In catching-up countries, these lock-ins may be much less severe.[22] This can open up space for catching-up countries, where infrastructures, but also production and consumption patterns, are still less consolidated.
- Geographical conditions in some developing countries may prove especially favourable for the development and implementation of new solutions, including e.g. solar or geothermal energy and biofuels (see Box 8). This may lead to the relocation of R&D from industrialised countries to these countries, thus enabling the emergence of *"lead markets for sustainability innovations"* (Walz / Meyer-Krahmer 2003, 16).
- Many sustainability-oriented innovations developed in the industrialised countries may not be adequate for quick deployment in catching-up and developing countries: They often require very high up-front investment, making sustainable solutions unaffordable for large shares of the population and small and medium companies. They may also need regular maintenance that can be reliably provided in industrialised countries through a high density of relevant technology-oriented services, though not in developing countries. Thus, it may be a feasible strategy for catching-up countries to develop into providers of sustainable solutions for their world regions and beyond, i.e. for countries with similar factor endowments.

Box 8: Development of technological capabilities in Brazil's biofuels sector
Biofuel production in Brazil is based on sugarcane for ethanol fuel and vegetable oils, mostly from soya, for biodiesel. Brazil is the world's second largest producer of ethanol, with an output of 24.5 billion litres in 2008, and its leading exporter. In 2008, ethanol consumption overtook petrol, and currently around 87% of new cars sold are flex-fuels able to run on a blend of ethanol and gasoline. Biodiesel production was initiated only in 2005, and in 2008 output reached 1.1 billion litres. Although Brazil had been experimenting with the use of ethanol as transport fuel since the 1930s, the take-off of the industry dates back to the aftermath of the first oil crisis and the collapse of sugar prices in the first half of the 1970s. Following that, in 1975, the Brazilian National Alcohol Programme (Proálcool) was created to promote the production and use of sugarcane ethanol as a transport fuel. The programme rested on several policy measures, including compulsory blending requirements, low-interest loans to sugar cane and ethanol producers to expand production, price setting and guaranteed purchases and distribution of ethanol. In 2004, the National Biodiesel Production and Use Programme was launched to foster the production of biodiesel. The programme regulated an initial addition of 2% of biodiesel to diesel, with an increase planned to 5%. The initial development of the sector from the mid-1970s involved the deployment of a mature and rather simple technology, followed by engineering efforts to implement incremental changes to the technology to increase the scale of production. Subsequently, R&D efforts were carried out that led to the generation of novel knowledge and applications within the sugarcane technological trajectory. One important example here is the continuous introduction of new varieties of sugarcane, with higher amounts of sucrose produced per hectare. Presently, R&D projects are geared towards the creation of a variety of technological alternatives and new technological trajectories. They include the search for alternative feedstocks for biodiesel production and new production processes.
Source: Dantas / Figueiredo (2009)

22 While in Europe the deployment of renewable energies may be hampered by vested interests related to the historically grown coal and nuclear energy pressure groups, in countries such as India, where a large proportion of the population still does not benefit from grid-based energy supply, it may be easier to come up – and succeed – with non-traditional solutions.

On the other hand, **specific setbacks and potential barriers** can be identified that could hinder the development of SoIS, specifically in developing countries. For instance, while they are increasingly strong global players, anchor countries are still characterised by high levels of poverty. Governments achieve their legitimacy mainly by delivering social progress, i.e. employment creation and poverty reduction, and not so much by improving the environmental quality of the growth process or lowering the carbon footprint of the economy. This would imply that the resources dedicated to the environmental dimension of sustainable development might be directly competing with other efforts that may, in many countries, be given higher political priority. This refers not exclusively to the financial resources but also to the human resources available at the policy making and management levels of the societies concerned, as the shaping and monitoring of SoIS require especially high governance capacities and implementation capabilities.

It thus appears to be an open research question whether the balance of advantages and disadvantages is positive or negative when it comes to assessing whether sustainability-oriented innovations are a viable opportunity for anchor countries to reach a technological par with the OECD world. Coming up with an answer to this question is, however, of crucial importance in assessing the possible contribution of anchor countries and their innovation systems to the transition towards more sustainable development paths and strategic options for international cooperation in this context.

5.3 Towards global innovation systems for sustainability?

Globalisation is obviously affecting the generation of knowledge and the development and deployment of technologies. The number of internationally co-authored scholarly papers is continuously increasing, including papers with the participation of researchers from developing and anchor countries. International research networks are emerging, triggered by special funding arrangements, such as the EU Framework Programmes, in which partners in the South are invited to participate. Whereas in the past international cooperation in science and technology was mainly shaped by interests and decisions of individual researchers or organisations, international cooperation in publicly funded research is increasingly organised in keeping with deliberate political strategies. One example is the *Strategy for Internationalisation of Science and Research* approved by the German cabinet in February 2008.

Internationalisation is also affecting private sector R&D, mainly through the relocation of knowledge-intensive activities by technology-based companies. It is still a matter of debate how these internationalisation processes proceed and to what extent they also involve non-traditional actors such as anchor countries.[23]

New international discourses are emerging on how the formation of global innovation systems that may assist the transition towards more sustainable development patterns can be shaped by policy makers. These are mainly triggered by an increasing awareness of the severity of climate change and other global challenges (energy, food security) and the urgent need to decouple economic growth from emissions and resource depletion. It seems

23 See Altenburg / Schmitz / Stamm (2007) for China and India.

obvious that the existing mechanisms that govern international and multilateral cooperation in science, technology and innovation are not adequate to bring about the required solutions within the time frame set by the speed of erosion of natural resources.

The search for solutions to this dilemma will most likely be high on the agenda in the years to come. It seems already clear that traditional patterns of North-South technology transfer will neither be a feasible option nor accepted by developing and anchor countries. On the other hand, it is also clear that the required technological solutions cannot be developed from scratch in the context of catching-up processes (see Chapter 3 of this paper). The solution has clearly to be sought in an intelligent combination of national and international efforts. **This requires a deeper understanding of the emergence of (sustainability-oriented) innovation systems in anchor countries (5.1 and 5.2), but also of how these processes at the national level relate to increasing efforts in international cooperation.** To name some of the questions that would need to be addressed:

- Does international cooperation in sustainability-oriented disciplines and topics have an impact on innovation policies, one leading to an assignment of higher priority to the environmental dimension of sustainability?
- To what extent and under what conditions does international cooperation contribute to domestic learning processes and increasing levels of “technological mastery”?
- To what extent can international dialogues and cooperation lead to improvement of the institutional settings required for a quick deployment of environmentally sound technologies?
- Which are the most successful or promising formats for bilateral and multilateral cooperation in science, technology and innovation, and especially for the development and deployment of environmentally sound technologies?
- To what extent can technology-based private companies be integrated into international cooperation networks that are primarily geared to addressing global public goods?
- To what extent do the existing international regulations on intellectual property rights (IPR) foster or hinder international and multilateral cooperation in science, technology and innovation?

6 Final remarks: The need to bring different research and discourse communities together

This paper addresses the urgent and complex task involved in effectively decoupling economic growth from environmental pressures in anchor countries. What seems obvious is that, using the given set of technological solutions, this decoupling cannot be achieved in the time frame set by the speed with which emissions are reaching unsustainable dimensions and natural resources are eroding. What is needed is to increase the *frequency* and the *depth* of innovations. Technological solutions need to be developed at a higher rate and brought into practice at a quicker pace. And their impact on resource efficiency needs to be significantly enhanced.

In some areas, incremental innovations appear insufficient and radical innovation seems to be required. One example is the development of clean coal technologies. Considering that power stations erected today will largely shape energy systems for the next several decades, the fast development of CCS (carbon capture and storage) technologies seems to be a clear imperative that could call for a well-coordinated and -funded global mission involving all R&D and innovation actors that may be able to provide the knowledge and expertise required to enable a quick technological breakthrough.

In any case, providing the required *decoupling solutions* calls for new and concerted international action in science, technology and innovation, clearly not limited to the industrialised countries of the North but also involving actors in the developing world, and here first of all anchor countries that have accumulated technological capabilities and are striving to catch up technologically with the OECD world.

How global sustainability challenges can be addressed by national and multilateral innovation policies is still a largely open question. This can partly be explained by a failure of the research community to adequately inform policy makers. This, in turn, is largely due to a division of the research community as such into those researchers that deal with technological innovation and innovation systems on the one hand and those that deal with environmental challenges and the effectiveness of environmental policies on the other:

- Innovation (system) research, on the one hand, has for too long largely neglected the pressing challenges of sustainable development, essentially limiting the scope of research to the features of innovation systems that contribute to the competitiveness of national economies, mainly in advanced industrialised economies.
- Researchers concerned with the preservation of the global environment, on the other hand, have largely ignored the potential power of technological innovations for reconciling the need to satisfy socio-economic needs with need to preserve global ecosystems. Far too often, the discourse has centred on possible *threats* that specific technologies (such as genetic engineering) may imply for ecosystems.

In Chapter 5 of this paper, we outlined a rather challenging research agenda that might provide answers to the question how economic growth and social progress might be decoupled from environmental pressures, especially in anchor countries. Carrying out this research agenda will make it necessary to bring together **three research and discourse communities**, namely IS researchers with researchers dealing with the mitigation of environmental problems and, finally, the development research community.

- IS research can explain how technological and innovation capabilities within a sector or country are shaped through the interplay of actors from the private and the public sector, governed by rules and regulations largely influenced by policies.
- Environment-related research can shed light on what the most pressing challenges are in relation to the environmental dimension of sustainability and thus also in the areas in which technological solutions would be essential to mitigate them.
- Development research can contribute knowledge regarding the level of complexity at which the development and deployment of environmentally sound technologies has to be conceptualised - at the micro-level of the firm or local community, at the meso-level of organisations, at the macro-level of policies and polities, and finally at the meta-level of the rules and norms prevalent in a given developing society.

While the links between the environmental and development communities are relatively firm, and some links exist between the IS and development communities, the main challenge seems to lie in bringing, first, the environmental and IS communities and then all three communities together with a view to exploiting the synergies between them.

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