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Sustainability Transitions and the Nature of Technology

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Abstract For more than 20 years, sustainable development has been advocated as a way of tackling growing global environmental and social problems. The sustainable development discourse has always had a strong technological component and the literature boasts an enormous amount of debate on which technologies should be developed and employed and how this can most efficiently be done. The mainstream discourse in sustainable development argues for an eco-efficiency approach in which a technology push strategy boosts efficiency levels by a factor 10 and more in industrialised and developing countries. A minority argues for a socio-cultural lifestyle switch, relying on new values, quality of life, sufficiency and redistribution strategies, with calls for appropriate and soft technologies. It is remarkable, however, that the articles, books and policy debates on sustainability seldom explicitly draw in a discussion of the nature of technology, how technology influences and is influenced by society, and what this implies for sustainable development. The mainstream interprets technology as neutral and instrumental: technology is no more than an instrument to reach a goal; it cannot be judged on its intrinsic characteristics, only on its use. The alternative view often builds on an autonomous and substantive interpretation of technology: technology is an autonomous, almost uncontrollable power that fundamentally reshapes our culture. A more balanced approach seems to be growing in the research on socio-technical sustainability transitions where the focus shifts to the co-evolution of technology and society, and to the networks, seamless webs and complex multi-actor processes that may carry a sustainability transition forward. This approach builds on insights from recent traditions in the philosophy and sociology of technology, in particular the social construction of technology (SCOT) and actor-network theory (ANT). While this provides for a better understanding of the nature and potential role of technology in sustainability policies, it remains to be seen whether it will actually influence the choice between technologies. This article investigates the different conceptualisations of technology in the sustainability debate. It first distinguishes between different approaches of sustainability and how these are related to differing views on technology. It then moves on to how the socio-technical transitions research incorporates insights

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from contemporary philosophy and sociology of technology. It reflects on the potential of transitions research to give guidance in technology choices, suggesting that the transition approach might be strengthened by drawing in insights from critical theory of technology and by taking a more political stance in defining sustainable development.

Keywords Sustainable development · Sustainable technology · Socio-technical transitions research · Philosophy of technology · Transition governance

1 Introduction

Over the last 20 years, sustainable development has grown into one of the main policy concerns from the international to the local level. Although a lot of interpretations exist of its meaning and of how to apply it in practice, the essence of the concept relates to reaching a high quality of life within ecological limits and with respect for international justice. The concept had been used before, but in 1987 it was widely launched into political, public and academic discourses by the World Commission on Environment and Development (WCED 1987; Sathaye et al. 2007) and became the leading concept for the 1992 Earth Summit in Rio de Janeiro. Since then, it has been adopted

> "as an overarching goal of economic and social development by UN agencies, by the Agenda 21 countries, and by many local governments and private-sector actors (…) Despite the intrinsic ambiguity in the concept of sustainable development, it is now perceived as an irreducible holistic concept where economic, social, and environmental issues are interdependent dimensions that must be approached within a unified framework" (Halsnaes et al. 2007, 122).

The debate on sustainable development has always had a strong technological component. The development and diffusion of new and more technology, in particular environmentally sound technology, is regarded as one of the main pathways to simultaneously solving environmental and development problems. The literature on sustainable development boasts an enormous amount of debate on which technologies should be developed and employed and how this can most efficiently be done. It is remarkable, however, that these articles and books seldom explicitly draw in a discussion of the nature of technology, how technology influences and is influenced by society, and what this implies for sustainable development. In most cases, the literature on sustainable development, and as a corollary the political debate on sustainable development, departs from a rather simplified view of the nature of technology. It predominantly interprets technology as neutral and instrumental: technology is no more than an instrument to reach a goal; it cannot be judged on its intrinsic characteristics, only on its use. Most of the developments and insights from the more recent philosophy and sociology of technology seem to have bypassed the sustainability debate. This is in particular true for the understanding that technology and society are shaping and being shaped by one another, and all the implications arising from that (such as how values influence technologies, how power relations change through technologies, how technologies shape daily lives, etc.).

Is this problematic? Philosophers and sociologists of technology suggest that a better understanding of the relationship between technology and society "is the key to building a better world" (Johnson and Wetmore 2009, p. 441). Since the political goal of sustainable development is exactly this building of a better world, there are reasons to assume that it may be problematic when the interpretation of the nature and the role of technology is flawed in the sustainability discourse, in particular because technology is assigned such an important place. If the sustainability community works with wrong conceptions of technology, then the advice on which technologies should be developed and how they can be employed may also be seriously flawed.

There is at least one notable exception to this general appreciation of the outlook on technology in sustainable development, and that is the growing amount of literature on socio-technical system innovations and sustainability transitions (e.g. Elzen et al. 2004; Geels 2005; Smith et al. 2005). This literature explicitly draws on insights from relatively recent branches in the philosophy and sociology of technology, in particular the social construction of technology (SCOT) and actor-network theory (ANT). Through an interdisciplinary approach that further relies on innovation studies, evolutionary economics, governance studies and sociology, the socio-technical transitions literature tries to explain how major transformations in socio-technical systems happen, and how these insights can be used to influence transitions towards more sustainable systems and societies. This article investigates how insights from SCOT and ANT are incorporated in the sustainability transitions literature and whether this brings a new spirit to the sustainability debate. Is it helpful, in particular in guiding policies towards more sustainable technology choices?

Before trying to answer that question, I first delve deeper into how technology is conceived of in the sustainability debate. This is more nuanced than has been presented until now, with broadly two interpretations that stand out: the mainstream interpretation of neutrality and instrumentality, and an alternative interpretation that rather stresses the autonomy and substantivism of technology. The second part of the article shows how these interpretations are linked to particular interpretations of the meaning of sustainable development. The third part of the article discusses the empirical turn in the philosophy and sociology of technology, and then illustrates how the new conceptualisation of the relation technology-society is embedded in socio-technical transitions research. It also discusses important policy implications and formulates some suggestions to strengthen the transitions perspective. The concluding section brings together the main insights.

2 The Meaning of Sustainable Development and the Implied Views on Technology

In order to be able to say something meaningful about the nature and role of sustainable technology, it is first necessary to be more explicit about the different interpretations of sustainable development. I discuss the interpretation problem in 2.1., after which in 2.2. I turn to the implied views on technology.

2.1 Sustainable Development in the Plural

In the fall of 1983, the General Assembly of the United Nations created a well supported commission to examine the state of the environment and the development problem, and to formulate actions and policy proposals to tackle these two interrelated global problems. Under the presidency of the former Norwegian prime minister Gro Harlem Brundtland, the World Commission on Environment and Development delivered its final report in 1987, *Our Common Future* (WCED 1987): ‘sustainable development’ was the way forward, according to the Commission. In the oft-cited definition of the report, sustainable development is development that “meets the needs of the present without compromising the ability of future generations to meet their own needs” (ibid., p. 8). In the following sentences, the text states that the present state of technology and social organisation and the absorptive capacity of the biosphere imply limits for development. However, it is added, these are not absolute limits since "technology and social organization can be both managed and improved to make way for a new era of economic growth" (ibid.). In order to raise consumption in the developing world to industrialised country levels and eradicate poverty, and taking into account population growth, the Brundtland report argues for a five- to tenfold increase in manufacturing output (ibid., p. 15). In developing countries, this supposes a yearly minimal economic growth rate of five to six percent, which will partly depend on the level and pattern of growth in industrialised countries. The report reckons that growth rates of three to four percent are necessary in industrialised countries (ibid., p. 51) Are such growth rates environmentally sustainable? The answer in the report is positive, at least if the quality of growth changes: growth has to become less material- and energy-intensive and more equitable in its impact (ibid., p. 52). New technologies play a central role here because they offer the promise of higher productivity, increased efficiency and decreased pollution (ibid., p. 16). To revitalize growth in the South, greater technology transfer, larger capital flows and freer market access for the products of developing countries are necessary (ibid., p. 89). While the Brundtland report places a lot of trust in technology "for raising productivity and living standards, for improving health, and for conserving the resource base", it also warns that many technologies bring new hazards and "are not all intrinsically benign" (ibid., p. 217, 219). This demands amongst other things improved risk assessment and risk management.

The Brundtland report received worldwide an enormous amount of attention and formed the basis for the 1992 United Nations Conference on Environment and Development (UNCED). According to Sneddon et al. (2006, p. 255) the Brundtland report is "a vital historical marker" in that it highlighted the critical relationship between human development and the environment. It raised the global awareness that development and economic growth will have to take into account social and environmental preconditions, that humans are dependent on their environment, and that environment and development problems are worldwide interconnected. Robinson (2004) calls this linkage the "radical aspect" of the report. Following Brundtland and UNCED, new principles have been introduced in the international debate on development and environment, such as e.g. the principles of intergenerational equity (between present and future generations), of intragenerational equity (between current generations worldwide) and of common but differentiated responsibility (all countries have a responsibility for sustainable development, but developed countries should take the lead).

Brundtland and UNCED also initiated an "explosion of work" (Sneddon et al. 2006, p. 255) in thinking about the implications of sustainability and it was immediately obvious that the concept such as used in the report and at the conference, was highly ambiguous. The most immediate criticism focused on the policy advice to increase the world economic output five- to tenfold. This was perceived as trying to solve the problems with the same models that caused them, albeit in a form somewhat more sensitive to environmental concerns. This is the "reformist element" of the report (Robinson 2004). Furthermore, over the years it has become clear that 'sustainable development' can be interpreted in many different ways, because central concepts such as needs, equity, environmental limits or quality of life are necessarily normatively charged. The different interpretations reflect the political and philosophical position of the different actors in the game (such as governments, business, NGO's, labour unions). Accordingly, the debate around the meaning of sustainable development and the political, economic, social, ecological and technological solution pathways that should be followed is an area of a lot of contention. Different authors have sought to shed some light on the myriad of interpretations that exist. Sachs (1999) e.g. draws a distinction between different perspectives on sustainable development on the basis of how finiteness is interpreted, while Hopwood et al. (2005) make a classification on the basis of the importance

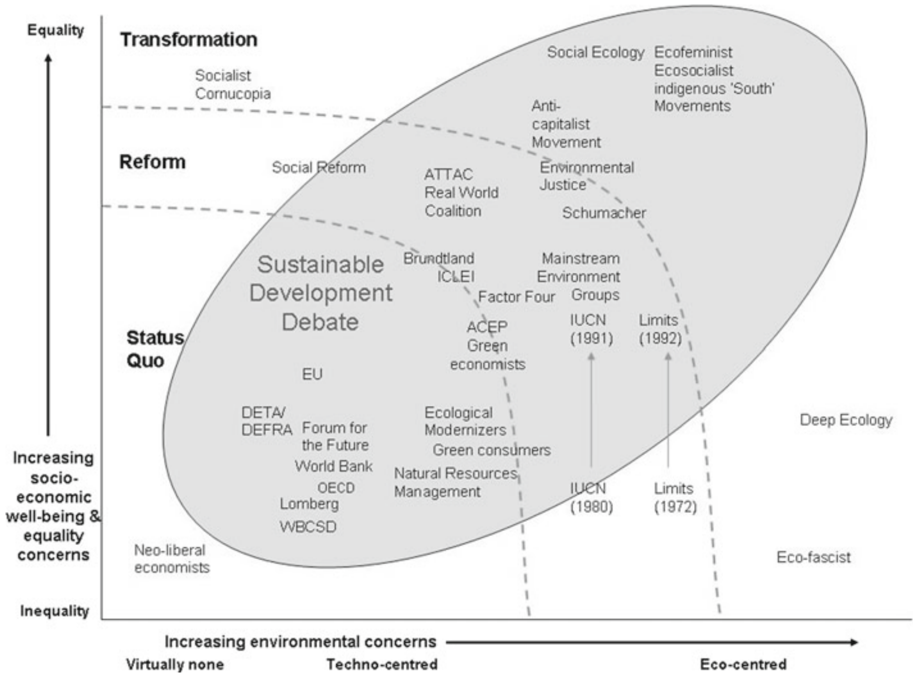

Fig. 1 Source: Hopwood et al. (2005), p. 41

given to environmental and socio-economic issues. Both distinguish between three perspectives which resemble each other a lot in contents. I start from the classification of Hopwood et al. here because their two-dimensional mapping allows for easier comparison of different views (Fig. 1), but I complement it with insights from Sachs.

Hopwood et al. map different interpretations of sustainable development by using a socio-economic axis that covers the level of importance given to human well-being and equality, and an environment axis that covers the priority given to environmental concerns. This allows them to draw a broad distinction between three views on the nature of change necessary to reach sustainable development: status quo, reform and transformation (ibid., p. 42). The shaded area in Fig. 1 more or less indicates the range of views within the sustainable development debate. Those falling out of the shaded area tend to pay too one-sided attention to either environmental or socio-economic issues.[1]

In the status quo view, sustainable development can be achieved within the present structures of society, without making fundamental changes to economic structures and activities, power relations and decision making. Development is equated here with economic growth, because growth provides resources to pay for environmental measures and technologies, and can help solve poverty problems. The main driver is business and the main instruments are markets and technology. Sachs (1999, pp. 78–83) calls this the "contest perspective" because

[1] This does, however, not imply that all views falling inside the shaded area would necessarily describe themselves as being part of the sustainable development debate. The term sustainable development has a too contested meaning for that, in particular for groups that strive for deep transformations of society. According to (Robinson 2004, p. 370) it is therefore "not surprising that some have found it desirable to develop alternative terminology to express some of the same concerns about the linkage between environmental and social issues".

it relies on international competitiveness to drive growth and ecological modernisation. Eco-efficiency through technology is the key strategy for business, and government policies should be geared to this goal, in particular through price mechanisms. Environmental problems in the South can be solved through technology transfer from the North, capacity building and growth strategies.

The reform approach also thinks that problems can be solved within present economic and social structures, although major changes to politics and lifestyle will be necessary. The reforms have to focus on "technology, good science and information, modifications to the market and reform of government" (Hopwood et al., p. 43). Governments have a key role in guiding these processes, also on a global level through e.g. multilateral regulations and other forms of global governance. Sachs uses the term "astronaut's perspective" (Sachs 1999, pp. 83–86) to indicate that this approach sees sustainable development as a challenge for global management. The fragility of ecosystems demands global monitoring and global, rationally planned interventions. This also implies addressing the North-South divide because the planet cannot be saved (and managed) without cooperation between all nations. A Marshall Plan for the South is an option here, including the diffusion of environmentally sound technologies, economic reforms and efforts to stabilise the world population (ibid. p. 85).

Finally, in the transformation view, the socio-ecological problem is rooted in the economic and power structures of our society and in the way humans interrelate with nature. The historical development of these structures and mindsets has led to a society that dominates and exploits nature and people, and only a fundamental change in societal structures and people's values and attitudes can bring on change. There is a strong emphasis here on social equity, with local communities and people renewing control over their lives, resources, economic and political decision-making. Political action of groups outside the centres of power (indigenous groups, women, the poor and working class) is an essential strategy. This resembles Sachs "home perspective" where the stress is on developing sustainable local livelihoods and radically restructuring the development patterns of the North, whose lifestyles cannot be generalized around the globe, yet serve as the example for most Southern elites. An efficiency revolution is necessary but will be counterproductive when growth is not challenged. Sachs himself calls for new models of prosperity and a "twin-track approach" where efficiency and sufficiency are combined in an "intelligent rationalization of means and prudent moderation of ends" (Sachs 1999, p. 88).[2]

Over the years, the mainstream of the debate—mainly carried by UN organisations, national governments, national advisory councils on sustainable development, OECD, World Bank, international ngo's etc. —has been situated in the status quo view, with some influence of the reform view, in particular in relation to the role of government in e.g. the drawing up of national plans for sustainable development, involvement of stakeholder groups, monitoring of global and national trends. Since the perspective of this article is the role assigned to technology in the sustainable development debate, I cannot go much deeper here into how the debate itself is currently evolving. There is, however, an important evolution that I want to mention because it will be useful further on. The years of debate have made it obvious that it is impossible to try and pin down the concept of sustainable development to one clear definition, with unambiguous policy goals and strategies. Instead of loathing this ambiguity and dismissing sustainable development as unworkable, scholars are exploring ways of dealing with it and seeking "to retrieve the ideals of sustainable development (equity within and across generations, places and social groups; ecological integrity; and human well-being and

[2] The idea of new models of prosperity is the focus of a recent book by Jackson (2009), 'Prosperity without Growth?' The book is currently causing some furore in sustainability circles because of its thoughtful and eloquent treatment of the theme.

quality of life) via a reconstructive exercise" (Sneddon et al. 2006, p. 264). In this exercise, sustainable development is thought of as a framework that allows debating the fundamental choices humanity is facing (such as the need to reconcile ecological sustainability, social justice and economic stability), instead of interpreting it as a consistent set of concepts and a desired end-state. This approach acknowledges "the inherently normative and political nature of sustainability" (Robinson 2004, p. 381), even takes it as point of departure or "embraces" it (Sneddon et al.), and thus devotes as much attention to the process characteristics of sustainable development as to its content. I cite Robinson at some length to show the enormous conceptual shift in how the importance of sustainable development is formulated.

> "Here we can argue for the view that sustainability can usefully be thought of as the emergent property of a conversation about desired futures that is informed by some understanding of the ecological, social and economic consequences of different courses of action (…) What is needed, therefore, is a process by which these views can be expressed and evaluated, ultimately as a political act for any given community or jurisdiction. The power of the concept of sustainability, then, lies precisely in the degree to which it brings to surface these contradictions and provides a kind of discursive playing field in which they can be debated" (Robinson 2004, pp. 381–382).[3]

2.2 Sustainable Development Approaches and Technology

In order to discuss in more detail the perception of technology in the different sustainability perspectives, I depart from a scheme of Andrew Feenberg in which he compares different views on technology (Feenberg 1999, p. 9). The scheme is based on two axes. The horizontal axis describes the role of human action in the technical sphere: is technology an autonomous force or is it controlled by human intervention? The vertical axis describes the connection between technical means and human ends: is technology neutral and can it be employed to reach any means or does it incorporate values and as such co-constitutes the ends people aspire to?

According to Feenberg, most interpretations of technology fall into two major types: instrumentalism or substantivism. The most widely accepted interpretation is the instrumentalist one: it is commonsense that technologies are tools to reach a human goal (and thus humanly controlled) and that these tools are neutral: "A hammer is a hammer, a steam turbine is a steam turbine, and such tools are useful in any social context" (Feenberg 2001, p. 6). Consequently, the transfer of technologies between social contexts —e.g. from industrialised countries to developing countries—is not a major problem and only inhibited by cost. According to Feenberg, the neutrality hypothesis builds on efficiency as the universal guiding norm of technology, applicable in every context. If technology is only a means, it cannot be assessed in itself, but only in how it is being used. The second classical position is the substantivist one. This interpretation is associated with philosophers such as Heidegger and Ellul, who state that technological development follows its own logic, one invention building

[3] It probably comes as no surprise that this has also important implications for the role reserved to science. In the view of Robinson and comparable authors science can inform but no longer resolve the questions of sustainable development. Other forms of knowledge are needed as well and the value judgements of science should be open to examination and discussion (see for a comparable argument the article of Gert Goeminne in this volume; Goeminne et al., in press; Goeminne and Paredis, in press). Grin (2007) pleads for a form of knowledge generation in which experts and other actors, based on different kinds of knowledge (scientific, experiential, local, tacit) try cooperatively to define a problem and find solutions, in the process also discovering values, preferences, power issues and other forms of knowledge generation.

Table 1 Varieties of theories of technology (adapted from Feenberg 1999)

Technology is:	Autonomous	Humanly controlled
Neutral (complete separation of means and ends)	Determinism (e.g. traditional Marxism)	Instrumentalism (liberal faith in progress)
Value-laden (means form a way of life that includes ends)	Substantivism (means and ends linked in systems)	Critical theory SCOT, ANT Post-phenomenology (choice of alternative means-ends systems)

on the other, without anyone or any institution being able to stop this evolution or redirect it. This development is not neutral, because in this process technology changes our culture and shapes the whole of social life, introducing new values (such as efficiency and effectiveness) and new virtues (such as accuracy and labour ethics) (Bos 2004). The substantivist position usually evaluates this evolution negatively, in that modern technology undermines cultures, subjects human will and creativity, and ultimately destroys human civilisation. The determinist position is characteristic of a lot of progressive thinkers (e.g. in traditional Marxism) who claimed technology serves the fulfilment of universal natural or biological needs and ends all people have, and it follows an automatic and determined path of progress. The lower right-hand corner is typical of relatively recent interpretations of technology: society and technology co-evolve and mutually influence each other. Feenberg only places 'critical theory' in this section, to which he counts amongst others Foucault, Habermas and himself. But it can easily be argued that the Social Construction of Technology, Actor-Network Theory and Ihde's postphenomenology belong here as well. I return to this section of Table 1 in part 3 of this article. Here I stick with instrumentalism and substantivism, because these two positions dominate the view on technology in the sustainable development debate. The mainstream holds an instrumentalist view, while a minority is strongly substantivist in its analysis but still sees possibilities of human control when looking for alternatives to modern technology.

2.2.1 The Mainstream Interpretation: Technology as a Tool for an Eco-Efficient Society

Although, as discussed above, a distinction can be drawn between at least three approaches to sustainable development—status quo/contest, reform/astronaut, transformation/home—this is not the case for the way the nature of technology is viewed. In the status quo and reform approach, technology gets an instrumentalist interpretation, and since the mainstream of the sustainable development debate is situated in the status quo perspective with some elements of reform, technological instrumentalism dominates the debate. Examples of instrumentalism—in its combination of neutrality and human control over technological development—abound in the sustainability debate, with technology providing a solution for environmental and social problems alike, sometimes referred to as the notion of technological fix. Dyson (2009) e.g. is convinced that a combination of solar energy, genetic engineering and the internet will solve poverty in the world; the only problem is to make them cheap and universally available. From a very different corner, Karlsson (2009) argues that the transition to sustainability is in need of a "global Fordian compromise" with open markets and huge investments in nuclear fusion, nanotechnology and other converging technologies that can initiate a new era of technological progress and high economic growth. In what can currently be considered the vanguard of the sustainability debate, i.e. the climate debate, IPCC reports invariably count predominantly on technology for mitigation and adaptation. Already in 2000, the Special Report on Emission Scenarios (IPCC 2000), that still underlies IPCC's emission projections, concluded that technology was of similar importance for future GHG emissions as population and economic growth *combined*. "The development and diffusion of new technologies is perhaps the most robust and effective way to reduce GHG emissions", state Banuri et al. (2001, p. 83) in the IPCC's third assessment report (TAR), and they mention cost and market failures as the most significant barriers to innovation and diffusion of these technologies. The latest assessment report (AR4) also thinks that "any response to climate change will depend critically on the cost, performance, and availability of technologies that can lower emissions in the future" (Halnaes et al. 2007, p. 147).[4]

The reasoning underlying the instrumentalist approach to sustainable technology is very well expressed in the frequently used IPAT equation, or $I = P \times A \times T$. This formula defines humanity's impact on nature (I) as a function of the size of the Population (P), the Affluence (A) or consumption levels of the population, and the Technology (T) used to extract resources, transform them into goods and services, and dispose of them. In an illuminating article, Chertow (2001) has shown how in the early seventies the equation was originally used in discussions amongst on the one side Paul Ehrlich and John Holdren and on the other side Barry Commoner to determine which variable was the most damaging to the environment. While Ehrlich and Holdren saw population and economic growth as main contributors to the environmental crisis, Commoner blamed "ecologically faulty technology" (cited in ibid., p. 15). However, when with the Brundtland report sustainable development enters the stage, the nature of the debate changes in at least two ways: preservation of the environment and economic development are no longer considered incompatible, and technology is no longer seen as a source of pollution but as the greatest hope for reconciling economy and environment and initiating the transition to a more sustainable society.

> "The overall shift from pessimism to optimism, captured here through changing interpretations of the IPAT equation and its variants, is shown to be partly fatalistic, in that few alternatives exist to the imperative established by the Brundtland Commission; partly pragmatic, in that technological variables often seem easier to manage than human behaviour; and partly a continued act of faith, at least in the United States, in the power of scientific advance" (Chertow 2001, p. 26).

The new technological optimism is almost inherent in the IPAT formula itself. First, even with population control measures it will be difficult to halt global population levels (P) before they reach 8 to 9 billion people, let alone diminish them. And second, large segments of the populations in developing countries strive for better lives with higher levels of material wealth (A), while populations in industrialised are not keen on sacrificing their wealth. So, the factor technology (T) remains as the one easiest to be handled. This is not only a negative choice, however, because in the course of the last two decennia new technological fields such as the field of industrial ecology have taken off, and new policy concepts such as factor 4, factor 10

[4] There is however a remarkable difference between TAR and AR4. While AR4 fits into the reform approach to sustainable development and climate change, the earlier report TAR shows some flavours of a transformation approach in that it devotes several pages to alternative pathways that go beyond existing institutions and behaviour (see in particular Banuri et al. 2001, p. 95–103). Apart from the more conventional eco-efficiency strategy to decouple growth from resource flows, in these pages TAR also discusses a strategy of decoupling wellbeing from production in four dimensions: intermediate performance levels, regionalization, appropriate lifestyles, and community resource rights. I return to some of these aspects in paragraph 1.2.2. There is no doubt that the influence of one of the TAR's lead authors, Wolfgang Sachs, is visible here. This aspect has completely disappeared from the more recent AR4. For a discussion of this feature of TAR, see also Paredis et al. 2006.

and leapfrogging have entered the debate. These kind of approaches argue for a technology push strategy that can boost efficiency levels in industrialised and developing countries, and they share essentially the same baseline: "Technology and markets bring the solution, where the role of technology is to drastically improve the eco-efficiency of the economy. No major lifestyle changes are needed, although some political steering and new institutions may be necessary".

Industrial ecology aims at creating closed loop industrial systems, in imitation of biological ecosystems, where the waste outputs of one industrial process serve as the inputs of another (Harper and Graedel 2004). Such a re-engineering of the industrial system should allow for huge reductions in throughput of resources and in the production of waste. Leapfrogging is the idea that developing countries need not pass through the dirty stages of industrial growth, but that they can bypass this stage through transfer of modern, clean technologies that use fewer resources and/or generate less pollution (Perkins 2003). This goal can be achieved when several conditions are met, such as a shift from end-of-pipe technologies to clean technology, investment in clean technology from the early stage of industrialisation in order to avoid lock-in, technology transfer from developed economies, developing countries' governments that provide incentives for industry, and international concessional financing for clean technology.[5] The IPCC states that technology transfer is particularly relevant for developing countries, because they are currently in a phase of massive infrastructure build up. "Delays in technology transfer could therefore lead to a lock-in in high-emissions systems for decades to come" (Halsnaes et al. 2007, p. 158).

Factor 10 and factor 4 refer to the ambition to boost the efficiency of resource use with a factor 4 and more. The famous and influential book *Factor Four* (Von Weiszäcker et al. 1997) states that "in the past, progress was the increase of labour productivity. We feel the resource productivity is equally important and should now be pursued as the highest priority" (p. xviii). They call it an exciting message, because an efficiency revolution will be profitable and thus make countries stronger in terms of international competitiveness. Particular to the approach is that it rejects supply-side technical solutions and "high-tech fantasies" such as nuclear energy and fusion power, space solar power, or sinking CO_2 into the oceans. Half of the book is filled with fifty examples of how new technologies can quadruple resource productivity in the field of energy, materials and transport. The authors have no doubts as to the global applicability of these technologies. What keeps them from being diffused is a correct price structure. With the introduction of an ecological tax reform, humanity can take control over the direction of technological development. The neutral side of this instrumental approach to technology is illustrated in the last thirty pages of the book. There it is suddenly argued that an efficiency revolution does not solve the problems if growth continues: "efficiency will essentially serve to buy time. We urgently need to make good use of that time to develop a civilisation that is truly sustainable" (ibid., p. 293). So, while the technological revolution unfolds, in parallel and seemingly completely separated from it, we need to develop a better understanding of well-being and satisfaction. The whole book is a passionate plea in favour of better technology and markets, but, so read the final sentences, to seek

> "the whole purpose of a human being (…) we have politics, ethics and religion (…) Like any tool, [efficient technology] can only help us a little towards, and can never

[5] Perkins' research criticises these common claims and argues that leapfrogging is much more challenging because it demands among other things the capacity building in developing countries to select and absorb clean technologies, and the development of a strong national innovation system to become autonomous agents in eco-innovation. Apart from this more nuanced policy view, he stays within the instrumentalist technology paradigm and regards leapfrogging as a promising strategy to reconcile economic development and environmental protection. "Above all, leapfrogging will require far-reaching political will" (Perkins 2003, p. 185).

substitute for, the renewal of our polity, our ethical principles and our spirituality. The resources that we need most urgently to rediscover and to use more fully and wisely are not in the physical world, but remain hidden within each of us" (ibid., p. 299).

2.2.2 The Minority View: New Values, Different Power Structures and Appropriate Technologies

While the status quo and reform approaches to sustainable development adhere to an instrumentalist view of technology, the transformation view often sees modern technology as a power that is very difficult to control and that simultaneously exploits and destroys nature, people and culture. This strongly echoes the substantivist interpretation of technology. From this perspective, sustainability is ultimately dependent on new socio-cultural values, different power structures and social innovation instead of on technologies and competitive markets. The work of Otto Ulrich is exemplary of this position, but more or less comparable views can be found with scholars and activists such as Vandana Shiva, Wolfgang Sachs, Maria Mies, Murray Bookchin and a lot of grassroots organisations.[6] According to Ulrich, modern technology is deeply rooted in "the central myth of European modernity" (Ulrich 1992, p. 278) that promises a good life and a dream of happiness without sacrifices. Technology helps to fulfil that dream by creating the material conditions for it and allowing an unremitting development of production and consumption. Ulrich states that what looks like a highly productive industrial system is in fact a parasite on the earth and humanity. Almost all industrial technologies and products "take the form of techniques that plunder the earth's resources and externalize their costs" (ibid., p. 281), but we are blind for this problem because modern technology has the unique feature that it transfers costs in time and space. Apart from the environmental cost, modern technology also has huge social and cultural costs, because it has caused "a great transformation of the entire society, culture and psychological constitution of the people" (ibid., p. 285): we have become devoted to the industrial way of living and its immoderateness, even to the extent that we willingly participate in wage work and in a forced mobilization for the endless production of goods and services for an anonymous mass market (Peeters 1996). The first step on the way out is "industrial, technological and economic 'disarmament"' and "renunciation" of misplaced scientific-technocratic triumphs such as atomic energy, the chlorine and most of the synthesizing industry, the automobile and industrialized agriculture (Ulrich 1992, p. 281, 285). It hardly needs explanation that Ulrich is highly sceptical of technology transfer to the developing world. In his view "the majority of industrial technological products are not generalizable" to the South, because they will only exacerbate the plundering of natural resources and lead to cultural imperialism and destruction of native cultures. This is even true for clean technologies, because they also "force their laws upon society in such a way that cultural self-definition and autonomy cannot be maintained for long" (ibid., p. 284).

It is obvious from this description that technology is interpreted as value-laden and autonomous: the industrial mega-machine unstoppably changes societies for the worse. Starting from this analysis, two remarkable things happen. First, authors that defend this position simultaneously argue for and still see manoeuvring room for the development of alternative, appropriate, intermediate, soft or "other" technologies. This is remarkable because it is in fact in contradiction to their substantivist analysis of modern technology, which leaves no opening for alternatives to the industrial system and modern technology. Second and as a

[6] In the early nineties, Sachs edited two influential volumes of essays on development and ecology that give a good overview of relevant authors and the discourses used. See Sachs 1992 and Sachs 1993.

consequence, when developing arguments for a different technological development, these authors have to move to a position that allows human control over technology. Achterhuis (1995) has remarked that this often leads to an implicit move to an instrumentalist view on technology: in order to regain control over technology, it is argued, we have to re-embed technology in societal structures where it should be steered by new norms and values. Man should remain master over technology, and so technology has to be made into a tool again, at the service of humanity. While this move to instrumentalism may be true in some cases, it is often also more nuanced. Influenced by his work at the Wuppertal Institute, where a strong focus on eco-efficiency strategies is visible, Sachs has developed his idea of the above-mentioned twin-track approach: efficiency and sufficiency should be combined. This is not only a necessity to keep growth under control and to stay within the physical limits of ecosystems, it also

> "makes the transition to sustainability easier because the pressure for higher efficiency of means is softened when certain levels of sufficiency in goals are socially accepted. Such a conclusion is not astonishing if one sees history moving in a co-evolutionary manner. From the co-evolutionary perspective, socio-cultural forms evolve in interaction with technical forms, just as technical forms evolve in interaction with socio-cultural forms" (Sachs 1999, p. 185).

Sachs clearly moves here to the lower right corner of Feenberg's scheme (Table 1) and it contradicts Achterhuis' remark of instrumentalism as a remedy for a substantivist analysis. It is true however that Sachs does not elaborate further on how this co-evolution should be conceived of and what it can mean for the transition to a more sustainable society. I return to this theme explicitly in the next part of this article, because it is the central focus of an emerging field of research, known as research in socio-technical system innovation and sustainability transitions.

I end this part with some reflections on which technologies are promoted under this view and why. The basis is still to be found in the ideas of Schumacher (1973) and the ensuing work on 'appropriate' or 'intermediate' technologies. Schumacher was in particular interested in such technologies for developing countries, but from the mid-seventies onwards, there was also an Appropriate Technology Movement in a lot of industrialised countries, and when this movement began to dry up in the mid-eighties, its ideas inspired thinking about technologies for a sustainable society. Smith et al. (2005) shows how the ideas about technology and the characteristics they should have, fitted into the vision of society developed in the AT movement: a vision as an antithesis of industrial society, that imagined people living communally in self-sufficient autonomous villages or urban terraces. In the AT vision, new technologies had be supportive of a society that adhered to decentralisation and the small scale, participation and local control, cooperation and simplicity, and ecology and quality of life.

> "The soft, gentle features of AT were contrasted and defined in contrast to, the hard, brutish technologies perceived in modern industrial society: small scale, not centralised; ecologically sound, not unsound; resource efficient, not materials intense; long-lasting, not throw away; participatory, not technocratic; supply based upon needs, not profits; using production cycles, not lines. Exemplary technologies included small-scale wind power, solar heating, biogas, organic food, autonomous housing, wastewater recycling, heat pumps, small hydro-power, and the craft-based engineering of equipment. Practical opportunities would be sought in eco-housing, organic food, renewable energy, and small, co-operatively run, alternative enterprises" (ibid., p. 111).

Obviously, the criteria with which technologies are evaluated, are much broader than the one and only efficiency criterion of the mainstream interpretation. Vergragt (2006) thinks that in current times many of the elements of appropriate technologies can be used in synergy with high-tech developments (e.g. in information and communication technologies) to promote technologies that can contribute to a more sustainable world. He mentions elements such as orientation towards human needs, control by and empowerment of local communities, small scale and distributed energy, efficient and environmentally sound, low cost or cost effective, and labour intensive. "The challenge going forward is to learn from past mistakes, and to combine elements of appropriate technologies with some aspects of high-technology into a new paradigm of sustainable technology" (ibid., p. 13).

A glimpse of what such a combination may look like, is to be found in the already mentioned TAR of the IPCC, in particular in the first chapter of the mitigation report (Banuri et al. 2001). For several reasons it is worthwhile to dwell on this for a moment. First, it is unusual that ideas that bear close resemblance to the transformation perspective on sustainable development and alternative views on technology, flow through to an influential and peer-reviewed report such as the TAR. This part of the report illustrates well how the original AT ideas can be given a renewed content in the context of current sustainability challenges. Second, although it remains dark how the co-evolution between society and technology should be conceived of in this view, it nevertheless provides a rich source of inspiration on what the direction and content of such an evolution might be. Third, and anticipating the discussion further on in this article, this content might also be of relevance to the socio-technical transitions research, that focuses on how socio-technical regimes evolve and can be transfigured into more sustainable configurations, but hardly provides insights in the direction of that change.

Banuri et al. take as starting point that climate change has to be addressed and comprehended in relation to broader societal goals. They distinguish between three classes of approaches to climate change policy: the first approach focuses predominantly on efficiency and cost-effectiveness of climate policy (and has as such a lot of similarities with the status quo perspective on sustainable development), the second approach focuses on equity considerations of climate policy (and has similarities with the reform perspective), while the third approach focuses on global sustainability, where a solution for the climate problem is part of a much broader transformation towards sustainable lifestyles and sustainable consumption and production patterns, with concomitant changes in technologies, institutions, lifestyles and worldviews (ibid., p. 96). Climate change mitigation is perceived here as a co-benefit of two decoupling processes: decoupling growth from resource flows, and decoupling wellbeing from production.

Which options are open to decouple growth from resource flows?

- Eco-intelligent production systems: this is in fact exactly the option that was forwarded by Von Weiszäcker et al. (1997) in their Factor Four book and that was discussed above. Innovation should be shifted way from labour-saving advances towards resource-saving technologies. This can be done through eco-efficient innovation, industrial ecology, a shift from products to services, and dematerialisation of consumption.
- Resource-light infrastructures: refers in particular to the development path taken by developing countries and recalls the leapfrog argument. Since the physical infrastructure in these countries is still being developed and installed, they have an opportunity to avoid the resource intensive trajectories of industrialised countries and immediately invest in cleaner, less costly, more equitable and less emission-intensive development patterns (Banuri et al., p. 99)

- Appropriate technologies; technologies that build on indigenous knowledge and capabilities of local communities have enormous potential for improving people's living conditions (in particular rural and urban poor), while also leading to environmental protection. Examples are low-cost housing, small hydropower units, low-input organic agriculture, local non-grid power stations, biomass-based small industries. Banuri et al. develop a remarkable argument here in favour of intermediate performance levels. Performance levels of technologies can vary in dimensions such as level of power, speed, availability of service, yield, labour intensity. It is usually taken for granted that performance will and should increase, but the authors suggest however thinking about intermediate performance levels, i.e. deliberately designing technologies with levels of performance that lie below the maximum feasible. These could have at least two advantages. When they are also highly eco-efficient, they will consume lower absolute amounts of resources than comparable technologies designed for high-eco-efficiency and high performance. Furthermore, they promise higher employment impact, lower investment costs, local adaptability, and potential for decentralisation.
- Full cost pricing: this policy aims at reforming price structures in order to bring economic rationality more in line with ecological rationality. Price distortions can be removed through elimination of environmentally counterproductive subsidies or by shifting the tax base gradually from labour to natural resources.

All these strategies aim at dematerialisation of the economy, but in particular in industrialised countries this may not be enough to lead to absolute decreases in resource use and environmental pressure, the more so because under conditions of permanent economic growth (defined in the traditional sense of GDP growth), the gains from eco-efficiency will be eroded by growth in volume. So, an additional strategy of decoupling wellbeing from economic output is necessary to reduce resource use and GHG emissions, and to open up space for developing countries. Sachs' twin-track strategy is literally cited here. Banuri et al. interpret the options described as part of long-term social learning processes, since the conditions for their public acceptance are not often present at the requisite large scale. Four tracks are being proposed:

- Intermediate performance levels: the above-mentioned argument is repeated, also applied to industrialised countries. A resource-light economy may be easier to reach relying on deliberately designed technologies with levels of performance that lie below the maximum feasible. Examples are cars and trains with lower top speeds, but other fields of application could be construction, ventilation, refrigeration, crop cultivation, energy delivery systems. Central to the argument is that lower performance expectations on the demand side could be critical to make renewable energy sources and locally adapted materials technically and economically more viable.
- Regionalisation: a low-input society probably needs a great reliance on regional markets using regional sources to avoid long-distance transportation (co-existing alongside of global markets relying on global sourcing). Furthermore, solar power and biomass-centred technologies may be best developed in a decentralised fashion. While a resource-light economy will in part be a regionalised economy, care should be taken that this does not impede technology transfer.
- Appropriate lifestyles: beyond a certain threshold it is doubtful whether consumption of more goods increases wellbeing. Sustainability strategies could focus on e.g. intensifying the use of goods (through co-ownership, renting, leasing), choosing more wealth in time rather than more wealth in goods, and emerging lifestyles that value quality and non-material satisfaction.

- Community resource rights: since one-third of mankind derives its sustenance directly from nature, an important element of more sustainable development is ensuring the rights of communities over their own resources. Resource use by outsiders then becomes a matter of negotiation and trading on more equal terms.

3 Sustainability and the Social Construction of Technology

Although I have tried in this article to describe how technology is interpreted in the sustainable development debate, in fact there is hardly any discussion about the nature of technology in the sustainability community. There is of course a wide-ranging literature and debate on which technologies should be used for making societies more sustainable, but this hardly ever includes a remark on the *nature* of technology and what the nature of technology implies for the development of sustainable technologies and societies. Points of view on the nature of technology are almost always kept implicit. In practice, this means that technology is overwhelmingly interpreted as a tool by the mainstream of the sustainability debate, malleable for human use and employable in every context. More radical interpretations of sustainable development take a substantive attitude towards modern technology, but still believe in some manoeuvring room for the emergence of different, more appropriate and sustainable technologies, suited for and supportive of different societies.

This situation implies that what over the last 20 years has become common sense for philosophers and sociologists of technology —that society influences technology and technology influences society—has not flowed through to the bulk of the sustainability debate. There are two pockets where the co-evolutionary perspective on technology and society is gaining ground: the design community and the emerging research field of socio-technical transitions. I will concentrate on this last field in 3.2., but first I focus on some relevant themes and insights that over the last 20 years have emerged in the philosophy and sociology of technology.

3.1 The Empirical Turn

Although it is present everywhere in societal debates, nowadays instrumentalism is hardly taken seriously in the philosophy of technology. And while it is still an immensely influential reference, also the strongly substantivist perspective that pervades the classical philosophy of technology of for example Heidegger and Ellul, is not exactly fashionable these days. In fact, the philosophy of technology has moved to the lower right corner of Feenberg's scheme (Table 1): over the last two decades it has become accepted that technology is neither neutral not autonomous, but that technology and society simultaneously influence and constitute each other, although major points of discussion remain over the nature and interpretation of the relation. An important cause of this shift is a turn from studying the essence of technology in general towards empirical studies of concrete manifestations of technologies. By accurate analysis and description of the evolution of particular technologies in their context, scholars have shown that technology is socially constructed: social groups from engineers over manufacturers to users, political decisions, institutions, cultural preferences, user behaviour etcetera have an influence on the conception, production, diffusion and use of technologies. Achterhuis (2001) sees three common characteristics of this "empirical turn". First, this approach opens the black box of technological developments: technology is not autonomous but the social forces that act upon it are brought into the open. Second, the solid notion ‘Technology’ is broken up in many different technologies each of which can be independently analysed. Third, this approach stresses the co-evolution of technology and society.

It is for this article not useful to discuss and compare the different strands of the contemporary philosophy of technology, such as the Social Construction of Technology (SCOT), Actor-Network Theory (ANT), post-phenomenology or critical theory. But I want to draw attention to some of the achievements and insights that have entered the field and that are of importance for the development of the research on sustainability transitions. One such insight are the “seamless webs” Hughes refers to in order to indicate how a technology functions only through an interwoven combination of technical elements (physical artefacts), scientific elements (e.g. research data, books, articles), economic elements (e.g. price structures), institutions and organisations (legislation, firms, banks, R&D structures), cultural elements (worldviews, norms and values), natural resources and so on. A technology thus forms part of a “socio-technical system”, and it is this assemblage of things, institutions, people, practices and meanings that the analysis should focus on. Johnson and Wetmore (2009) define a socio-technical system as “a cluster of material objects, social practices, social relationships, and social organization” (p. 94). From this intertwinement it follows that cultural norms are intrinsic to technologies and socio-technical systems:

> “Technologies are developed, promoted, and used because people perceive that they will fulfil a certain need, accomplish a certain task, or achieve a certain goal within a given set of circumstances. Technologies are not simply chosen at random. People are motivated to integrate technologies into the fabric of society because they have certain values and they want to promote those values. Once created, sociotechnical systems can sometimes seem to take a power of their own. They facilitate and constrain certain actions and thereby facilitate and constrain certain values. In other words, the intertwining of society and technology is not neutral; it is value-laden. Values shape technologies we get and technologies subsequently have a significant effect an the values that are realized in a society” (ibid., p. xiv).

It is in particular Latour who, through his actor-network theory, has drawn attention to the fact that because norms are intrinsic to technologies, a lot of normative decisions are in fact delegated to technologies and artefacts. In some of his well-known examples (the safety belt in cars, the Berliner key) he shows how artefacts have an embedded script that constrains and shapes the behaviour of human actors. Socio-technical systems—Latour rather uses the term networks—are thus not only made by negotiations between humans, but non-human actors (artefacts) have an active role in the functioning of systems as well.

The development of technologies and systems as a social process is underlined in the constructivist argument that technologies exhibit “interpretative flexibility” (Pinch and Bijker 1987): there is not one predetermined solution, form and function a technology necessarily takes, but there is a whole range of possible solutions, forms and functions. Different user groups have different needs and values and it is through a process of interaction between groups that a particular design and meaning stabilises. In their paradigmatic case study of the development of the bicycle at the end of the ninetieth century, Pinch and Bijker convincingly show that what has become the standard design of a bike, started from competing designs that were favoured by different social groups (women, elderly men, sportsmanlike young men, the engineers and producers involved). This is an important point because it proves that technology is not autonomous, but that there is room for consciously influencing of technologies by social groups, and thus also by policy. But from that point onward, a lot of discussion focuses on how far this flexibility reaches and whether there is a certain obduracy to technologies and technological systems that cannot be negotiated, and also whether elements such as power relations, financial resources, market structures and engineers' mindsets put constraints on the array of choices realisable.

On these and related questions constructivism has been heavily criticised by amongst others Langdon Winner and Andrew Feenberg for its narrowness of perspective. Winner and Feenberg recognise the contribution of a constructivist approach in disclosing the interweaving of the social and the technical sphere, in providing an empirical model to study how technologies have actually developed, and in revealing how social groups influence design and meaning. Feenberg (more than Winner) sees three important implications for the study of technology (Feenberg 1999, pp. 83–84): 1. technical design is not determined by a general criterion such as efficiency, but by a social process; 2. that social process is not about fulfilling "natural" human needs, but concerns the cultural definition of needs; 3. competing definitions reflect conflicting visions of modern society realized in different technical choices. However, the criticism on constructivism is that it restricts itself to profound analysis and descriptions of how technologies have come into being. It focuses so much on micro-level analysis that its conclusions have only local relevance for specific case studies: "constructivism so disaggregates the question of technology that it is sometimes difficult to see its relevance to the legitimate concerns of essentialism" (ibid., p. x). In a famous article, Winner lists some of these legitimate concerns that featured prominently in the classical study of technology, that have lost nothing in relevance in the technotope we live in today, but that are neglected in most constructivist case studies (Winner 1993). Winner sees a disregard for the social consequences of a particular technical choice for different people and groups, for the qualities of everyday living, and the distribution of power in society. He notices that groups that have no voice and are suppressed or deliberately excluded, do not feature in the analysis. Perhaps his most biting criticism is for the "disdain for anything resembling an evaluative stance or any particular moral or political principles that might help people judge the possibilities that technologies present" (ibid., p. 371). Very detailed and precise case studies then lead "to a political stance that regards the status and its ills and injustices with precision equanimity. Interpretative flexibility soon becomes moral and political indifference (…) There is also no desire to weigh arguments about right and wrong involved in particular choices in energy, transportation, weaponry, manufacturing, agriculture, computing, and the like" (ibid., pp. 372–373). It goes without saying that in the light of this article and its focus on sustainable development and how the nature of technology should be interpreted, these kind of remarks are highly relevant. Bos' evaluation (Bos 2004) is that the insights from constructivism are a conditio sine qua non for a politics of technology, but that they only leave open the *possibility* of different futures. Policy advice of constructivists can only be process-related and gives no guidance in choices between technological options.

The answer seems to lie in finding a middle ground: keeping in mind the concerns over technologies as formulated by substantivism, while not forgetting essential insights from the social construction of technology. This is what Feenberg tries to do in his version of a critical theory of technology: search for an approach that combines an empirical orientation with a critical evaluation of ongoing developments. On the one hand, Feenberg supports the substantivist idea that technology has some inherent, distinguishing features, with normative implications. Technologies have a "technical code" that is a material translation of an interest or an ideology into the structure of that technology. This technical code steers use and behaviour in a certain direction with a bias towards the interests of powerful groups in society. "Really existing contemporary technology favors specific ends and obstructs others" (Feenberg 2005, p. 54). However, from this formulation it also follows that the technical code does not completely determine a technology in concrete practices. Although some ends are favoured, Feenberg brings in constructivist insights to show that individuals and social groups can challenge the technical code and influence design and use. Because technology is contextualized in the social domain, it exhibits a form of interpretative flexibility, although it is not completely malleable. This analysis of technology at two levels is what Feenberg calls his "instrumentalization theory", where the primary instrumentalisation refers to the decontextualised, constant characteristics of a technology built into it by its developers with certain interests in mind, and the secondary instrumentalisation is how a technology gets meaning in the real world and is realised in a social context.[7] To simplify somewhat, alternatives to existing technology and socio-technical systems become imaginable in this approach, either through changing the technical codes that are built-in in technologies and/or through new appropriations of technologies in context. Feenberg stresses the significance of different power structures—e.g. through active intervention of ignored or disempowered groups in the technology debate—to move to different technologies with different consequences (ibid., p. 54). In a recent article, Feng and Feenberg (2008) state that instrumentalisation theory is a critical version of constructivism, not only paying attention to the interests or plans of actors (as in SCOT and ANT), but also to the cultural background and the values and practices that are taken-for-granted in our society. From his previous work, we can infer that capitalism is probably the most important background force for Feenberg.

3.2 Constructivism, Technology and Sustainability Transitions Research

I realise of course that this is a rather rough sketch of insights developed in the contemporary philosophy of technology, but I mainly wanted to draw attention to some important achievements and insights from constructivism, and some important criticisms, in order to show next how this is taken up in a young branch of research. Johnson and Wetmore (2009) state that "if one wants to influence the direction of technology and society, one must first understand their relationship" (p. 95) and "understanding how values are entwined in sociotechnical systems is crucial to steering technology to a future we want" (p. 205). If this is correct, then it must be admitted that most positions on technology in the sustainability community are problematic, because not in line with current understandings of the relation between technology and society. When sustainable development practitioners and policy-makers work with wrong conceptions of technology, their advice on how to use technology for sustainable development may also be seriously flawed. However, over the last 5 to 10 years, a new shoot in the sustainability field has incorporated a conception of technology and its relations with society that relies heavily on SCOT and ANT. This is what is currently referred to as research and policy in "socio-technical system innovation and transitions" or "sustainability transitions". The origins of the field lie in the Netherlands, and most research as well as the first policy applications have been developed there. Meanwhile, interest in the approach is growing in particular from European researchers, with the first European Conference on Sustainability Transitions being held in Amsterdam in June 2009, and a second conference foreseen for 2011 in Lund. Amsterdam also saw the preparation for a Sustainability Transitions Research Network.

[7] The two levels are only distinguished analytically, although Feenberg admits that in modern societies the theory gets more complicated, because functions of the secondary instrumentalisation are often also distinguished institutionally (such as artists in a design division working in parallel with engineers in a technical division) (Feenberg 1999 and Feenberg 2005).

3.2.1 A Bird's-Eye View on Transition Research

In the way it has developed, this research field revolves essentially around two questions. First, how do radical, long-term changes in socio-technical systems happen and how can they be analysed? Second, can such transitions be influenced and, if so, how? In the background lies the assumption that understanding transitions and how they can be influenced, is a necessity for solving the deeply rooted problems in current consumption and production systems that are responsible for a lot of sustainability problems. "In order to solve such deep societal problems, changes from one system to another may be necessary. An understanding of the dynamics of transitions may assist policy makers to help bring about these changes" (Geels 2004a, p. 916). Although I will focus mainly on how technology is conceptualised in this field of research, it is necessary to understand that it draws on insights from different scientific domains to develop a broad, interdisciplinary picture of how change happens in socio-technical systems.[8] For the analysis of transitions, the field draws mainly on sociology and sociology of technology, evolutionary economics, innovation studies, history, and complex systems theory. The research into influencing and governance of transitions draws additionally on political sciences, management studies and social learning theories.

The point of departure of most of the research is the existence of "persistent problems" in current industrialised societies (Loorbach 2007). Examples are the energy and climate change problem, the problems associated with the global food chain and industrialised agriculture, the mobility problem with traffic congestion, air pollution and associated health consequences: all problems that are deeply rooted in our societal structures, occurring at different levels of scale, with a variety of actors with different perspectives involved, to be solved in the long term but with a lot of uncertainties regarding evolutions and solutions. The term "transition" is used as an encompassing term to indicate the kind of change needed in solving these problems. A transition is a transformation process "in which existing structures, institutions, culture and practices are broken down and new ones are established" (ibid., p. 17). In order to study transitions, several common conceptual notions are used, that also serve as bridging concepts between the various disciplines involved in the research. I follow the discussion from Fischer-Kowalski and Rotmans (2008) to give a concise overview. The first one is the concept of co-evolution: the interaction between societal subsystems influences the dynamics of the individual societal subsystems, leading to irreversible patterns of change. Economic, cultural, technological, ecological and institutional subsystems co-evolve in many ways and can reinforce each other to co-determine a transition. A second common concept is the multi-phase concept that describes a transition in time as a sequence of four alternating phases, each with its own characteristics: a predevelopment, a take-off, an acceleration and a stabilization phase. These phases do not follow a set pattern, but are meant as a heuristic to recognise what is happening and to give guidance in formulating policy. A third concept is co-design and learning: transitions demand new forms of knowledge and in particular a reframing of knowledge, problems and solutions. That can happen through an interactive process of co-production of knowledge with a range of stakeholders. A fourth concept is transition governance (sometimes also referred to as transition management): because of their complexity and uncertainty, transitions cannot be steered in the traditional sense, nor are market instruments sufficient as tools. The hope is, however, that it is possible to influence the direction and speed of a transition. Transition governance is meant as a process

[8] As can be expected in a young, rapidly evolving research field, different interpretations exist of the exact object of analysis (socio-technical systems, societal systems), of core concepts (such as transition, regime, niche, landscape) and the relation between the concepts. Since my article is not a discussion of transition research *an sich*, I will only go into details of interpretation when absolutely necessary.

of searching, learning and experimenting, with government and stakeholders working at the co-production of long-term policies.

I dwell a little longer on the last common concept because it features so prominently in the literature and it provides a bridge to the discussion of how technology is conceptualised. This last concept is the multi-level perspective (MLP) and it describes transitions as a consequence of interaction between different scale levels, not geographical scales, but functional scales with increasing degrees of structuration: a micro-, meso- and macro-level. The meso-level is called the (sociotechnical) regime. According to Rotmans et al. (2007), a regime is a dominant set of structure, culture and practices in a certain societal system (such as the energy or mobility system). This definition diverges considerably from the more common definition, as used by some of the main theorists in the field such as Frank Geels and Johan Schot, where we see an explicit reference to the SCOT-literature. Building on Rip and Kemp (1998) definition of a technological regime, defined as “the rule-set or grammar” shared by the engineering community involved in design and production of technology, they refer to Bijker’s sociology of technology to broaden the concept to a socio-technical regime: also scientists, policy-makers, users and special-interest groups contribute to the evolution of systems. “The sociotechnical regime concept accommodates this broader community of social groups and their alignment of activities” (Geels and Schot 2007, p. 400). Regime rules structure the activities of actors and thus provide for strong steering, however not deterministically. They are “dynamically stable” (Geels 2005, p. 77) in the sense that they leave room for creativity and adaptation to new situations and for improving dominant design, but with leaving the basic design intact. While change at the meso-level of regimes is incremental, at the micro-level we find technological niches, where radical novelties emerge. In niches, a lot of experimentation is going on, with configurations being less stable and a higher degree of uncertainty. Niche rules provide only for limited structuration of activities of niche actors, but these activities are carried by small networks of dedicated actors. Finally, the macro-level is called the socio-technical landscape and refers to “the technical, physical and material backdrop that sustains society” (Geels and Schot 2007, p. 403). The landscape is an exogenous factor that is beyond the direct influence of regime or niche actors, but that makes some actions easier than others. It usually evolves rather slowly and contains deep cultural patterns, macro-political developments, natural circumstances (climate change is currently an important landscape factor) and material environments (infrastructures), although sometimes fast changes through shocks may occur (economic crisis, war).

Regime rules align the activities of different social groups and provide for coordination and orientation of activities. This explains the stability in the regime and leads to interlinked trajectories in several dimensions (technology, scientific knowledge, markets, infrastructure, culture and symbolic meanings, industry networks and sectoral policy) (Geels 2004a,b). Although the regime is entrenched in a lot of ways, in certain periods trajectories may begin to diverge and tensions grow. This is the outcome of a combination of increasing landscape pressures, internal regime contradictions and development of promising niches. During such a period, windows of opportunity may open that provide chances for radically altering the regime (Fig. 2):

> “The multi-level perspective argues that transitions come about through interactions between processes at these three levels: (a) niche-innovations build up internal momentum, through learning processes, price/performance improvements, and support from powerful groups, (b) changes at the landscape level create pressure on the regime and (c) destabilisation of the regime creates windows of opportunity for niche innovations.

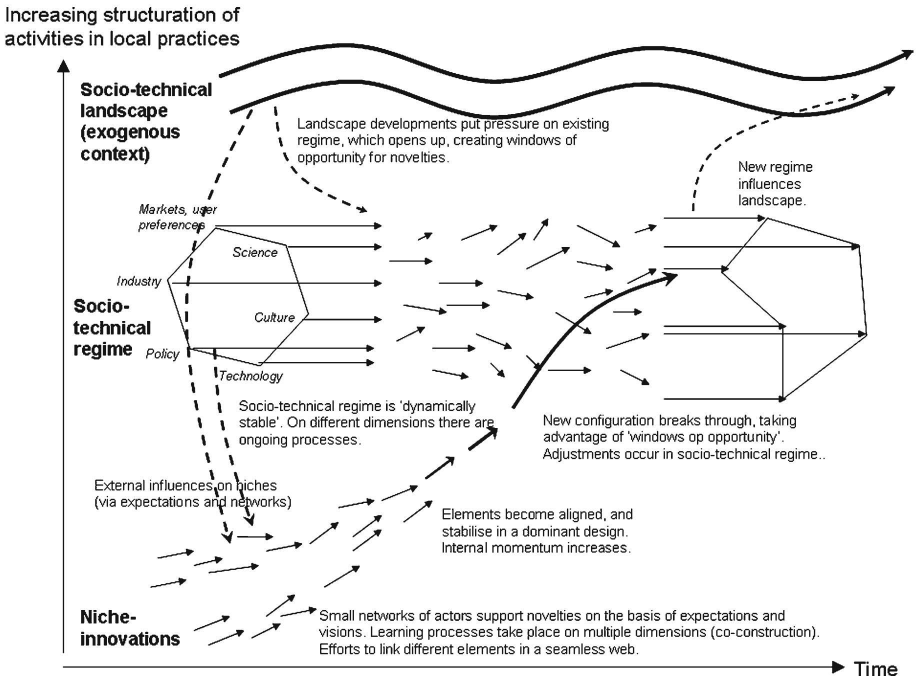

Fig. 2 Source: Geels and Schot (2007), p. 401

The alignment of these processes enables the breakthrough of novelties in mainstream markets where they compete with the existing regime" (Geels and Schot 2007, p. 400).

3.2.2 The Nature of Technology in Transition Research

It may already be obvious from the description above, that transition literature is full of co-evolution between technology and society. Most authors in the field take this as a given by now and do not discuss it in depth anymore, but in some of the formative texts of the field (such as Rip and Kemp 1998; Geels 2005), the conceptualisation of technology is made explicit. I will use the work of Geels as a reference here.

Geels states that his conceptualisation of technology is based on schools of STS (Science and Technology Studies) such as SCOT and ANT, that share two basic notions about technology: technology is heterogeneous and not just a material contraption, and technologies only function through linkages between these heterogeneous elements. Rip and Kemp draw these two notions together in a pragmatic definition of technology as heterogeneous "configurations that work". This is for Geels a useful conceptualisation of technology to study systems innovations "because it emphasises the inherent linkages between technical and social aspects" and can be used from firm level to the level of socio-technical systems. How this is embedded in transition theory becomes clearer when Geels formulates an analytical framework of three interrelated dimensions to study transitions (Fig. 3). He defines a socio-technical system as cluster of elements and their linkages that are needed to fulfil societal functions (such as transport, communication, nutrition) (Geels 2004a). These elements include

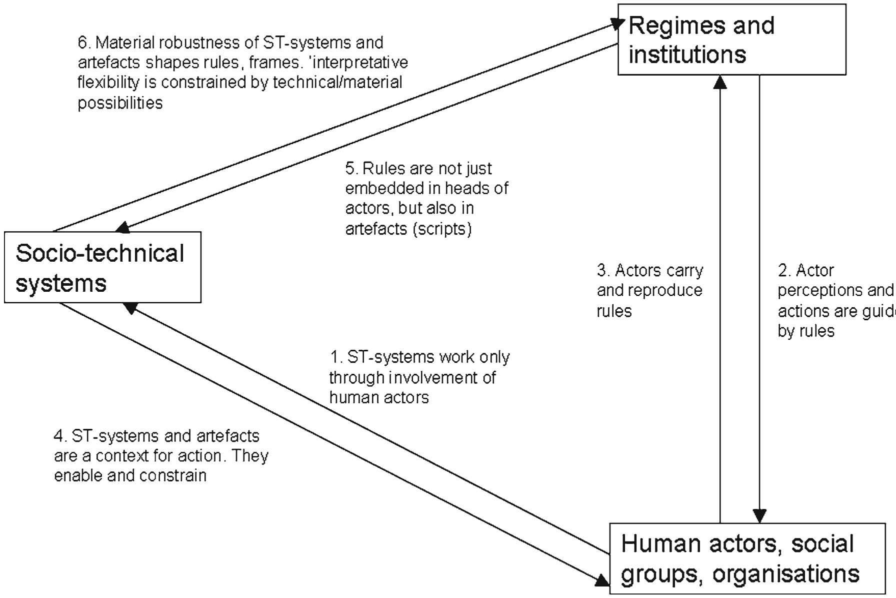

Fig. 3 Source: Geels (2005), p. 17

technology, supply networks, regulation, user practices and markets, cultural meaning, infrastructures, maintenance networks (Geels 2004b). A socio-technical system only functions through the actions of people and organisations, and thus in relation to networks of actors and social groups. Day after day systems are actively created, maintained and reproduced by human actors, embedded in social groups such as public authorities, producers, consumers, scientists, labour unions, ngo's, media. The actions of these groups are not arbitrary, but members share a particular language, problem perceptions, norms, preferences etcetera. In other words, consciously or unconsciously they share sets of cognitive, normative and regulative rules (or a regime).[9] While systems, actors and regimes can be distinguished analytically, they are always related in practice and exhibit six kind of interactions (Geels 2005, pp. 16–24). For the description of these interactions, as shown in Fig. 3, Geels constantly refers to SCOT and ANT, e.g. in how actors create and reproduce socio-technical systems (arrow 1); how technologies shape perception, behavioural patterns and activities (arrow 4), how rules are not only carried in an actor's head but also embodied in artefacts and practices (arrow 5); and how interpretative flexibility is limited by a certain obduracy of artefacts (arrow 6).

The goal of transition studies is not just to analyse how systems work in interaction with actors and rules, but to understand how changes happen from one socio-technical system to another. To construct a conceptual perspective on socio-technical transitions, Geels starts from an early version of the MLP developed by Rip and Kemp (1998) that mainly focuses on technological regimes and that is not very explicit about the interactions between the different levels. Working from a wide-ranging, multidisciplinary literature review, Geels searches for building blocks that can better inform a socio-technical perspective and that is stronger on the relations, interlinkages and co-evolutions between levels and actors (Geels 2005,

[9] Although I present the theory here as a consistent whole, there is considerable debate about the meaning and exact contents of regimes and systems. Compare e.g. Smith et al. 2005; Konrad et al. 2006; Markard and Truffer 2008; Smith and Stirling 2008. See also Paredis (2009) for a discussion.

pp. 28–75). Building blocks are brought in from amongst others innovations studies, evolutionary economics, history and STS. I restrict myself to a short description of the building blocks brought in from science and technology studies, i.e. SCOT, ANT and Large Technical Systems Theory (LTS). Figure 4 gives an overview of the main building blocks that are integrated in the socio-technical MLP and where they come in to explain the dynamics of change. As already mentioned above (3.1.), Hughes coined the term 'seamless web' to highlight how heterogeneous elements are linked with each other in a socio-technical system. All these elements need to be aligned to make a configuration work, and this happens in several phases that account for the development of large technical systems. During these phases, interlinkages grow stronger, but when the linkages weaken, systems become unstable. Geels uses this insight from LTS as one of his building block to understand the change from one system to another (ibid., p. 31). From the SCOT approach, he first takes the insight that the interplay between social groups is necessary to understand the development of technology. New technologies in niches originally have a lot of interpretative flexibility, but when a niche develops, the variation diminishes and a consensus grows on the dominant meaning and design of a technology ('closure'). From later developments in SCOT (here referred to as SCOT2), he borrows the concept of 'technological frame', developed by Bijker in order to take into account that human actors and interactions between social groups are constrained by factors that limit the flexibility of technological development (such as problem definitions, current knowledge and theories, design criteria, goals) (ibid., 43). Finally, from ANT he takes the insight that it is the accumulation of heterogeneous elements and their interlinkages that bring a technology into being. ANT studies also show that new technologies often link up with older ones to improve their overall functioning, and that introducing novelties in existing networks may trigger wider social changes and transformations (ibid., p. 53).

From this description, it is obvious that the way technology is conceptualised in socio-technical transition studies, is completely in line with the insights learned in contemporary philosophy and sociology of technology, in particular in the constructivist tradition. In the beginning of this article, I referred to a statement of Johnson and Wetmore (2009) that a better understanding of the relationship between technology and society is crucial to steering technology, and in the end to building a better world. There is little doubt that transition research paints a better and more nuanced picture of technology in relation to society than is the case in other approaches of sustainability discussed above. So, if Johnson and Wetmore are correct, transitions research may be an important contribution for sustainable development policies. Besides, the field is not only interested in description and analysis, but building on lessons learned, also wants to contribute to a governance perspective on sustainability transitions. What then are the main lessons for steering socio-technical systems (and the technologies involved) that derive from this field of research? I discuss important policy implications in the next paragraph and formulate some suggestions to strengthen the transitions perspective.

3.2.3 Politicising the Transition Perspective on Sustainable Technology (and Development)

Since technology plays such a pivotal role in transition research, the question surfaces whether the field provides some guidance in the choices that have to be made between technologies for a more sustainable society. Do policy-makers and other social groups find guidelines for choosing between technologies, or do these studies pronounce themselves in favour of certain technologies? The answer is 'no'. I am not aware of studies where the existing socio-technical regime is first analysed in terms of sustainability criteria and where next an analysis is made of the sustainability potential of niches. Instead, almost all scholars start from a kind of pre-analytical vision that most current socio-technical regimes are unsustainable as such

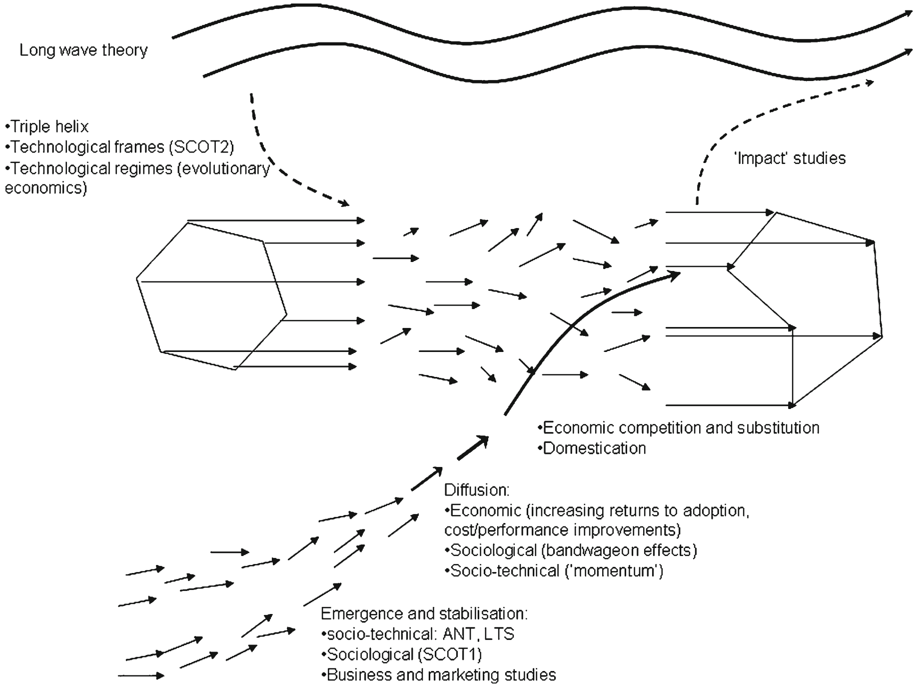

Fig. 4 Geels (2005), p. 94

and thus that they are in need of radical restructuring. The case studies that are being done,[10] are usually analyses of how systems have evolved (e.g. Geels and Schot 2007: Dutch electricity sector—Correljé and Verbong 2004: from coal to gas in the Netherlands —Loorbach 2007: the Dutch waste system—Belz 2004: the Swiss agri-food chain) or the cases are chosen from alternatives and niches to the current regime and discuss there inner functioning and potential for change (Raven 2005: biomass for energy production—Verbong et al. 2008: Dutch renewable energy—Ravenn and Verbong 2007: combined heat and power—Smith 2007: ecohousing and organic food in the UK—Nykvist and Whitmarsh 2008: mobility niches in the UK and Sweden). However, as far as I have been able to study, the technologies, systems and niches analysed are never evaluated on their contribution to sustainable development goals, such as in how far they succeed in staying within ecological limits and promoting equitable development paths. They are studied because they are niches, because they hold potential for changing the regime, and because the analyst assigns them a higher degree of sustainability than regime technologies. What we find are detailed investigations of how actors interact and the different roles they take on, how learning happens within networks, how interactions between regime and niche take place, what the role of expectations is, etc. But the research results do not seem able to provide guidance in whether certain technological choices are preferable over others, and if so, on what basis. My assessment is that this is at least partly attributable to the conceptualisation of technology, rooted in constructivism. Such a conceptualisation provides no tools for weighing different alternative technological choices. This is the reason for Feenberg's attempt at developing a critical version of

[10] I leave out historical studies here.

constructivism, as discussed above. Further down, I return to a possible embedding of such an approach in transition research.

But first, if there is no guidance in choice between technologies, then what do we learn from transitions research? In general, all policy advice is process-oriented, not content-oriented. One of the main learning points for sustainable technology policies is that they should not focus on individual products and processes, but on socio-technical systems, and on the relations between the different levels in these systems (niche, regime, landscape). Because we are talking about socio-technical systems, traditional technology push strategies are not adequate, since they neglect co-evolutionary dynamics (Schot and Geels 2008). Instead, for sustainability transitions to happen, it will be necessary to disturb existing socio-technical regimes with their concomitant persistent problems. A general strategy for transition governance is then to increase pressure on current regimes, in that way working towards windows of opportunity to change regime structure, culture and practices. The elements such a strategy can consist of include (Elzen et al. 2004; Smith et al. 2005; Raven 2005; Loorbach 2007): (a) translating landscape pressures (such as climate change, economic recession) into a necessity for regime change; (b) further increasing pressure on the regime through exposure of internal regime problems and formulation of alternative policies; (c) stimulating of niche development through networking, resource mobilisation, knowledge exchange and capacity building; (d) realisation of linkages between actors and developments at the three levels; (e) development of a long-term perspective on sustainable development that shapes expectations and aligns the activities of the involved social groups.

These kind of guidelines are worked out in more detail in several policy approaches for influencing transitions, of which the best known are Strategic Niche Management (SNM) and Transition Management (TM). Initial SNM work focused predominantly upon internal niche dynamics in the hope that niches would become strong enough to oust unsustainable regimes. More recent SNM work has left this somewhat optimistic path, still stresses the importance of niches for transitions, but links their development to external processes through the MLP (Schot and Geels 2008). Transition Management is a governance methodology, in which innovators with various backgrounds, perspectives and ambitions are brought together to develop a common problem perception of the targeted social system (e.g the energy system), develop a long-term sustainability vision for that system, path-ways towards the vision and short-term experiments that are meant to test the pathways in practice. The hope is that through social learning in this network of innovators and through the development of shared long-term visions and agendas, it is possible to influence the expectations and actions of societal actors, to initiate a long-term policy path, and to increase influence on regular short-term policies (Rotmans et al. 2001; Rotmans 2003; Loorbach 2007).[11] Transition management has attracted quite some attention from scholars interested in sustainable development, not in the least because it was implemented in Dutch policy in 2001, when the Dutch government initiated several long-term transition processes (the best known is the Energy Transition). Inspired by this example, the Flemish government decided in 2004 to experiment in its environmental policy with transition management (in the fields of sustainable housing and building, and sustainable materials management).

Probably the most often formulated criticism on transition management (and to a lesser extent SNM) is that it underestimates the political dimensions of its undertaking. “A large part of the transition management literature stays on a conceptual and programmatic level. It tends to overlook the political processes through which transition management is realised”

[11] A recent special issue of Policy Sciences (2009, no 42) discusses the ins and outs of transition management. For a general overview of experiences to date and a discussion of critical issues, see Voss et al. 2009.

(Voss et al., p. 277). The open processes of envisioning, deliberation, and collective second order learning that are central to the approach, often turn into a consensus exercise "of what is best for everyone" or are captured "by incumbent players with an interest in the status quo". What happens next, and this is very visible in the Dutch energy transition, is that while TM aims for "radical, system-wide sustainable development as a goal", we again get "technology development, global competitiveness and economic growth" as transition goals (citations from ibid., p. 289). The risk it thus that, in spite of the progress that has been made in transitions research in comprehending the relation between technology and society, in spite of the process-related policy orientations that can be derived from that, and in spite also of the growing enthusiasm for this approach in the sustainability research and policy community, we end up with a perspective that supports the status quo.

In line with the arguments developed in this article and the concern over the role of technology in sustainable development policy, I want to briefly elaborate on two possible pathways to strengthen the transition approach. Both aim at making the political dimension more explicit in transition research, because in my view, this is the only way through which transitions can be saved from an "anything goes"-interpretation.

The first pathway aims at broadening the conceptualisation of technology in transition research. With their roots firmly in constructivist ground, transition studies can provide no guidance in technology choices, or formulated differently, any technology can still be framed as "sustainable". The question can be raised whether a research field that wants to contribute to radical change, should not take more notice of this problematic aspect of constructivism. One pathway for introducing more difference in the evaluation of technologies, is Feenberg's instrumentalisation theory. Such an approach would probably focus more on the 'technical codes' that are brought into design processes and which function as taken-for-granted values and practices in our culture. Transition research would then not only reflect on the processes that explain regime shifts, but also reflect on "how alternative values can be brought into the design process so that the technical codes that determine the design are humane and liberating rather than oppressive and controlling" (Feng and Feenberg 2008, p. 117). Although it is not explicitly positioned in transition research, the research of Bram Bos demonstrates how such an approach might proceed (Bos 2004). Bos shows how current socio-technical systems in pig husbandry and arable farming usually aim for control over the living beings (humans, animals, plants) that function in them. Technology, detailed regulations and enforcement have to rule out 'uncontrolled' behaviour that is detrimental to the overall systems goals, such as optimisation of yields. These control actions often lead to conflicts between the interests of living beings and the system goals, setting in motion a control race that seems to necessitate an escalation in control measures (ibid., p. 183). Bos shows however that it is possible to imagine a development route for these systems that sharply diverges from this dominant pattern. Current systems are "based on the false presupposition that living beings following their own agenda will only be cooperative if they are forced to do so" (p. 185). In contrast, a route of 'interest-guided influence' is also possible, with systems that create space for synergy between interests and goals of living beings and system goals. From his research, Bos concludes for example that organic agriculture functions much better in this respect than systems built on genetically modified organisms. In terms of the discussion on technology in transitions, what has happened here, is that through inquiry into the technical codes of different socio-technical systems, Bos is able to evaluate them and provide guidance in choosing between systems.

My second pathway for strengthening transition research starts from the observation that giving guidance in such a choice obviously demands a normative positioning of researchers vis-a-vis different technology options and socio-technical systems.[12] The question then is, in the case of sustainability transitions, where such a normative frame may come from. What can easily be noted is that the transitions literature hardly dwells on what sustainable development exactly means, on how environmental limits should be interpreted, and even less on what equity implies. It is impossible to say where this approach should be fitted in in Hopwood's and Sachs's different interpretations of the meaning of sustainable development. It seems enough to state that one is in favour of sustainable development. Thus, Schot and Geels (2008, p. 548) argue that "while SNM recognises that different definitions of sustainable development exist, it is based on the assumption that sustainable development captures enough common ground to act upon." Does it make sense to have a literature that is full of exclamations about the need for 'radical change' in current socio-technical regimes, but that only expresses itself on the processes of change, and keeps all virtually all options open on the content and direction of the change necessary? The way to explain this is to refer back to the turn in the sustainability debate I noted at the end of paragraph 2.1: sustainability is no longer interpreted as an end-state that can be strictly defined, but as a social process in which different forms of knowledge and preferences are combined "to give rise to an emergent, co-produced understanding of possibilities and preferred outcomes" (Robinson 2004, p. 381). This is probably the only way to make progress in sustainable development policy and practices, but what over the years seems to have happened in the transition field, is that the scientific input for such a co-production has become restricted to input about processes at play in system change. While this was perhaps not the intention, it makes the transition agenda more vulnerable for interpretation in any direction and for capture by incumbent actors.

It is necessary to start the debate in the transition community about the direction of change that is needed—deeper than "we need sustainable development"—that is in line with the radical changes advocated. This will not only clarify what a transition stands for, but it is also necessary to develop criteria to be give guidance in technology choices, to evaluate whether processes are on track, to provide substance to first and second order learning processes. Such a track should of course not be developed as a blueprint, but as a contribution from the transition field to the deliberative construction process sustainable development is. Inspiration for such a framework can be found with several authors already mentioned in this article. Sneddon et al. (2006) propose a set of conceptual and normative perspectives based on ecological economics, political ecology and Amartya Sen's freedom-oriented development, supported by a practice of deliberative democracy. Jackson (2009) develops a framework that allows for prosperity without growth, building on respect for ecological limits, protection of capabilities for flourishing, and a sustainable macro-economy. I have illustrated at length how Banuri et al. (2001) see a sustainable society as flowing from two decoupling processes: decoupling growth from resource flows, and decoupling wellbeing from production.

4 Conclusions

In a review article of the state-of-the-art of the philosophy of technology, Ihde (2004) remarks that this branch of philosophy is a twentieth century development. He notes how the 'forefathers'— Heidegger, Ellul, Marcuse and the later Mumford—had "a tendency to lump all technologies under a single, generalized or transcendentalized 'Technology', and to see

[12] In the case of Bos, it supposes minimally that he estimates interests of living beings (not only human beings, but also animals and plants) higher than current system goals and the technical codes embedded in current agricultural systems.

such Technology as a danger or threat for humankind, (high) culture, or the future" (ibid., p. 123). Two tendencies brought important change here. The Dutch philosopher of technology, Achterhuis, was one of the people to draw attention to the more empirical orientation of American philosophers of technology (such as Ihde himself, Feenberg, Dreyfus, Haraway, Winner, Borgmann). These are "less dystopian than their European forebearers, do not transcendentalize technologies, are more 'empirical' in the sense that particular technologies are analyzed, and overall are more pragmatic—this set of tendencies, Achterhuis argues, has tended to replace those of the earlier generational views in contemporary philosophy of technology" (ibid.) Combined with the influence of the sociology of technology, under the form of in particular SCOT and ANT, this has moved contemporary philosophy of technology and the conception of the relation between society, technology and human influence to the lower right-hand corner of Feenberg's classification (see Table 1).

While the co-evolution of society and technology has become common sense in the philosophy of technology, it has for the major part not flowed through to society and everyday understandings of technology. I have shown how in one of the main debates concerning our common future—the debate on sustainable development in its global dimensions of quality of life, environmental limits and equity— the outdated instrumentalist position is overwhelmingly present. More radical groups in the debate adhere to a substantivist position in their analysis of technology, while trying to find manoeuvring room for a different, more appropriate form of technology. The more complex understanding of the intertwining of technology and society has, in the sustainable development debate, reached the design community and the socio-technical transitions community. In the second part of this article, I have tried to show how a constructivist approach to socio-technical systems is embedded in the transition research field. This has caused a leap forward in grasping how radical changes in socio-technical systems happen and how these insights can be useful for advancing sustainability transitions. Some challenges remain however, that are in particular related to providing guidance to the direction of technological search. A critical approach to the constructivist conceptualisation of technology, such as defended by Feenberg, and a more political stance in defining sustainable development seem some of the necessities—and a research challenge—for the coming years, if the transition field wants to stay relevant. There may also be a challenge here for philosophers of technology: namely developing a practice of 'engaged knowledge' (Goeminne et al., forthcoming) through more involvement in debates on technology and society outside the research community, so that what is common knowledge for philosophers seeps through faster to the society at large.

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