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SUSTAINABLE DEVELOPMENT AND ICT INTERPRETED IN A NATURAL SCIENCE CONTEXT

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SUSTAINABLE DEVELOPMENT AND ICT INTERPRETED IN A NATURAL SCIENCE CONTEXT

The resulting research questions for the social sciences

Sustainable development (SD) is a political concept with a strong normative component. In this article, we show which implications follow from this normative component if it is interpreted in a natural science context. We conclude that from a natural science point of view, a far-reaching dematerialization of consumption is a necessary condition for SD. We further conclude that information and communication technologies can only support SD if they are applied as enablers of dematerialized (less material-intensive) types of consumption. Macro-level data on consumption shows, however, that average material flows per capita are still increasing. In this problematical situation, we see a need for framework conditions that provide incentives for dematerialization and specialized research on the psychosocial conditions on the basis of which consumption patterns could evolve towards a more dematerialized economy.

Keywords information society; sustainability; societal metabolism; material flow; dematerialization

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1. Introduction

The most prominent definition of *sustainable development (SD)* was given by the World Commission on Environment and Development: In order to be considered sustainable, a pattern of development has to ensure 'that it meets the needs of the present without compromising the ability of future generations to meet their own needs' (WCED 1987). We regard this definition – also

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known as the 'Brundtland definition' – as the original definition of SD and will implicitly refer to it unless stated otherwise.

A basic hypothesis of this paper is that the normative implications of the Brundtland definition, if taken seriously, have been underestimated in the discussion of SD during the last two decades and that this underestimation (among other negative consequences) leads to a misconception of the role of information and communication technologies (ICTs) in SD.

In Section 2, we will explain why we believe that the normative idea of SD is more radical than generally recognized. For this, we will introduce the concept of the *sustainability dilemma* by going back over the natural science interpretation of SD, i.e. reformulating the concept in terms of mass and energy flow. We will also show that this view is not equivalent to a reduction of the SD concept to its 'ecological dimension' and will fundamentally question the so-called multidimensional concepts of SD, concluding that the idea of multidimensionality has been serving as a vehicle to water down the original SD concept.

In Section 3, we will show the currently prevailing misconceptions distorting the role of ICTs in SD while we refer to what we call the 'techno-optimistic' view expressed by the documents produced at the World Summit on the Information Society (WSIS) and a 'techno-pessimistic' view expressed by some scholars as an antithesis to the WSIS position. We will introduce a more differentiated concept of 'ICTs for SD' and show how it leads to a new interpretation of the macroeconomic data that seem to support the techno-pessimistic view.

We will finally argue that the implementation of SD in its original and radical sense is bound to three necessary conditions: economic incentives to dematerialize production and consumption processes, technological progress in ICT applications enabling dematerialization, and research on the psychosocial conditions on the basis of which consumption could be dematerialized.

2. The sustainability dilemma

In the following, we want to show why natural scientists read the Brundtland definition as the formulation of a dilemma (for which we have introduced the term 'sustainability dilemma', Hilty 2008). This first of all requires transforming the definition into a normative statement, such as 'We *should* have SD, and this would be a development that meets the needs of the present without compromising the ability of future generations to meet their own needs'. It is important to notice that this statement combines two ethical claims, *intra*generational justice (meeting the needs of the present) and *inter*generational justice (not compromising future generations).

Second and more important, we ask what the implementation of this requirement would mean in physical terms, showing that – given the metabolic rates of today's economies – it will be impossible to implement the two imperatives of SD (intragenerational and intergenerational justice) at the same time due to physical limits.

Physically, a national economy is a metabolic system that takes in mass and energy flows from the ecosystem and from other economies (Baccini & Brunner 1991; Fischer-Kowalski & Haberl 2007; OECD 2008). These material entities are then transformed by production and consumption processes and sent back to the ecosystem or to other economies. According to the principles of mass and energy conservation, everything that comes in and is not stored must come out again. Recycling reduces the throughput of some material flows, but consumes energy (Krivtsov *et al.* 2004).

What does it mean from this point of view for a national economy to fulfil the first part of the normative statement mentioned earlier, i.e. to meet 'the needs of the present'? We take the national economy of Switzerland as an example because this country has one of the highest standards of living and is also known for high environmental standards and recycling rates. Furthermore, it is considered a 'service economy' because of the large contribution of the service sector to the gross national product (GDP). Therefore, we would expect Switzerland to have a relatively dematerialized economy. However, according to official statistics (FSO 2008), the Swiss economy had a direct material input (DMI) of 111 million metric tons or 14.8 tons *per capita* in 2006. More than 40 per cent of this material was imported and less than 60 per cent provided by domestic agriculture and mining. The DMI does *not* include the so-called hidden flows that are induced in other countries to produce the goods exported from there to Switzerland, which are estimated to amount to *an additional 33 tons per capita* in 2006 (FSO 2008).

The DMI data alone, although revealing only a part of the truth, suggest that not every national economy could use the same pattern of production and consumption, i.e. to import 40 per cent of the physical mass necessary to fulfil the needs of its people. It is also obvious that, under the theoretical assumption that all countries had the opportunity to reach a similar level of *per capita* material consumption, the pressure on the global ecosystem and the rate of mining non-renewable resources would necessarily increase by roughly one order of magnitude.

At the global level, 58 billion metric tons of resources were extracted from nature in 2005 (OECD 2008). This includes fossil fuels, metals, industrial and construction materials as well as biomass. Converted to per-capita terms, this amounts to roughly 9 tons for every person on a global average. Although the current rate of resource extraction seriously affects the global ecosystem, the increase is expected to continue. This even includes the use of fossil fuels, although that is supposed to be limited by climate policies. The OECD estimates that global resource extraction will exceed 80 billion tons in 2020. This means that mankind will have doubled the annual global rate of resource extraction within only 40 years (1980–2020). This development is mainly driven by the catching-up process of the emerging economies and by continued population growth.

Let us look at some more specific examples: The *per capita* consumption of aluminium in industrialized countries today is higher than in a typical developing country by a factor of 14 and that of steel by a factor of 130. An average North American consumes about 340 kg of paper per year, whereas an Ethiopian – on the other end of the scale – about 300 g. This list could be continued almost indefinitely. Even if the figures are only snapshots, very imprecise and some of them outdated, their magnitude reveals the basic dilemma of all sustainability policies: the lifestyle of the rich industrialized countries cannot be adopted in its present form by the whole globe, nor can any lifestyle that is as material-intensive as that of today's richest service economies.

In fact, the physical and biological constraints on an intended globalization of the lifestyle of the richer part of the world have been voiced by natural scientists from the beginning of the SD discourse (Schmidt-Bleek 1994; Von Weizsäcker *et al.* 1997). The most recent formulation of this core issue can be found in the declaration of the World Resources Forum (WRF), a consensus built among natural scientists to be brought to the attention of economists and politicians (WRF 2008, p. 1):

> Globalizing the traditional model of economic growth is leading to rapidly increasing consumption of limited natural resources, followed by ecological disruption. Current economic and environmental policies have not been able to stop these trends. . . . Rising global consumption of raw materials (minerals, fossil energy carriers and biomass), air, water, soil and space (land use for human settlements, infrastructures, industry, mineral extraction, agriculture and forestry) is beginning to affect the life-sustaining services of the earth, which are not replaceable by technical means. . . . Today, the fundamental flaw in human activities is the enormous consumption of natural resources per unit output of value or service.. . . . The environmental safety threshold has already been surpassed, as is evident from developments such as climate change, widespread water shortages, desertification, massive erosion and increasing natural disasters such as hurricanes and floods. And yet, only some 20 per cent of humankind enjoy the full benefits of the mainstream economic model, while all people – in particular the poor – have begun to suffer the consequences of its flaws.

In this sense, we define the sustainability dilemma as the physical impossibility of extending the present consumption patterns of the industrialized countries to all parts of the world without putting a great burden on future generations.

Advocates of a 'multi-dimensional' concept of SD may object that this argument would only reflect the 'ecological dimension' of SD, while neglecting the others, namely the economic, the social and the cultural one. In contrast to this view, we believe that the sustainability dilemma is fundamental and not specific to any particular aspect of SD for the following reasons.

First of all, if the dimensions are interpreted as separate spheres where SD is supposed to be implemented, namely the ecosystem, the economic system, society and culture, the multidimensional concept turns out to be simply ill-defined. The reason is that the four spheres are not at the same conceptual level. In particular, the economic system is a subsystem of society, and culture is the process of societal development.

A different, more considerate interpretation of the four dimensions would be to read them as implicit normative goals: protection of the ecosystems (ecological sustainability), economic growth or welfare (economic sustainability), social justice or solidarity and peace (social sustainability), cultural continuity or diversity (cultural sustainability). Given this interpretation, the sustainability dilemma turns out to be still fundamental to all four 'dimensions', since obviously none of these goals can be achieved without preserving the 'life-sustaining services of nature' (WRF 2008, p. 3). Furthermore, the sustainability dilemma only exists because a maxim of social justice is required to be applied to both present and future generations; it is therefore inherently social.

Why have multidimensional conceptions of SD then been able to become so popular? In our view, the main reason for the popularity of the multidimensional concept – which was essentially propagated by the United Nations Conference on Environment and Development (UNCED) in Rio de Janeiro in 1992 – is that the multidimensionality mitigates the radical nature of SD. Following the German physicist and philosopher Meyer-Abich (2001) we think that the normative idea of SD, strictly interpreted, would be 'revolutionary' and that for this very reason it contains 'an inherent guarantee of ineffectiveness' (Meyer-Abich 2001, p. 293). In our view, the SD discourse therefore sought a less revolutionary idea and found the multidimensional concept, which creates the impression that if we do not succeed in one segment of sustainability (e.g. ecological sustainability), we could compensate for this flaw in other segments (e.g. economic sustainability). Behind this thinking, there is an idea that has been called 'weak sustainability', which assumes that human-created capital can replace natural capital. It would therefore be compatible to substitute e.g. 'swimming pools for seashores, leisure parks for historic regions, fitness centres for cross-country runs and walks' (Meyer-Abich 2001, p. 296). Although the question of the substitutability of capital is indeed a crucial and open one, a natural science point of view includes the insistence that there is a core of 'life-sustaining services of the earth, which are not replaceable by technical means' (WRF 2008, p. 1).

We conclude from this section that, assuming a natural science view of human consumption, there is no meaningful way of assigning the sustainability dilemma to one of more aspects or 'dimensions' of SD. As a consequence, there is no meaningful interpretation of terms such as 'ecological sustainability', 'environmental sustainability', 'economic sustainability', 'social sustainability' or 'cultural sustainability' as long as 'sustainability' refers to SD. It is impossible to segment the normative component of the SD concept into these dimensions because the sustainability dilemma must be solved in any case, irrespective of the specific focus of a given discourse.[1]

From this point of view, there is only one way to solve the sustainability dilemma: reducing the *per-capita* material input into the economic system, e.g. to 6 metric tons per year for non-renewable materials including fossil fuels (WRF 2008). If we rule out the possibility of a general reduction in the present levels of final consumption, this can only be achieved by producing more well-being with less input of natural resources, i.e. by a far-reaching *dematerialization* of production and consumption processes.

3. Dematerialization and the role of ICT

The call for dematerialization is the logical consequence of the sustainability dilemma. The dematerialization discourse was started about two decades ago with statements such as the following: 'Considering the fact that for every person in the United States we mobilize 10 tons of materials and create a few tons of waste per year, it is clearly important to gain a better understanding of the potential forces for dematerialization. Such an understanding is essential for devising strategies to maintain and enhance environmental quality, especially in a nation and a world where population and the desire for economic growth are ever increasing' (Herman *et al.* 1990, p. 346).

Since the mid-1990s, estimates have been discussed according to which the material intensity per service unit must be reduced by a factor of 4–10 if the lifestyle of the rich North is to be applied across the whole globe (Schmidt-Bleek 1994, 2009). By and large, there are no doubts as to the technical feasibility of this aim (Von Weizsäcker *et al.* 1997).

Viewed from this perspective, there is only one relevant role ICT can play in supporting SD: enabling or facilitating the dematerialization of production and consumption processes. This idea leads to the vision of an ICT-enabled 'weightless economy' or 'sustainable information society', as suggested by Coyle (1997), Heiskanen *et al.* (2001), Schauer (2003), Isenmann (2008), as well as by the authors (Hilty & Ruddy 2000; Hilty 2008).

Empirical data show that thus far the diffusion of ICT (in particular the PC and the Internet) has not made this vision a reality, i.e. has not dematerialized the economy in terms of mass and energy flows (for a critical survey, see Fuchs 2008). Referring to the example of Switzerland again, we have to face the fact that the total material requirement has increased by 17 per cent between 1990 and 2006 (FSO 2008) despite the diffusion of the PC and the explosion of the Internet during that period. What we would have expected to see from a techno-optimistic SD view is a decrease by some 50–80 per cent.

We want to discuss in the following sub-sections how the sustainability dilemma and the actual impact of ICT on the material intensity of the economy are perceived from optimistic and pessimistic perspectives on technological development, taking the WSIS process as representative of the former

(3.1) and the antithesis formulated by Fuchs (2008) as an example of the latter (3.2). We will then present our own view of the role of ICT in SD and discuss its political implications (3.3).

3.1 *International development, environment and the WSIS*

International development is a discourse older than the environmental discourse. Despite the historic compromise reached at UNCED in Rio in 1992, policies of environment and development have never been satisfactorily reconciled with each other. This schism was continued at the WSIS, where development trumped the environment as regards their respective relationships with ICT.

On the one hand, the WSIS was an event like others intended to produce an aspirational declaration that would not comprise any part of binding international law. At the same time, it was a new type of world summit, in which certain interests in the United Nations System hoped to discover what aspects of the broad area called 'the Information Society' could be better managed from a multilateral instead of nation-state perspective. The Internet, an artefact of the US military, had begun to take on features of the business model of a public utility through a commercialization phase made possible by a new communication protocol developed at CERN in Geneva. This new Internet access, though, was not reaching all consumers/citizens universally.

Admittedly, there was from the start a development impulse characterized by the intention of the signers of the declaration at the Okinawa Summit of the G-8 industrialized states in 2001 'to combat the digital divide'. In keeping with this spirit, the first phase of the WSIS that ran in 2003 in Geneva, Switzerland produced the Geneva Plan of Action. Eventually, though, the new topic of Internet governance emerged in an attempt to democratize ICANN and open up a closed system like the International Telecommunication Union (ITU) to civil society. Internet governance came to dominate the discourse to such a degree that even SD was subordinated to it (Willard & Halder 2005; MacLean *et al.* 2007).

The Geneva Plan of Action included three paragraphs under Subheading 20 'E-environment', which constitutes one of several action lines (WSIS 2003a, p. 9):

(a) Governments, in cooperation with other stakeholders, are encouraged to use and promote ICTs as an instrument for environmental protection and the sustainable use of natural resources.
(b) Government, civil society and the private sector are encouraged to initiate actions and implement projects and programmes for sustainable production and consumption and the environmentally safe disposal and recycling of discarded hardware and components used in ICTs.
(c) Establish monitoring systems, using ICTs, to forecast and monitor the impact of natural and man-made disasters, particularly in developing countries, LDCs and small economies.

There are only two passages where a weak reference to SD is made: 'sustainable use of natural resources' in paragraph (a) and 'sustainable production and consumption' in paragraph (b). There is no indication that the fundamental nature of the sustainability dilemma has been understood – the dematerialization issue is not mentioned as a necessary condition for the 'sustainable use of natural resources'. Furthermore, 'sustainable production and consumption' are curiously put in the specific context of electronic waste. Although e-waste is an important issue in which the authors' group invested considerable research effort (Hilty 2005; Kräuchi *et al.* 2005; Wäger *et al.* 2005; Sepúlveda *et al.* 2010), merely improving the disposal situation would fall far short of what would be needed to escape the sustainability dilemma.

In contrast to this weak reference to SD, the 13 pages of the Action Plan contain many detailed references to the importance of using *ICT for development*. Moreover, the reduction of SD to development by ignoring the sustainability dilemma is made explicit in the WSIS Declaration of Principles: 'Sustainable development can best be advanced in the Information Society when ICT-related efforts and programmes are fully integrated in national and regional development strategies' (WSIS 2003b, principle 43). A major section of the 2003 event in Geneva was devoted to ICT for development under the acronym 'ICT4D'.

The second phase of the WSIS, which took place in 2005 in Tunis, Tunisia, produced the 'Tunis Agenda for the Information Society'. There, the Geneva ideas on the work to be undertaken involving the natural environment were echoed in a few references in the following paragraphs (WSIS 2005):

- 23 (f) deals with 'ICT applications and content aimed at the integration of ICTs into the implementation of poverty eradication strategies and in sector programmes, particularly in health, education, agriculture and the environment'.
- 90 (g) deals with 'improving access to the world's health knowledge and telemedicine services, in particular in areas such as global cooperation in emergency response, access to and networking among health professionals to help improve quality of life and environmental conditions'.
- 90 (p) deals with 'strongly encouraging ICT enterprises and entrepreneurs to develop and use environment-friendly production processes in order to minimize the negative impacts of the use and manufacture of ICTs and disposal of ICT waste on people and the environment. In this context, it is important to give particular attention to the specific needs of the developing countries'.

This shows that the second phase of WSIS fell back behind the Geneva Action Plan instead of progressing. Paragraph 23 (f) confirms that ICT is viewed from a traditional development, not *sustainable* development perspective.

90 (g) mentions health, quality of life and environmental conditions without showing any awareness of the sustainability dilemma. We also recall that the tsunami over Indonesia and Sri Lanka had occurred just prior to that time, so that improvements in 'emergency response' (as a prime example of end-of-the-pipe solutions) were in great demand. 90 (p) mentions 'environment-friendly production processes'. Despite the use of the anachronistic term 'environment-friendly', this passage represents the last hope of finding the idea that ICT could revolutionize production and consumption. But instead of that, this statement turns out to be restricted to the 'manufacture of ICTs and disposal of ICT waste'.

In the second phase of WSIS, the procedural problem remained that still no institution had come forth to carry on with the topic ICT and the environment beyond 2005. The most likely candidates from the United Nations System named as possible moderators or facilitators were WHO, WMO, UNEP, UN-Habitat, ITU or ICAO (WSIS 2005). Therefore, the ITU had to carry on itself until 2008, when it invited WMO and UNEP to reconsider taking on the leading role under the new, popular ICT-related priority climate change mitigation. This eventually marked a new positive direction in ICT and the environment in the ongoing WSIS process, in that the Focus Group on ICTs and Climate Change was set up and succeeded by the ITU-T Study Group 5 Environment and climate change in 2009 (ITU 2009). However, neither of the new groups has addressed the broader dematerialization issue. Climate change can in fact be understood as one of the material flow problems we face: '[C]limate change . . . is the consequence of enormous human-induced material flows, mainly of fossil fuels and of biomass' (WRF 2008). However, merely focusing on climate change runs the risk of neglecting other vital material flow problems.

We conclude therefore that the whole WSIS process has ignored the sustainability dilemma and consequently failed to recognize the necessary role of ICT as an enabler of dematerialization. The WSIS documents promote ICT as an enabler of traditional economic development, i.e. quantitative growth based on increasing mass and energy flows. In practical ICT-related development projects, this also seems to be the dominating view of the local stakeholders (Streicher-Porte *et al.* 2009).

Neglecting the dematerialization issue makes it possible to maintain an untainted optimistic view of the role of technology, since the hopes attached to the technology are not dashed by the reality of economic metabolism. However, SD will not be possible if efforts are confined to taking this position, which is too optimistic regarding both the beneficial impact of technology and the traditional model of economic development.

One reason for this failure of the WSIS process might be a mutual misunderstanding between the ICT experts and sustainable development experts in the WSIS process: 'People with ICT backgrounds don't fully grasp SD, and vice versa' (Andjelkovic 2005, p. 2).

3.2 *The failure of ICT under the current socio-economic conditions*

We take the paper 'The implications of new ICTs for sustainability' by Fuchs as an example of a view of ICT in SD which recognizes the necessity of dematerialization and critically reflects on progress made in implementing this goal in economic reality. We regard Fuchs' position as pessimistic concerning the role of ICT in SD because he concludes by denying ICT any inherent potential for change.

Fuchs first reviews empirical results regarding the impact of ICT on commuting, the resource productivity of the ICT sector and the substitution of virtual for physical products, pointing out that 'total distance travelled per employee is constantly rising' (Fuchs 2008, p. 291) and 'the knowledge society is not an immaterial society' (Fuchs 2008, p. 299). He attributes these sobering results to the fact that 'sustainable development in the context of the information society has primarily been considered from the ecological perspective', despite his (multi-dimensional) view that '[a] sustainable information society is a society that makes use of ICTs and knowledge for fostering a good life for all human beings of current and future generations by strengthening biological diversity, technological usability, economic wealth for all, political participation of all and cultural wisdom' (Fuchs 2008, p. 308).

We largely share Fuchs' recognition of the symptoms (no progress in dematerialization despite ICT diffusion), but not his diagnosis. Although we strongly believe that 'biological diversity, technological usability, economic wealth for all, political participation of all, and cultural wisdom' (Fuchs 2008, p. 308) are goals worth striving for, we can also imagine a situation in which all these goals would be reached with the aid of ICT, but not in a sustainable way. This is because reaching these goals, as hard as it seems, does not imply that the sustainability dilemma would be solved.

Fuchs attributes the failure of ICT to two causes:

(i) a consideration of SD 'only from the ecological perspective' (as cited earlier), whereas he advocates a multidimensional concept of SD,
(ii) his belief that technology will not solve environmental problems unless 'new models of economic production and social relationships' are in place (Fuchs 2008, p. 308).

We have already refuted the claims made in the first part of the diagnosis (i) in Section 2 by rejecting the 'multidimensional' concept of SD. The second part (ii) will be discussed in the following. Interestingly, it is the exact antithesis to the techno-optimistic view we have deduced from the WSIS documents. Whereas ICT is viewed as an almost autonomous agent of change in the WSIS documents, Fuchs advocates the necessity of fundamental changes in the socio-economic framework before any beneficial effects of the technology could be reasonably expected. Our view is between these two positions, as we will explain in the next sub-section.

3.3 *Economic incentives and technological enablers*

Both the techno-optimistic and the techno-pessimistic views of ICT in SD underestimate the fundamental nature of the sustainability dilemma. Both tend to water down SD by adopting a multidimensional concept that creates the illusion that socio-economic achievements could lead to sustainability while offering no prospect of how the mass and energy flows through the economic system could be restricted to sustainable levels.

Recognizing the sustainability dilemma implies that a dramatic increase in resource productivity (dematerialization) is a necessary condition for SD. Given that dematerialization is so important, the next question we must address is whether and under what conditions ICT can contribute to this change. The current observation that resource productivity has not increased at the macro-level so far despite massive ICT diffusion does *not* imply that ICT is in principle incapable of bringing about dematerialization or that the life cycle of ICT hardware (production, use, disposal) will always offset the benefits of its use in terms of mass and energy flows. We consider this pessimistic conclusion an improper generalization of specific observations in the current socio-economic situation. The following two arguments support our view.

The first argument is based on an analogy, replacing resource productivity with labour productivity for a thought experiment. In the 1980s and 1990s, the so-called 'IT productivity paradox' was discussed in economics and management literature for a long time. Robert Solow, the 1987 Nobel laureate in economics, initiated the debate by stating that 'we see the computer age everywhere except in the productivity statistics' (Solow 1987). The common belief that computers increase labour productivity was surprisingly not supported by macro-economic data, just as it is the case for resource productivity today. The subsequent controversy motivated a range of interesting research projects on the question as to how IT affects the productivity of organizations, and how productivity on the organizational level aggregates to productivity on the macro-level. The firm-level data showed substantial variation across firms, leading to the conclusion that the effect of IT was dependent on the organizational conditions under which IT was applied (Brynjolfsson & Hitt 1998, p. 52). For the same reason, the observation that dematerialization has not occurred at the macro-level during the period of massive ICT diffusion does not imply that ICT is in principle incapable of enabling economic dematerialization. Unleashing the dematerialization potential of ICT may depend on organizational conditions in a way similar to the case of labour productivity.

A simulation study commissioned by the Institute for Prospective Technological Studies of the European Commission concluded that, under conditions generally conducive to environmental protection, ICT reduced the overall environmental impact by around 20 per cent, whereas under the least favourable conditions, ICT was responsible for 30 per cent of the additional environmental impact. However, under average conditions, the positive and negative effects of ICT on the environment had the tendency to cancel each other out, so that no clear effect at the macro-level occurred (Erdmann *et al.* 2004). Technologies are used as means to ends, which implies that they enable purposeful change if and only if the ends are defined accordingly at the micro-level. In a market economy, this is a matter of incentives that take the form of price signals.

This leads to our second argument: ICT has not brought about a dematerialization of production and consumption processes to a relevant extent thus far because the incentives have not been strong enough to use this technology to this end. The currently budding revolution in the automotive market (the trend towards more fuel-saving, hybrid and even all-electric vehicles) shows that incentives have to pass a certain threshold until market participants (both consumers and producers) start changing their decision behaviours. In this case, the incentive is provided by rising fuel prices. However, the effect of the incentives is constrained by the availability of enabling technologies, such as efficient batteries for hybrid and electric cars.

Applying this pattern of thought to ICT and dematerialization means that rising prices for materials and energy will create revolutionary changes in production and consumption models, and will cause mass and energy flows to decrease, if the enabling ICT applications are available. However, there will only be room for big leaps if people's view of material goods changes: in many fields, consumption patterns will have to change from purchasing material goods (transferring material property), which are then used and destroyed, to purchasing services instead. Since the material goods needed to produce the service are owned by the service provider, he has a strong incentive to see them being put to optimal use and to maximize service life. ICT is an enabling technology to implement the business models needed for this type of change.

4. Conclusions

We have shown that the Brundtland definition of SD, read as a normative statement, leads to a fundamental dilemma from a natural science point of view for which we introduce the term 'sustainability dilemma'. This dilemma has been widely ignored in public discourse since the UNCED in Rio de Janeiro in 1992, when 'multidimensional' concepts of SD started to become popular, which paved the way for weaker interpretations of sustainability.

Both technological optimists and pessimists seem to underestimate the radical nature of the sustainability dilemma and, consequently, the necessity of purposefully deploying ICT to help dematerialize production and consumption processes. ICT will grow into this role if and when the economic incentives pass a certain threshold to change behaviour and trigger innovation towards dematerialization, which has not been the case so far. Given this view, psychosocial aspects of consumption may become a major inhibiting force in the process of change towards SD by slowing down the adaptation of consumers to the changing incentive situation. Therefore, the following research questions appear to us to be worth consideration for future social science research on consumption:

- Why is the material throughput per capita still rising in rich societies in which 'light' and 'virtual' are attributes with positive connotations? How can we trace back consumer needs to the most relevant mass flows, and where in this causal chain is there room for improvement?
- What are the psychosocial obstacles for individuals to change from a material-property-transfer mode to a service-transfer mode of consumption in areas where this would be technically possible and would have a dematerialization effect, viewed from a life-cycle perspective?
- In which specific areas of consumption has ICT-enabled dematerialization been successful, and in which areas has it been tried without success? What general insights regarding the conditions of successful change of consumption patterns can be derived from the existing empirical body of knowledge?

If the vision of a sustainable information society is to become a reality, it will be necessary that social scientists working on these issues cooperate in interdisciplinary projects with scientists who assess the life-cycle-wide material and energy flows attributable to products and services, as well as ICT developers who understand the resulting requirements to be placed on ICT applications.

Note

1 One exception may be the decomposition of SD into three *nested* aspects (human, social and ecological compatibility, the human individual being viewed as part of society and society as part of the ecosystem) as explained by Isenmann (2008).

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