Strategies for Sustainable Technologies: Innovation in Systems, Products, and Services

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Abstract

Engineering is about designing efficient products, processes, and systems. But if it is not so clear which products, processes, or systems will provide the most sustainable solutions to the current challenges, engineering efficiency is a dangerous thing as the wrong things might be designed efficiently, which might make things worse at the end! The question is what to design to contribute to SD.

Raising this issue might easily lead to a long treatise of definitions of SD. But clearly SD is an issue that depends on place and time: Contagious diseases, suppression, and starvation were for long the most pressing sustainability issues. Now resource depletion, climate change, and inequity appear to be much more important articulations of sustainability.

To work as an engineer on the whole concept of SD is too encompassing. More specific articulations of SD, like "energy efficiency," "zero waste," and "accessible for all" could be guiding principles for engineering design. However, one should be aware not to identify one single SD articulation as the essence of sustainability. Various articulations of SD always play a role, and dilemmas between these SD articulations might occur.

A fundamental question is whether an engineer, by consciously altering a design to make it contribute more to SD, can change the main stream of technology in a sustainable direction. Many attempts to change the main stream of engineering design failed. Can anybody actually influence the course of technology, or are engineers forced to move along in the mainstream of techno-scientific progress? For long, this has been a heavily debated issue in the history and philosophy of technology.

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There are various mechanisms that limit designers from successfully introducing radically new designs. However, under some specific conditions, radically new technological options might be rapidly introduced. Can these transitions be stimulated and managed: Can large-scale and radical socio-technical systems changes be guided in desired directions? Or do these historic transitions just happen more or less coincidentally?

Development of new technologies is no longer an individual endeavor. The time of the great inventors is over. An innovation takes not just research and design, but also well educated staff, entrepreneurial facilities, adjacent technologies, market development, and political support. The technological innovation systems approach systematically analyzes what it takes to produce innovations and be regionally successful with it. Currently, various regions of the world aim at becoming the high-tech area that produces the solutions for climate change and the energy crisis. Which regions will be the winners that are able to produce the sustainable technologies of the future?

1 Introduction: The Need for a Technology Strategy

In our time, new technologies are rarely created by a single person. Successful innovation is often not even just a matter of a single company. It often takes customer supplier-cooperation, e.g., when new materials are applied to make lighter or cheaper products or public-private cooperation when infrastructures have to adapt to facilitate a new technology. Innovation might fail by many reasons that reside outside the company. Moreover, decisions regarding the development of a new technology can have far-reaching consequences.

For a company, success in developing a new technology might create the know-how base and the market position to achieve more successes and become the leader in that technological area. For society at large the choice of specific standardized technologies is almost irreversible.

The means for innovation are limited. Research and development are expensive and so are the costs of innovation failures that will undoubtedly occur. Societies need to make strategic choices in order to contribute optimally to sustainable development. Choices have to be made regarding:

1. Prioritization of problems
2. The time frame in which solutions are required
3. The most promising technological way to solve problems: by changing complete socio-technological systems, technological components, or parts
4. Dilemmas regarding (unintended and unforeseen) side effects that are attached to various technological solutions

Without being aware of the choices that are behind our efforts to innovate for SD, innovation intended to support SD could turn out to counteract it.

2 Sustainable Development as a Challenge for Technology

2.1 Articulations of Sustainable Development

Sustainable development is not one thing, it is many things. The principle of sustainable development, providing for all on this planet, now and in the future, leads to various more concrete goals for engineers: Closing materials loops, providing energy from renewable sources, and cutting pollution are rather concrete goals. Engineers could easily work on them. But part of sustainable development is also that the technological systems are safe, do facilitate development processes to create more equity, and do not destroy ecosystems. These more specified demands are *articulations* of sustainable development. For engineers articulations of SD are crucial as they allow setting doable targets for engineering design. But various articulations of SD are not well aligned. They might sometimes create dilemmas: Nuclear power stations create electricity with low levels of CO_2 emissions, but create long-lasting waste and create a safety risk. Hydropower is renewable energy, but often not CO_2 free and might devastate river basin ecosystems. Biofuels close the carbon cycle, but their cultivation might be a threat to food production and an incentive to convert natural ecosystems to agricultural land. All of these energy technologies might be called sustainable ánd unsustainable. Sustainable development creates many dilemmas for technology development. But given the magnitude of the challenges, the choice on these dilemmas should be made publicly and transparently. It is a political choice if safety or ecosystems should be compromised to produce CO_2 free energy. And of course the real challenge is to turn these dilemmas into paradoxes, i.e., developing innovative technology that could contribute to all articulations of SD (Mulder et al. 2011).

2.2 Incremental Innovation and Radical Innovation for SD

"Normal innovation" is very often not as exciting as one thinks reading the many stories of the great inventors. The images of innovators that are painted by the glorious stories on inventions do not represent the day-to-day praxis of the laboratory. "Normal innovation" is generally incremental. It aims at improving existing technologies by small modifications, removing "bugs" from the production process, or in general improving efficiency. Incremental innovations are often almost unnoticeable improvements of details. However, over a longer period, these small improvements accumulate to significant improvements. For example the fuel efficiency gains in civil aviation were between 1960 and 1980 in total about 55–67%, between 1980 and 2000 in total about 20–26%. One expects that another 20–26% can be achieved until 2040 (Peeters et al. 2005). The energy efficiency gains of a car are even lower. The energy efficiency of cars improved between 1972 and 2000 with 30% at maximum (Kwon 2006).

If one relates these efficiency improvements to the sustainability challenges that the world is facing, it is quite clear that the required improvements will not be produced.

In the early 1970s, scientists debated which factors mainly contributed to the environmental problems: consumption growth, overpopulation, or the state of technology. Ehrlich and Holdren (1971) formulated a relationship between these factors, the so-called IPAT equation:

$$\mathbf{I} = \mathbf{P} * \mathbf{A} * \mathbf{T} \tag{48.1}$$

I = Total environmental impact of mankind on the planet

P = Population

A = Affluence, number of products or services consumed per person, i.e., for economists the annual gross national product per capita

T = Environmental impact per unit of product/service consumed. T is often called the factor "technology efficiency." However T diminishes as technologies become more efficient. Moreover, T also includes more or less non-technological issues like product reuse and the organization of production.

This IPAT equation gives more clarity regarding the magnitude of technological efficiency improvements that have to be achieved. Comparing the situation in 2000 with the one in 2050, an estimate for the required improvement in the T factor can be inferred.

- *Environmental impact*. Our current use of natural resources is unsustainable. Suppose a goal of cutting it by half.
- *Population growth* has been exponential. In the year 2000, world population was approximately six billion. In the past decade, population growth rates have been declining. This is especially due to the devastating effects of the HIV/AIDS epidemic. Not only is the direct death toll important, but also and especially the fact that youngsters do not reach the age of reproduction. Population growth is hardly affected by wars. Only long-term demographic policies might stabilize the global population. The global population in the year 2050 is predicted to be between 8 and 11 billion people. Therefore, a rough estimate of population growth is a factor of 1.5.
- *Affluence*. The economies of the rich world are growing on average by 2% annually. Over a 50-year period this implies a growth factor of 2.7. In order to reach a more equitable world, the developing nations need to grow by 7.8% annually. The combined consumption of rich and poor countries will then be 10.8 times the starting level.

If the I factor should be halved, P grows by 50%, and A grows by a factor of 10.8, then T should be 32.4 times reduced, i.e., technology should be 32.4 times more environmentally efficient than it is today (Mulder 2006).

Based on similar analyses, several authors argued in favor of radical or systems innovation. Examples are:

- Von Weizsäcker et al. 1997 who promoted a factor 4.
- In October 1994, a group of 16 scientists, economists, policy makers, and business leaders published the "Carnoules Declaration." The declaration called for a radical increase in resource productivity and expressed the hope that within our generation, nations can achieve a tenfold increase in the efficiency with which they use energy and materials (Factor Ten Club 1997).
- The Netherlands Sustainable Technology Development (STD) research program (Weaver et al. 2000) aimed at improvements by a factor 20.

These leaps in efficiency of technological systems are regarded to be only realistic by radical innovation, i.e., groundbreaking technological and socio-organizational change. Radical innovation often implies "systems" innovation as the radical innovation can only be achieved by changing the configuration of the various elements within a technological system, instead of merely improving on a single element.

First attempts for "radical innovation" quite often occur. In industrial laboratories various groundbreaking ideas are explored. However, when closer to actual industrial introduction, the industry is more reluctant as:

- New technologies require new thinking in the organization.
- Sunk costs: current investments will be (partly) lost.
- Gains are often controversial.
- Technological/financial risks are large.
- Cooperation of external parties is crucial but cannot be enforced.

For these reasons, many promising sustainability-oriented systems innovations in the lab phase were never introduced in "real life" (Moors and Mulder 2002; Moors et al. 2005).

Although the world needs radical innovations to create leaps in the environmental efficiency of production, incremental innovations are important. If radical innovations are introduced, they are often rather inefficient in their early stages. Then incremental innovations can rapidly increase their efficiencies.

3 The Course of Technology: Engraved in Nature, Coincidence, or Social Construction?

What drives technological change? A view that is often implicit in popular media is that technological change is autonomous. This means that technological change is not influenced through economic, social, and legal powers. "The progress of the technology cannot be halted," or "As Einstein had not invented the general theory of relativity, someone else would have done it." Often, the core of this way of reasoning is the assumption that technology is fed by scientific knowledge.

Scientific knowledge is accumulating (as results are published and stored), and therefore technology development can utilize more and more knowledge. Moreover, improved technologies help to improve other technologies. Hence, technology will improve continuously, autonomous of any actor in society. Technology policies and technology strategies are in this vision futile, as nothing can influence this process.

One of the best-known philosophers that approached technology as an autonomous force is Jacques Ellul 1967. Ellul's constant theme in all his publications is the imminent "technological tyranny over mankind." Ellul creates a sharp divide between the traditional (for him: preindustrial) technology and modern technology. Traditional technology was according to him:

- Limited in its application (because technology had been made for specific functions on a specific place).
- Only marginally dependent on resources and especially dependent on craftsmanship.
- Local in its character (because local circumstances are used, and local culture has to be taken into account).
- The result was that classic technology allowed the possibility of choice, that is to say individuals and local communities could to a far extent determine the shape of the technology that they applied.

Contrasting to traditional technology, Ellul characterized modern technology through:

- Automatism, i.e., there is only one "best" way to solve a particular problem, which is compelling wherever one is on this planet.
- Self-replication, i.e., new technology strengthens the growth of other technologies. The result is exponential growth.
- Indivisibility. In order to participate in modern society, the technological lifestyle must be accepted completely, with its good and bad sides.
- Cohesion, i.e., technologies of different areas have much in common.
- Universalism, i.e., technology is geographically as well as qualitatively omnipresent.

For Ellul this meant that modern technology is devastating human freedom. In his view, the future of mankind is extremely gloomy, for there is no way back.

Besides these fatalistic views, there are also very optimistic autonomous technology views. Especially a number of futurists propagate bright images of future technologies. Unimaginable speeds of transport, the conquest of space as the "final frontier," living at the ocean floor or on Mars, it can all be done. Whether society really needs these techniques is of no concern. It is imaged as the inevitable "progress."

The autonomous technology worldview is dubious:

- It supposes one-way traffic between science, technology, and society. Technology is the product of scientific growth and technological self-replication. However, historically this is incorrect: Technology often pre-cedes the formulation of underlying scientific principles. This holds for instance for the steam engine that was already a century in use before Sadi Carnot formulated the Carnot cycle in 1824. The Carnot cycle explains the transformation of heat in work. The first airplane flew in 1903, but the aerodynamic theory that explained why this worked was only discovered by Prandtl around 1920 (Anderson 1997).

- Historical analyses show that technological innovation is not a process that inevitably leads to one specific result. The context in which a technology is developed determines the resulting technology.

Governments, companies, but also NGOs and citizen groups can influence the course of technology. Especially in infrastructures, there are many examples where this has taken place.

However, this does not imply that "anything goes." There are strong mechanisms that limit the options for technological change. One of those is *positive feedback*: The more successful a technology becomes, the more production costs can be cut, the more specially designed accessories (or software) become available, and the more people are accustomed to the product. This in turn contributes to the success of the product, which makes the product invulnerable for attempts to replace it by new technologies. The result is often spontaneous standardization: one product spontaneously becomes the market standard (DVD, software, batteries, Operating Systems: "many people hate Windows, but still use it!"). Moreover, the more a technology is adopted, the more attractive the technology becomes for further optimization. If companies develop new technologies under conditions of positive feedback, it typically leads to "winner takes all." The first on the market will set the standard that cannot be broken anymore after being accepted. The consequence is also that the "best" technology does not necessarily win: after a standard has been established on the market, a better technology has no chance to compete, unless it is really accepted as being very much better.

Although the autonomous technology view is not very fashionable these days, it cannot be denied that there is a core of truth in it: In our globalizing society, there is very little scope for individuals, groups, or even national authorities to influence or even steer processes of technological change.

3.1 Technologies as Socio-technical Systems

Only very few technologies are inherently unsustainable. Very often, the sustainability of a technology is dependent on the SD articulation that is evaluated, and on the scale of use. For example, the car is one of the main pollutants of the urbanized society. Around the world, there are about 900 million cars and light vehicles. Given the rapid growth of motorized transport, especially in Asia, that number will soon surpass one billion (Plunkett Research 2010). Cars emit CO_2 and various other pollutants, especially in densely populated areas, cause almost one million fatalities and even far more casualties every year (WHO 2004), and deplete finite resources like fossil fuels and various ores. This is clearly an unsustainable situation. But is "the car" unsustainable? For example, in regard to the SD articulation depletion of fossil fuels, one could calculate how much fossil oil is formed by natural processes, and how many cars could be fuelled by that. For such a calculation, one needs some assumptions such as the speed of oil formation which has differed over time, and fuel efficiency and annual mileage are not exactly known. The number of cars that can drive using the naturally formed fossil oil is somewhere between 100 and 1,000. This number is at least a million times less than the number of cars that are actually on the streets.

The car is not just a single technology. It is the core of a whole system that includes oil exploration, transport, refining and distribution, steel, aluminum and polymer production, car factories, road construction, traffic police, garages, etc. Without cars, many people could not reach their work places anymore and most economic sectors would be instantly crippled. By this system of production, use, and maintenance the car is "entrenched" in society. This means that change is hard to achieve (Collingridge 1980).

In the early 1970s, the emissions of lead due to lead additives in gasoline, were no longer acceptable; it created lead poisoning, especially for small children in urban areas. However, replacing leaded fuel by unleaded fuel took about 25 years. Car engines had to be adapted, but especially the introduction of an extra fuel type took a lot of efforts for the logistic chains of the oil companies. History shows that lead additives in gasoline could have easily been avoided. In the late 1920s, lead additives were just the cheapest chemicals that could solve the knocking problem of internal combustion engines. There was considerable ignorance in regard to toxicity of chemicals and there was no need for action at a time when automobilization still had to take off. Lead additives to gasoline are a good example of a more general phenomenon: At the moment that options are still open, nobody knows the consequences; once society is fully aware of the consequences, there is no scope for change. This is known as the control dilemma (Collingridge 1980).

But then how to change these entrenched socio-technical systems? Naturally, the first step should be to recognize that there are several options, and that some of these options might be contradictory. For example:

- One can optimize the internal combustion engine car and its components.
- Introduce cars that use renewable energy.
- Improve public transport.
- Develop IT options that provide us products or services without the necessity to use a vehicle.

But can the world develop all these options and should that really be done? The first option is most in line with the current automobile system as it leaves the configuration of the current car transport system almost as it is. The second option might be called a system innovation as it aims at adapting the configuration of the existing car system by changing major features of the energy supply part of the system. The third option is aiming at promoting an existing competing system, and the fourth option could be called a transition as this option aims at establishing a completely new system that requires a completely different behavior of users.

There is no compelling necessity to choose a specific option; it is a socio-political choice. Perhaps given the urgency of the problems, all options are needed.

4 Steering Technological Change

4.1 Technology Policy

Innovation is important nowadays as it could help in bridging the gap between demands for affluence and the capacity of the Earth's natural systems. But what should be the role for governments in orchestrating this innovation? Should the government even have a role, if environmental effects are efficiently and effectively translated in costs, i.e., "the polluter pays" principle?

The point here is that no matter how sophisticated "polluter pays" measures are "the market mechanism alone fails or does not adequately ensure the optimum allocation of resources for the benefit of society, for industry in general or even for the individual enterprise itself" (Coombs et al. 1987).

There are several reasons why the government should (sometimes) intervene in innovation:

1. The development of new technology sometimes requires too high investments for individual firms; nuclear fusion is a typical example.
2. Innovation is an important success factor in international competition. Supporting specific sectors will bring more economic success for the nation.
3. The Government has an important role in infrastructures (energy, transportation, telecommunications) and therefore in infrastructures innovation.
4. Industry hardly invests in basic research that will lead to new technologies in the long term. These investments carry too much risk; even if successful patent protection is only 20 years, the research investment will not give a competitive advantage.
5. Industry invests only few resources in subjects that do not directly lead to technological advances (e.g., measuring methods, mathematical modeling) and in specialized education and training.
6. Small-scale companies, e.g., farms, cannot do research independently.
7. Some research topics involve ethical or cultural values, like health care, that restrict market relations as the outcome of the market is seen as unacceptable.
8. Public goods, like defense and justice, are the responsibility of the government.
9. Innovation contributes to the national prestige which often played a role in stimulating large projects (e.g., Concorde aircraft and space technology).
10. Innovation sometimes is expected to bring undesired side effects, like environmental problems, occupational safety and health, public risks, and privacy issues which require regulation/measures.

Any of these reasons might urge governments to introduce technology policy measures. Some of these issues also play a role at the regional level (Coombs et al. 1987).

4.2 Methods for Steering Technology Toward SD

In general, there are many types of government policy instruments to support innovation: research subsidies, loans, guaranteed prices for products, etc. Many of them are applied to stimulate the development of specific cleaner, more efficient technologies. Some approaches have been specially developed to stimulate the more radical innovations that are required for SD.

Various sustainability problems are really "wicked" problems (Rittel and Webber 1973). These problems are hard to solve because the problems are connected to features of our societies that are deeply entrenched in institutions and culture. Very often, it is not even clear what would count as a solution of the problem as there are contradictory requirements, and some of these requirements may not even be known yet. Moreover, there are various interdependencies. Solutions for a specific aspect of a situation might make things much worse for other aspects. Many wicked problems are therefore left unsolved.

Problems of road transport might act as a typical example. What "the" problem is, is often not really clear: congestion, air pollution, depletion of nonrenewable resources, or deterioration of (urban) conditions. Most "solutions" that are discussed today, only aim at one of these problems. However, in order to be able to innovate, the vague and ill-defined set of problems should be translated into something "doable," something that can be translated into an engineering project plan. "Road-pricing" is such a doable translation of traffic problems. Road pricing will contribute to soften some of the effects of traffic. However, all of the effects as such remain. How could industrial society change to a different state that requires far less (car) transport, consumes less energy, space, and materials, and creates less nuisances?

First of all, it is important to analyze what functions our traffic system fulfills for us. In this way, solutions can be found that are not part of the traffic system. Access to products and services is an important function of the traffic system. Information technologies might also provide access to services and products. Access to work might be provided by the same means, but also by public transport, while the remaining transport needs might be covered by easy accessible rental car services. Ultimately, various combined developments might lead to a new steady state.

4.2.1 Transition Management

Transitions are encompassing changes of societal systems (including technological systems, users, and governance). They have happened, and will happen. Historically, sailing boats were replaced by steamers, which were in turn replaced by (oil powered) motor vessels. These transitions seemed necessities given the progress of technology, but on closer observation, technology was only one of the factors. In transitions, sets of connected changes occur, which reinforce each other. Steamers created more predictable transport options, but required bunkering stations, expensive coal and the coal required space on board. Steel hulls facilitated steamers, just like increased efficiency of the engines, and the introduction and improved propellers (Geels 2005). These developments enabled shipbuilders to develop large steam liners that greatly spurred emigration to the USA (Cohn 2005). Moreover, the development of steamers enabled new developments that facilitated steamers: e.g., the Suez Canal was not suitable for sailing ships, but shortened the route between Europe and Asia considerably (Geels 2005).

History shows us many examples of transitions. But can these processes be initiated and steered in order to produce Sustainable systems, i.e., is transition management possible? Certainly, this cannot be achieved by management in the classic sense of using methods that will produce known outcomes. Transition management is probably able to spur a process of change, but as the complexities and nonlinearities are so dominant in the process, there is little certainty if the transition will actually lead to the improvements that were aimed for. That is a risk, but can be acceptable as there is often no alternative (Cf. Rotmans et al. 2001).

4.2.2 Niche Experiments

For sustainable development, governments should aim at stimulating the more radical innovations in order to produce leaps in environmental performance. Generally, those innovations involve technological as well socio-cultural and organizational changes. These changes are rather complex and users and producers might develop adaptations that trigger new adaptations: Learning takes place by which the fit between technology and its social environment is improved. Technologies will be better able to cope with the (hidden) demands of actors, and the actors should learn to benefit from the characteristics of the new technology in their own way. These experiments take place in market niches, parts of the market that offer more beneficial conditions for the introduction of the innovation. In this way there is some protection against the competition of the established, fully developed technologies. If the learning process in the niche leads to an improved fit between technological performance and social demand, then the innovation might be better able to cope with market competition.

Half a century ago, the markets in various countries demanded rather different products. New technologies developed in one country were only introduced much later in other countries, after many adaptations and learning had taken place. Although larger countries had various car manufacturers, there were typical "American," "German," "French," and "Italian" cars. That seemed to have disappeared in the world of today. Nowadays, conditions have become much more homogeneous around the world. Globalization has destroyed these naturally occurring niches. Hence, less variety of conditions is naturally present.

4.2.3 Backcasting

(see ▶Backcasting and Scenarios for Sustainable Technology Development)

4.2.4 Stimulating Learning and Network Building

Many innovations fail somewhere in the innovation journey that connects various different activities. This journey does not necessarily start with research and end with market introduction, as it might start with a market idea, and might contain various feedback loops.

Scholars reflecting on innovation emphasize the need to learn from others for a successful innovation, the necessity to understand the perspectives of others and cooperate with people with other skills. As there are often high fences created around innovations, there is a need to tear these down in order to reach these different perspectives (Cf. "open innovation," Chesbrough 2003). Especially in SD innovations, various articulations of SD might play a role, and various public as well as private actors and NGOs might contribute to valuable learning processes. Sometimes this requires careful social network creation: Various actors are not involved in the innovation journey, and some hardly interested in playing a role in it. Others might have an interest but mainly to derail the process. For instance, basic scientists are often hardly interested in pushing their results into an innovation journey, as this would require them to put lots of efforts in developing indications of commercial prospects. This leads to a phenomenon called "the valley of death"; promising ideas are not elaborated any further, as serious funding is required to elaborate the ideas, but very little certainty exists on the commercial prospects.

The early stages of the innovation journey are often dominated by engineers and scientists. Their perspectives on efficient products and processes are often not in line with the people that in later stages have to work with these processes and products, or even the people that have to carry the burden of (side) effects of that innovation. Radical technological change requires the cooperation of various stakeholders. Moreover, it requires learning. In order to facilitate these processes in early stages, when the technology is still malleable, stakeholder involvement is very important, and sufficient scope for learning constructive technology assessment processes, consisting of carefully prepared interactions of various actors, can contribute to reflexive learning in early stages of innovation processes and to a better alignment of innovations and sustainability demands (Rip et al. 1995).

5 National and Regional Technological Innovation Systems

Innovations for sustainable development, like any other innovations, will not occur at random spots of our planet. In information technology, biotechnology, and probably nanotechnology, there are hot spots of innovation. Being a hot spot of innovation is very attractive for a region, as it brings to the region high-paid jobs without industrial nuisances such as pollution. Various mayors dream of developing an innovation hot spot in their municipality.

But what does it take to become an innovation hot spot? Why are innovative companies concentrated in specific areas?

The best known innovation hot spot is probably "Silicon Valley," an area South of San Francisco. This area got its nickname in the 1970s, when it became the world center of microelectronic development. A little later, Silicon Valley also was the center of development of computers and various computer appliances, software, and Internet technology. At first glance, such a concentration seems rather irrational: The required experts are not available locally, and prices will rise due to growing demand.

However, the concentration of innovative activities attracts experts to the region. Experts easily might find interested companies/investors for their ideas and might easily find a new opportunity in such a region after their projects have finished. Companies might benefit from being in such a region by the constant flow of expertise and ideas between them, the availability of various specialized facilities, services, and customers for their business, etc. If the activities have sufficient clout, clever entrepreneurs will offer additional services that increase the innovative productivity and attractiveness of the region. A developed technological innovation system propels itself. But how to create such a system? How to get it started? The stakes are high for regions.

A technological innovation system is technology specific. The functions that it fulfils are:

- Entrepreneurial activities that turn resources and ideas into action.
- Knowledge development, i.e., research and development but also development of market information, etc.
- Knowledge diffusion through networks.
- Guidance of the search, i.e., activities that contribute to clarify the specific needs of users of the potential innovations.
- Market formation. Markets for new technologies are not self-evident. Regulation, training of customers might be insufficient. Protected spaces might help the new technology to survive competition of incumbent technologies.
- Resource mobilization. The system requires financial and human resources that need to be acquired.
- Creation of legitimacy/counteract resistance. New technologies often meet resistance that is related to vested interests related to existing technology (Hekkert and Negro 2009).

Often, authorities aim at creating a technological innovation system around existing research facilities. Facilities for (starting) entrepreneurs are often created, but real access to existing markets and customers is often lacking.

6 Summary

This chapter has argued that a sound strategy is required in order to work on innovations that will really contribute to long-term sustainable development. First it is crucial to recognize various articulations of SD, and recognize that there could be dilemmas. The chapter has emphasized the need to produce radical innovations. But to what degree is the progress of technology really a matter of social choice or an autonomous development? It is claimed that there are strong forces that prohibit steering of technology in specific directions, but it is not entirely impossible. Common legitimations for government interference in the innovation process are provided. As radical innovations are important to innovate for SD, the chapter discusses three approaches that aim at facilitating/stimulating (radical) technological innovation processes. Finally, it was discussed what it takes for regions to become successful in specific types of innovation. The concept of technological innovation system was discussed.

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