Sustainable technologies do not exist!

Innovation and sustainable development are broad, general concepts with positive connotations which are widely used in the social sciences, but usually in an ambiguous, imprecise way. This paper examines various definitions and meanings of sustainability as a preliminary step in analysing sustainable technologies. The term “sustainable technologies” is actually incorrect since sustainable development is not a question of technology or organisation regarding the sustainability of firms but rather a systemic matter. It is wrong to consider certain technologies as sustainable because it is physically impossible for a technology to have no impact at all on the environment: all production and consumption actions have environmental impacts. “Innovation for sustainable development” is a complex idea, due to the opposing requirements (for support and control) that it entails. Innovation policy must take a systemic outlook regarding innovation that combines benefits for users and for society as a whole.

Berrikuntza eta garapen iraunkorra kontzeptu oso zabal eta orokorrak dira. Konnotazio positiboa dute, eta maiz erabiltzen dira gizarte-zientzietan, baina gehienetan modu anbiguoan eta asko zehaztu gabe. Artikulu honetan berrikuntzaren eta iraunkortasunaren hainbat definizio eta esanahi aztertuko dira, teknologia iraunkorrei buruzko azterketa egin aurretik. «Teknologia iraunkorrak» esamoldea ez da zuzena, garapen iraunkorra ez delako enpresaren iraunkortasunari buruzko teknologia edo antolakuntzari buruzko gaia, baizik eta gai sistemikoa. Ez da zuzena zenbait teknologia iraunkortzat hartzea, fisikoki ezinezkoa baita teknologiaren batek eraginik ez izatea ingurunean, ekoizpen- eta kontsumo-ekintza guztiek dituztelako ingurumenaren gaineko eraginak. «Garapen iraunkorrerako berrikuntza» enuntziatu konplexua da, betekizun kontrajarriak (laguntza eta kontrolekoak) dituelako atzean modu inplizituan. Berrikuntza-politikak erabiltzailearentzako eta gizarterako onurak elkartuko dituen berrikuntzako ikuspegi sistemikoa hartu behar du.

La innovación y el desarrollo sostenible son conceptos muy amplios y generales, que tienen una connotación positiva, utilizados frecuentemente en las ciencias sociales, pero en la mayoría de los casos de manera ambigua y poco precisa. En este artículo, se estudiarán varias definiciones y significados de innovación y de sostenibilidad como paso previo a un análisis sobre tecnologías sostenibles. La expresión «tecnologías sostenibles» es incorrecta ya que el desarrollo sostenible no es una cuestión tecnológica ni organizativa sobre la sostenibilidad de la empresa, sino que es una cuestión sistémica. Es incorrecto considerar que ciertas tecnologías son sostenibles porque, físicamente, es imposible que una tecnología tenga un impacto cero en el medio ambiente ya que todo acto de producción y consumo tiene impactos medioambientales. La «innovación para un desarrollo sostenible» es un enunciado complejo debido a los requisitos contrapuestos (de apoyo y control) que lleva implícitos. La política de innovación debe adoptar una perspectiva sistémica de innovación que combine los beneficios para el usuario y para la sociedad.

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1. INTRODUCTION

In this paper I examine the notions of innovation and sustainable development, focusing on the question of whether the term sustainable innovation is a useful term. I will argue that the term sustainable innovation is a problematic term because no innovation is environmentally pristine and without negative impacts. Sustainable development is a system issue, not a technology issue or a company organisational issue of corporate sustainability.

The structure of the paper is as follows. Section 2 examines the multiple meaning of innovation and sustainable development. Section 3 deals with the distinction between system improvement and system innovation. The final section provides a summary and recaps the conclusions.

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2. THE MULTIPLE MEANINGS OF INNOVATION AND SUSTAINABLE DEVELOPMENT

The term innovation pops up in newspaper articles, government documents, in discussions in business and in academic papers. According to the Oslo Manual (OECD, 2005), innovation is the implementation and commercialisation of a new or significantly improved product (good or service), or process, a new marketing method, or a new organizational method in business practice. The manual states that innovation that is being developed or adopted may be new to the world or new to the company. Innovation does not require in-house investment in creative activities such as R&D. Firms can innovate by adopting technology developed by other firms or organizations.

There is a whole literature on innovation, created in the wake of Schumpeter and others. Schumpeter (1939; vol. I, p. 84) defined innovation as "doing things differently in the realm of economic life". Nowadays innovation is often seen as a novel product or production technology but that is not how Schumpeter defined it. For Schumpeter also , "the opening of new markets", "the conquest of new sources of supply" and "the carrying out of a new organization of any industry" count as innovation besides "the introduction of new goods" and "new methods of production a new good". Freeman and Perez (1988), drawing on Schumpeter makes a distinction between three types of innovation: incremental innovation, radical innovation and new technology systems.[1] Incremental innovations are successive improvements upon existing products and processes. Radical innovation, by contrast, is the introduction of a truly new product or process. There are some radical innovations that give birth to a whole new industry. Television, for instance, not only introduced a manufacturing industry but also programming and broadcasting services, which in turn widened the scope of the advertising industry. New technology systems are constellations of innovations, technically and economically interrelated and affecting several branches of production.[2] They are based on new knowledge (not just technological knowledge but also knowledge about consumer needs and understandings of what the product is about) an skills, they involve new technologies but also old technologies and new ways of doing things and a set of institutions which have grown into the process of development (product standards, associations, etc.).

Freeman notes that innovation is of importance not only for increasing the wealth of nations in the narrow sense of increased prosperity, but also in the more fundamental sense of enabling men to do things which have never been done before. It enables the whole quality of life to be changed *for better or for worse* (Freeman, 1982; p. 3, own italics). At a time when the term eco-innovation did not exist he noted that innovation "is critical for the long-term conservation of resources and improvement of the environment" *(ibid,* p. 4).

In the literature on innovation, a number of typologies have been developed. One such typology is the following based on the Oslo manual for innovation and the work of Freeman and myself.

1. *Product* and *service* innovations.
2. *Process* innovations.
3. *Organisational innovation* related to innovative ways of organising work in areas such as workforce management, distribution, finance and manufacturing. Business model innovation can also be viewed an organisational innovation.

[1] Innovation should be distinguished from invention. The concept *invention* refers to discovery. The overwhelming majority of innovations are not based on discovery but the outcome of applied R&D and search processes not resulting in discovery. The mountain bike is not based on scientific discovery but the result of tinkering. Halogen lightning is based on discovery but draws on much more than scientific discovery. It is based on understandings of user valuations, production technology and standards. In the creation of innovation, different types of knowledge are combined, which means that *innovation is better understood as recombination rather than technical discovery*, by drawing on technological advances, knowledge and skills from various areas (materials, electronics, software for design and testing, etc.) that are brought together in an organizational context.

[2] From http://www.carlotaperez.org/papers/1-technologicalrevolutionsparadigm.htm#6note.

4. *Presentational innovation*, covering innovations in design and marketing.

5. *System innovation: new technology systems.*

Innovations in the first two categories can be divided in technological and non-technological innovations (Cf. Rennings, 2000). Technological innovations comprise new products and processes and significant technological changes of products and processes. Non-technological innovation refers to changes that occur within organisations that are not directly attributable to products/services and production methods. System innovations are fundamental changes in the systems of provision, in which we have change at multiple points (in technology, products, practices, organisation, ways of thinking).[3] A system innovation of our time is the mobile phone, which instead of just a different product is a different system: with special transmitters, satellite communication, SIM cards as special chip technology such as SIM cards), special text messaging services and so on. It is associated changes in production chains, standards, user practices and cultural meaning that make it a sociotechnical system innovation.[4]

An important distinction perhaps not often enough made is between *disruptive* and *sustaining* innovations. Disruptive innovations are innovations that eventually overturn the existing dominant technologies or products in the market (Christensen, 1997). Disruptive innovations can be broadly classified into lower-end and new-market disruptive innovations. A new-market disruptive innovation is often aimed at special consumers, while a lower-end disruptive innovation is focused on mainstream customers who were ignored by established companies. Sometimes, a disruptive technology comes to dominate an existing market by either filling a hole in a new market that the older technology could not fill (e.g. more expensive, lower capacity but smaller-sized hard disks did for notebook computers in the 1980s) or by successively moving up-market through performance improvements until finally displacing the market incumbents (e.g. digital photography replace film photography).

Sustaining innovations build on previous knowledge within the innovating company, servicing existing product markets and users. Sustaining technologies are often incremental improvements in performance of established products, however they can also be radical and discontinuous. An example of a sustaining innovation is the catalytic converter which helped to improve the environmental performance of the internal combustion engine and so maintain the dominance of that technology. They were developed however outside the car industry.

Each of the innovations may product environmental benefits as a side effect or a deliberate goal. Examples of system innovations offering environmental benefits are being identified in the Dutch DTO programme. These include: novel protein foods based on non-meat proteins (10-30 factor improvement), precision agriculture (up to factor 50 improvement), decentralised production of electricity using renewables and microturbines, underground transport of commodities in pipe lines (factor 10

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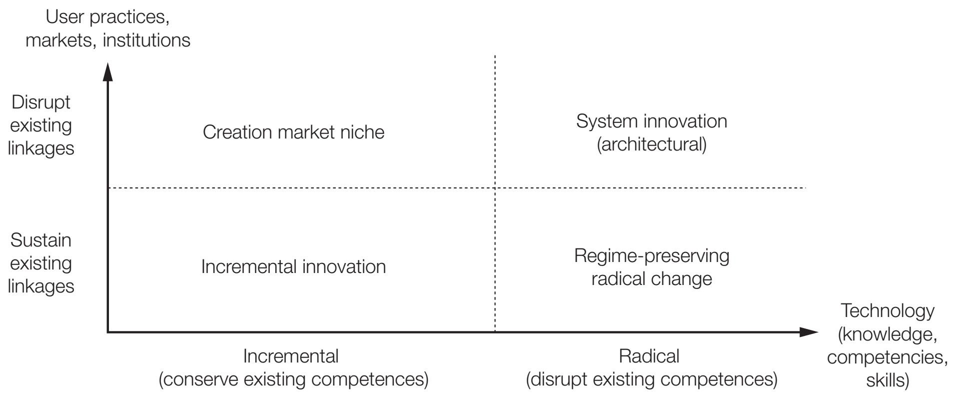
[3] Steward (2008) uses the term transformative innovation.

[4] The adjective “sociotechnical” is commonly dropped.

Figure 1

Typology of innovations (adapted from Abernathy & Clark, 1985)



Source: Own elaboration.

improvement in energy efficiency), and industrial ecology (Weaver *et al.,* 1999).

2.1. **Sustainable development**

Before the term sustainable development was used, we talked about the environmental protection. The focus was on conservation and preservation, not on creation and development. Of these the idea of environmental preservation was relatively clear: it refers to protecting the natural environment as a sink of waste, a source of natural resources for production and consumption, and provider of life-sustaining functions and amenities. For sustainable development we have over a hundred definitions, the most well-known one being "development that meets the needs of current generations without compromising the ability of future generation to meet their own needs'' (World Commission on Environment and Development, 1987; p. 23).

Sustainable development is not a single, well-defined concept and various positions and perspectives exist. Hueting and Reijnders (2004) argue that sustainability is defined by ecological boundaries that can be scientifically determined. McCool and Stankey (2004), however, stress that the question of what is to be sustained, is a societal one and therefore at once both a technical as well as a normative decision. Gibson (2001) points to the normativity of the sustainable development perspective because it includes society and societal development. Brand and Karvonen (2007) argue that sustainability is also locally specific and more a matter of local interpretation than of the setting of objective or universal goals. In a similar vain, Meadowcroft says that sustainable development "refers to a process and a standard—and not to an end state—each generation must take up the challenge anew, determining in what directions their development objectives lie, what constitutes the boundaries of the environmentally possible and the environmentally desirable, and what is their understanding of the requirements of social justice" (Meadowcroft, 1997; p. 37).

From this short overview we learn that there are different views on sustainable development. On the one end of the continuum sustainable development is perceived as an objective and clear concept that is based on scientific evidence and on which consensus exists. On the other end of the continuum sustainable development is seen as a normative and socially contested concept that is context dependent and rooted in societal preferences.

2.2. **Sustainability innovations**

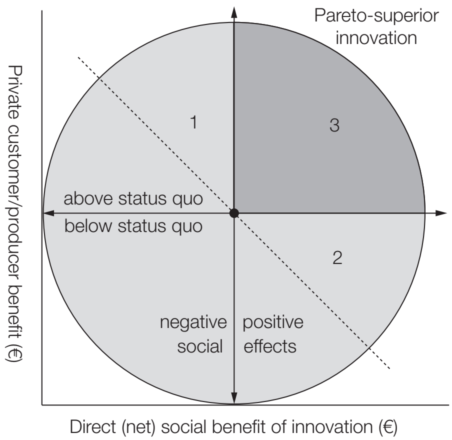
Eco-innovations are innovations with environmental benefit compared to relevant alternatives. Similarly sustainability innovations may be defined as innovations which have environmental and social (societal) benefits.

Wagner defines sustainability innovations in such as way (see figure 2). Innovations in areas (2) and (3) are sustainability innovations.

A problem often not addressed is how to operationalise the social aspect (where social refers to society and to health and well-being of individuals). It could be operationalised as consisting of health benefits, lower safety hazards, greater job satisfaction and absence of negative consequences for people elsewhere (other

Figure 2

Quadrants of private and societal benefits of innovation compared to the status quo



Source: Own elaboration.

parts of the world). Low-solvent paints would qualify as a sustainability innovation by being more environmentally benign and more benign to painters. Fair trade coffee could be viewed a sustainability innovation by offering income benefits to poor farmers. But what if the environmentally beneficial innovation is labour-saving or involves numbing work? Does this mean that it is not a sustainability innovation? Are those labour losses to be accepted because of income-generation effects of expenditures from wealth increases? Only a small proportion of the innovations would satisfy the criterion of it being Pareto superior, which means that no one is worse of. All radical innovations would not satisfy this criterion.

I also want to draw attention to something else which is that the effects vary over time and depend on aspects of use. Low-solvent paints should not be washed out in water with the chemicals going in the sewer. The release into the sewers is less of a problem if paint discharges are treated in collective waste-water treatment plants. But this is not without problems either: waste-water treatment plants produce waste called sludge. So we have another problem, which is sludge containing chemicals. In the Netherlands, the sludge is dewatered and burned in cement kilns to produce cement. This is done under a regime of regulations. This point to an important issue which is that impacts of products are *coproduced* by chains of practices. They are not technology-inherent but depend on how it is produced, the intensity of use and what is being done in terms of waste management. Impacts of a good also depend on material processing processes and way in which electricity is produced.

Sustainability of a good, technology or practice thus has to be assessed on a system basis, with attention to use and use contexts. The importance of use was underscored by the controversy over the Prius car, a hybrid electric car, versus the Hummer sport utility vehicle, with a study of CNW marketing findings that the Prius car was using more energy in their lifetime than a large SUV.[5] Further investigation showed that this conclusion was based on the assumption that the average Hummer H1 was assumed to travel 379,000 miles and last for more 35 years, while the average Prius was assumed to last only 109,000 miles over less than 12 years. The results of this study were deeply criticised, and a re-analysis with peer-reviewed data is said to lead “to completely opposite conclusions: the life-cycle energy requirements of hybrids and smaller cars are far lower than Hummers and other large SUVs”.[6]

Fossil fuel technologies are generally viewed as non-sustainable because they rely on depletable resources (gas, oil, coal) whose combustion produces greenhouse gases as well as other emissions. For stationary sources however carbon emissions can be captured and stored for re-use at a later time. Fossil fuels can thus be made more sustainable. Renewable energy technologies on the other hand are commonly referred to as *sustainable* energy technologies. Yet wind turbines kill birds and energy crops are grown in non-environmentally benign ways. Even photovoltaic electricity, arguably the most pristine source of electric power, is not completely free of

[5] CNW Marketing Research, Inc.’s 2007 study “Dust to Dust: The Energy Cost of New Vehicles From Concept to Disposal”.

[6] http://www.pacinst.org/topics/integrity_of_science/case_studies/hummer_vs_prius.pdf.

effects on the environment. As with any consumer product, the raw materials for PV systems must be shipped to factories, and completed products must be transported from factories to consumers. There is also an issue of safe disposal at the end of its lifetime. Sustainability can thus not be used as a label for particular technologies. Sustainability is better used as an evaluation point to identify things which are problematic from a sustainability point of view, to guide attention and channel investments on solutions to these problems. What happens is that it used as a positive label for things are considered less problematic from a sustainability point of view at a given time.

2.3. The need for a dynamic approach which takes into account issues of scale

Sustainability aspects should be assessed on a systems basis. In doing so there is an issue of scale and system boundaries, which I will illustrate with an example. Motor cars are becoming greener: vehicles emissions have fallen and they are more energy efficient. But as we know, cars are still polluting, they contribute to global warming, they use space and they make life less pleasant for others -- pedestrians, cyclists, children lacking play grounds. Some say that the problem of car-based forms of mobility is that there are too many cars (statements into that direction can be found in Urry). In general such a broad statement is not warranted. Cars are not causing problem in every area or in every respect; in some areas car-based forms of mobility are causing few problems for the people concerned; cars also fulfill socially useful functions (seeing one's friends, or going to work etc.) Sustainability is to be assessed in a qualified way.

When engaging in sustainability assessment one should take into account possibilities for improvement and risks. Electric vehicles may be used to illustrate the point. Battery electric vehicles do not emit emissions at the point of use. They are called zero-emission vehicles by proponents and called "emission-elsewhere vehicles" by others pointing to the emissions associated with power production. How to assess BEV from a sustainable development point of view? I would say that this is to be assessed in three ways:

- On the basis of today's system configurations in which the electricity is produced through the use of various fossil fuels, nuclear fuels and renewables using today's technology.
- For future system configurations in which there may be new elements (such as carbon capture and sequestering) and new generations of technology.
- From a transitioning point of view, as a step enabling further steps, helping societies to traverse a path towards more sustainable systems of production and consumption.

Whereas the first analysis would show that the societal benefits from moving to battery electric vehicles such as the Prius car are limited, the second type of analysis would show that there are large societal benefits to be obtained if the electricity supply would change, and the third step would identify steps towards getting towards a low carbon energy and transport system. Electric mobility might facilitate the greening of electric power supply by creating demand for green electricity and shaping investments in power production. Plug-in electric vehicles are attractive because they allow consumers to power their own car with green electricity if they want. Electricity stored in cars may be fed into the grid or be used by households at times when extra electricity supply is needed. From the point of view of the oil industry and car manufacturers battery electric vehicles are a potentially disruptive technology. In the SNM project I was involved in the mid 90s we identified electric propulsion and transport telematics as key technologies for sustainable mobility. Governments supported electric vehicles but not in a big way. They funded demonstration projects but did not create a market for it. The last thing only happened in the Netherlands in recent years, with the Toyata Prius car as the big beneficiary. It was thanks to Toyota who championed a hybrid electric vehicle, initially at a loss-making price, that electric propulsion is being supported.

Sustainability assessment has to consider issues of scale and temporal effects and the valuation thereof. Attention should be given to positive and negative effects.

2.4. **Paradoxical demands for policy**

The challenge of sustainable development can not be taken up through scientific analysis and policy approaches aimed at achieving predetermined outcomes. The uncertainty about cause and effect relations and feedback between steering activities and the dynamics of social, technological and ecological development defy such an exercise. Sustainability should be understood as a specific type of problem framing which emphasises the interlinkage of different problems and scales, as well as long-term and indirect effects of actions that result from it (Voss and Kemp, 2005, 2006).

Innovation for sustainable development put paradoxical demands on policy. On the one hand there is a need to stimulate innovations with sustainability benefits whose benefits as we know are undervalued in the market place, who have to compete with well-developed options that have benefited from dynamic scale and learning effects, system economies and from institutional alignment and integration (motor cars are a good example, societies are aligned to their use, not just through the creation of road infrastructures for driving and parking but also culturally, which is evident in the existence of car magazines and TV programmes such as Top gear). At the same time policy has to deal with risks associated with the new technologies aimed at creating positives, to make options as sustainable as possible. There is a need for support and control at the same time. The solution lies in balancing them. This can be done in several ways, by making support conditional on sustainability aspects (for example, that the biofuels are produced sustainably), by promoting risk assessment, introducing liabilities and relying on adaptive programmes involving evaluation.

There is no magic formula for policy. Often we learn about risks when the technologies are developed. This creates a demand to do something about it, but the side effects may not be easy to undo. There may exist a dilemma of control noted by Collingride that impacts cannot be easily predicted until the technology is extensively developed and widely used, and that control or change is difficult when the technology has become entrenched. A possible solution for this problem is to go for low-risk technologies which in the case of the electricity supply would mean solar energy. This brings me to the choice between improvement of the systems that we have and alternative new systems.

3. SYSTEM IMPROVEMENT OR SYSTEM INNOVATION?

From my publications about technological regimes shift and sustainability transitions (Kemp, 1994; Rotmans *et al.,* 2001; Kemp *et al.,* 2007) I may appear a proponent of system innovation. Indeed I am, but I am favouring a reflexive approach for the prudent promotion of system innovation with elements of control, in which policy is adaptive and oriented towards learning.

Before I go deeper into the issue of policies for system innovation, let me say that the both roads should be traversed: system improvement and system innovation. In the case of the paper and pulp industry, two trajectories were followed to limit chlorine releases: one involving the use of a non-chlorine bleaching agent (ozone) and the use of chlorine dioxide to be used in closed system. There was much controversy about which trajectory was environmentally superior, the stakes were very high, but on the basis of many studies it was the closed chlorine dioxide-using trajectory (called elemental chlorine free pulping) was not environmentally inferior (Smith and Rajotte, 2001).

At the outset it is never clear whether system improvement or system innovation constitutes the best response. In the short-term the greatest sustainability gain often can be obtained from a technical fix which is one reason why technical fixes are used (the other reason being that they are not disruptive from the incumbent point of view). This suggests one should follow both roads. In the energy sector we have a controversy about whether we should continue to rely on fossil fuels or should shift towards renewables and nuclear power. So far no country has decided to phase out fossil fuels. Different trajectories for carbon reduction are followed. In the European Union carbon reduction from power plants is pursued through the use of an emission trading systems and carbon taxes. To radically cut carbon reductions from fossil fuel use for producing electric power, different technologies are needed. It appears that the only technology capable of achieving this is carbon capture and sequestering, a very expensive solution. The combination of coal use and CCS is advocated as “clean coal”.

The problem for policy is that none of the systems is superior along all dimensions, costs, environment, security of supply, waste. Through technology policy and energy policy a portfolio of options is explored. It is interesting to observe that all countries explore a portfolio of options. It is hard to say whether the right options are supported. This is something that countries should determine for themselves. It is not something that can be determined scientifically, although an interesting attempt is made by van den Bergh *et al.* (2007) following an evolutionary logic, with an important role for an extended level playing field.

Up until recently, you might have said with justice that too little attention is given to renewables and too much too nuclear fusion. Fossil fuel research and nuclear fusion research received far more support from government than renewables and energy conservation, but renewables are getting now a lot of support through deployment policies. In 2020, in Europe 20% of the energy mix should come from renewable energy sources. There is the “minimum target” of 10 percent of the petrol and diesel market to be represented by biofuels by 2020. No sustainability requirements are made. They are simply viewed as sustainability targets, same as the target of 5.75 percent for biofuels by the end of 2010.

The production and use of biomass can offer environmental benefits, but it can also present increased environmental pressures. Air pollution and greenhouse gas emissions can often be mitigated by using bioenergy alternatives to fossil fuels. However, a substantial increase in the use of biomass from agriculture, forestry, and waste for producing energy could put additional pressure on farmland and forest biodiversity as well as on soil and water resources. Increased pesticide and fertilizer use, increased pressure on water resources and further overall intensification of European agriculture are some of the potentially negative side effects from an increased reliance on biomass for energy (Kramer and Schlegel, 2008?).

What this shows is that system innovation is to be pursued in a prudent way. Perhaps we should focus attention not on those options which are best from an economical point of view but on those options which are low-risk, high reward. The second generation of biofuels appears more attractive than the first generation from a sustainability point of view.

Current disadvantages for many, but not all, of the 1st-generation biofuels are that they:[7]

- contribute to higher food prices due to competition with food crops;
- are an expensive option for energy security taking into account total production costs excluding government grants and subsidies;
- provide only limited GHG reduction benefits (with the exception of sugarcane ethanol, Fig. 1) and at relatively high costs in terms of $/tonne of carbon dioxide ($/t CO_2) avoided;
- do not meet their claimed environmental benefits because the biomass feedstock may not always be produced sustainably;
- are accelerating deforestation (with other potentially indirect land use effects also to be accounted for);
- potentially have a negative impact on biodiversity; and
- compete for scarce water resources in some regions.

The second generation of biofuels produced from ligno-cellulosic feedstocks suffers less from these problems but several concerns remain over competing land use, although energy yields (in terms of GJ/ha) are likely to be higher than if crops grown for 1st-generation biofuels (and co-products) are produced on the same land. In addition poorer quality land could possibly be utilized but there is no guarantee that this will happen. If it is more economical to use good quality land, investments will favour good quality land.

In an earlier paper I examined visions for sustainable mobility. One such vision was the vision of customized mobility.

Customised mobility offers the *prospect* of sustainability benefits. There are two

[7] From http://www.renewableenergyworld.com/rea/news/article/2009/03/ieas-report-on-1st-to-2nd-generation-biofuel-technologies.

Table 1

Customised mobility

The substitution of car services by mobility services

This consists of the *use of mobility services customised to user needs.* Car use is *combined* with other types of transport provided by mobility providers. We will have new types of public transport such as individualised public transport where you are picked up from your home and brought to your destination. Public transport is given preferential treatment through special bus lanes.

Customised mobility involves changes in ownership, infrastructure, car accessibility and behaviour. The trend towards the ownership of more than one car is reversed. People increasingly use cars owned by car sharing organisations and public transport companies which can be accessed through smart cards and reserved.

Personal travel assistants (PTA) help people find mobility services and to make reservations.

Within such a system, we have *mobility agencies* and *mobility centers* where people can shift to other types of transport: light rail, public cars, bicycles etc. Intra and interurban traffic is linked at city mobility stations.

In such a system *car accessibility is reduced* through zoning policies, making cities more liveable, and we will have *a greater variety of cars,* for instance (silent) urban cars and (energy efficient) long distance cars.

Congestion, transport emissions and nuisance are considerably reduced, perhaps by a factor 5 (compared to factor 2-4 improvements that are possible with car-based forms of transport).

Source: Kemp and Rotmans (2004).

challenges here: to create such systems and to make sure that sustainability benefits are maximised. There is a tension between the two things. To create such systems one must get economic actors behind this and one task for policy is to do this. They may also rely on industry ideas for sustainable mobility, but it is best to collect ideas from the widest possible range of actors. The ideas should be discussed and evaluated perhaps by juries involving citizens (they should not be evaluated by economists on the basis of an cost-benefit analysis because many a good idea will be killed by CBA). The next step is to formulate adaptive programmes for system innovation.

Within these programmes, road maps could be made and various configurations could be identified and examined. There is an important role for strategic experiments from which one can learn useful lessons. The goal of the experiments is to learn not to prove something. The experiments should be more than demonstration projects. They should be set up in such a way that both suppliers and users learn about possibilities but also risks and problems. Basic assumptions and existing expectation should be tested through 2nd order learning. For example, car manufacturers should be stimulated to rethink their assumptions about what a car should be able to do whereas users should be stimulated to rethink their mobility needs and how to satisfy these. Of course there is always a chance that the supported technology turns out to be a failure. Failures should be accepted. This is a big problem in the current political system, and a serious handicap for system innovation. The use of learning goals for policy is something novel and radical. Politics traditionally is based on quantitative goals for policy outcomes. These still have a role to play but, as we said, should be supplemented by learning goals and goals for making a contribution to system innovation. Substantive goals should be used also for the overall transition and not just for achieving the outcomes.

Societal actors should be involved in this, not just business and government, for two reasons: to make it happen and to make sure that sustainability aspects receive due attention. Ideally one would have a top-down, bottom-up process in which national authorities and local actors are involved. Local government should be involved in local initiatives of making local transport more sustainable. National authorities should disseminate the lessons from experiences at the local level; they also should make sure that there is a good portfolio of experiments and facilitate learning across experiments.

It is important to note that these programmes are not just technology programmes. It is also about creating partnerships. Specific programmes often meet criticism from those who say that the government cannot pick winners. For instance, various government programmes to stimulate battery development have often been criticised because it did not lead to the widespread use of battery vehicles. That is certainly true but useful lessons were learned. The experiments with battery electric vehicles caused companies to focus on hybrid electric vehicles, using batteries, and encouraged companies to investigate lightweight construction and aerodynamic designs that are believed to be applied (how widely they will be applied is unclear). As to the nature of the programmes, these should be based on promising options, and the need for support should be continuously assessed. When the programme is not necessary or desirable it should be eliminated.

In the formulation of these programmes, one should not rely altogether on the solutions favoured by established actors who are likely to be locked into old ways of thinking and have an interest in the status quo. The most innovative electric vehicles were developed outside the automobile industry (Hoogma *et al.,* 2001).

On the basis of one of the vision elements presented above, a candidate programme would be a programme for customised mobility, based on reduced use of cars and greater use of other modes of transport. Customised mobility offers promises of making a positive contribution to various dimensions of sustainability. It offers benefits in the form of reduced congestion and leads to less emissions and accidents through a more selective use of cars and trucks. At present there is a gap between individualized and collective transport but various innovations may help to bridge the gap such as:

1. *Individual forms of public transport* that make public transport more flexible and more directly tied to the transport needs of the consumer. Examples are 'dial-a-bus' and collective taxis (such as the Dutch 'train-taxis'), using information technology for route planning and vehicle tracking.

2. *Collective use of private means of transport*, such as car sharing, bicycle sharing, ride-sharing (e.g. car-pooling), 'stock-market' systems for sharing long-distance trips, or voluntary schemes for transporting disabled or elderly people. The attractiveness of such systems increases with their size and incorporation of other innovations such as smart cards for accessing cars and bicycles.

3. *Transit information systems* and *mobility information services* that tell people how they can combine different modes of transport. These information schemes have to be complemented by Park-and-Ride schemes. The existence of such information services may help different transport companies to better align their services and optimise the overall transport system.

The above innovations could help car drivers to move away from the single-vehicle-for-all-time-use paradigm and the individual use of cars. In my view customised mobility should be a guiding principle or vision for transport policy and spatial planning because it is attractive from a societal points of view of sustainability *and* a user point of view, and because it needs a collaborative effort in terms of infrastructure (transfer places), reorganization of the sector (the creation of mobility agencies and cooperation between transport companies), technology (information and ticketing systems) and the setting of standards of interoperability. As may be clear from what I have written, user benefits and societal benefits are not something technology-inherent, they depend on wider systems aspects, including taxes, infrastructure, even cultural aspects on which policy has not influence.

It should be noted that customised mobility involves many 'innovations': innovations in vehicle technology (such as urban cars, long-distance cars, changes in ownership, better public transport, mobility centers where you can change from one type of transport to another, and mobility agencies who supervise and manage fleets of cars, busses, bicycles. Technology plays a role in it but it is very much an organisational issue.

System innovation policies are no substitute for framework policies such as emission trading: they are to be pursued besides those policies. Sustainable development requires control policies. There should be negative incentives for pollution and waste.

System innovation presents a difficult issue for policy as it involves substantive risky investments, conflicts between emergent and incumbent actors and reconfiguring the traditional sectoral and policy boundaries (Steward, 2008). At present neither innovation policy nor sustainability policy are configured to allow a serious pursuit of transformative innovation. Transformative innovation for sustainable development requires policy change (suggestions for how to do this are worked out under the label of transition management (Rotmans *et al.,* 2001; Kemp *et al.,* 2007; Loorbach and Kemp, 2008).

4. SUMMARY AND CONCLUSIONS

Innovation may help us get closer to sustainable development goals but for sustainable development there are no engineering solutions, nor are there management principles through which sustainability development can be achieved, despite claims to the contrary. Sustainable development is an ongoing quest in a developing world. Sustainable development as a progressive goal cannot be determined scientifically, it involves a normative element and science is not able to predict impacts. It is wrong to label particular technologies as sustainable because no one is. From this follows that innovation for sustainable development is a difficult concept for policy because of the conflicting requirements —of support and control— involved in it. More attention is warranted to system innovations, alternative systems of production and consumption, which are prudently worked at in a forward-looking and adaptive manner.

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