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Innovation policy roadmapping as a systemic instrument for forward-looking policy design

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The systemic characteristics of science, technology and innovation policies have been much discussed recently. This paper presents innovation policy roadmapping (IPRM) as a methodological framework for linking R&D results to systemic policy contexts and to forward-looking policy design. The paper explores the methodological background of the IPRM method and outlines its policy rationale. It also illustrates IPRM with two case studies from Australia and Finland. The case studies reflect on how the policy perspectives can be constructed in a dynamic context of societal drivers, solution and market development, and enabling technologies. The paper concludes by assessing the policy implications of the IPRM approach.

Keywords: innovation policy; roadmapping; systemicity; forward-looking policy design; foresight; socio-technical transformation.

1. Introduction

Since the 1960s, the results of R&D practices have increasingly been approached as knowledge inputs in the construction of science and technology policies. This trajectory has been continuously deepening, and along with the emergence of an emphasis on innovation policy in the 1990s, many new features, like the perspectives of users, societal regulation and markets, have become core parts of science, technology and, now, innovation policies. Because of these developments, in the 2000s it has become more common to talk about systemicity in the context of science, technology and innovation (STI) policies. As Smits and Kuhlmann (2004: 11) argue, innovation is a systemic activity that:

> . . . involves a variety of actions within the system, of which the innovating organization or innovator forms part.

The systemicity sets challenges not only to the researchers, developers and policy-makers, but also to the policy-making processes as such. Therefore, not just innovation activities, but also the policy-making process could benefit from the use of ‘systemic instruments’ (Smits and Kuhlmann 2004: 11–12) in fostering forward-looking aspects of policies.

This paper discusses how the methodology of roadmapping could be applied as an instrument in systemic policy contexts. In recent years, roadmapping has been increasingly applied as an instrument of strategy-making (Blackwell et al. 2008). Following this line of practice, the paper introduces a methodology for roadmapping systemic transformations. The IPRM method combines roadmapping and the forward-looking evaluation of policy development paths. IPRM integrates the approach of technology roadmapping—including such contents as enabling technologies, applications, products, markets and drivers—with the perspectives of systemic policies and policy instruments. IPRM is also targeted at the systemic level of multiple actors and organizations. Thus, this visionary process includes many participants and different interests.

This paper is structured as follows: in Section 2 we discuss the idea of systemicity and its connections to foresight and forward-looking policy design. In Section 3 we outline the methodological background and the policy rationale of IPRM. In this section, the features of IPRM are also discussed. The discussion aims to open a perspective on how policy development can be facilitated in a dynamic context of societal challenges and enabling technologies. In Sections 4 and 5, respectively, we provide two case studies from Australia and Finland. The function of the case studies is to demonstrate how the IPRM method can be utilized in the mapping of systemic policy-level trajectories. In Section 6, we draw together the arguments and conclude by assessing the future potential of the IPRM approach.

2. Systemicity, foresight and forward-looking policy design

The concept of a system has different emphases in different branches of the innovation literature. First, the innovation system literature highlights those organizations that participate in the emergence, diffusion and embedding innovations, such as universities, public and private R&D organizations, companies and various intermediate organizations, and the collective learning processes between these organizations (Smits et al. 2010). Secondly, the literature on systemic innovations and transition management emphasizes the dynamic relations of socio-technological landscapes, socio-technical regimes and niche-level innovations in the context of emerging technologies (Geels and Schot 2007). Thirdly, the literature on technological systems places the emphasis on networks of agents in a specific economic or industrial sector and the particular institutional infrastructure involved in the generation and diffusion of technology (Carlsson and Stankiewicz 1991).

In the field of foresight, the idea of systemicity, and especially the anticipation of potential system failures, has become a key rationale. In this view, system failures are approached as outcomes of 'rigidities and mistakes of innovation agents' and 'a lack of linkages and fragmentation between innovation actors' (Georghiou and Keenan 2006: 763). Foresight stimulates two types of systemic capacities. First, foresight provides actors with information and signals outside the immediate environment and helps to identify potential threats and opportunities. It thus helps to overhaul the so-called market lock-in. Secondly, foresight stimulates new social structures and linkages that could be useful in fostering the circulation of information in the system. Georghiou and Keenan (2006: 764) also propose that foresight has other functions, like exploring future opportunities in order to set priorities for investment in science and innovation activities, reorienting the science and innovation system, demonstrating the vitality of the science and innovation system, bringing new actors into the strategic debate, and broadening the range of actors engaged in science and innovation policy.

Weber et al. (2009: 955) argue that policy processes have gone through a conceptual shift in which a linear model of policy-making has been replaced with a more learning-based cyclical model. This observation means that policy-making is systemic in a double sense: it is about contemplating signals in a systemic environment through a systemic process of pro-action, action and reaction. In the learning-based model, foresight has a catalysing role. Foresight is about the formation of 'process benefits', about aligning expectations and building a 'self-fulfilling prophecy'. In a systemic view, foresight can thus be viewed as 'an integral element of networked and distributed policy making'. This is realized through three functions of foresight: informing, strategic counselling and facilitating (Weber et al. 2009: 956). Georghiou and Keenan (2006: 766) also distinguish three policy rationales of foresight. The first is the provision of policy advice by accentuating the long-term perspective. The second is the building of advocacy coalitions. Foresight builds up an 'interaction space' by stimulating new networks and communities through the formation of a common vision. The third foresight rationale is providing social forums. The foresight process provides a 'hybrid forum' for strategic reflection that broadens the range of participation on policy issues.

In the systemic settings, policy processes are increasingly processes of policy design. In our usage, policy design refers to an adaptive and experimental approach in which a selected variety of policy instruments are applied either simultaneously or successively. What these instruments are and how their sequential flow is organized depends on the characteristics of the system under policy intervention. These system characteristics are, for example: actor assemblages, enabling technologies and related infrastructures, a temporal scope of the system (e.g. what is short-term, what is long-term) and spatial scales of the system (e.g. local, regional and national). In policy design, multiple policy instruments are adapted and tested in parallel. Thus policy design aims to increase the resilience of the policy practices in the systemic contexts by allowing space for policy experimentation.

In our approach, foresight has a specific role and thus one could talk about forward-looking policy design. From our perspective, six functions of foresight defined by Da Costa et al. (2008: 369) aptly capture the functions of foresight in the context of policy design. The functions of foresight are:

- Informing policy (generating, usually research-based, views on futures).
- Facilitating policy implementation (widening the change capacities in a certain policy community).
- Embedding participation in policy-making.
- Supporting policy definition (transposing results of foresight processes towards policies).
- Reconfiguring the policy system towards long-term perspectives.

- Symbolic function, i.e. that policy is based on information that is shared and collaboratively interpreted.

In the following section, we discuss how roadmapping can be used in fostering forward-looking policy design.

3. IPRM: a framework for forward-looking policy design

3.1 Methodological background

IPRM is an integrative method that combines the two cultures of roadmapping with a sensibility towards systemic aspects of socio-technical transformation. The idea of IPRM is to integrate the analysis of technological change and the analysis of the wider societal setting and to enable systematic analysis of future-oriented ideas that could spring either from technological development, policy practices or more generic societal development.

IPRM builds on two cultures of roadmapping (on roadmapping, see Barker and Smith 1995; Kostoff and Schaller 2001; Farrukh et al. 2003; Kostoff et al. 2004; Phaal et al. 2004; Lee and Park 2005; Phaal and Muller 2009). The first is the culture of technology roadmapping, in which roadmapping is approached as a normative instrument to identify relevant technologies and align them with explicit product plans and related action steps. In this culture the roadmapping process is a systematic management practice aimed at product development. The second is the emerging culture of strategy roadmapping in which the roadmapping is perceived more as a dynamic and iterative process that produces weighed crystallizations, usually in a visual form, of an organization's long-term vision, and short- to medium-term strategies to realize this vision. It is based on an idea that roadmaps are like visual narratives that describe the most critical paths of future developments (Phaal and Muller 2009). This visual emphasis enables the use of roadmaps as crystallized strategy maps that open up a simultaneous perspective on both the macro-level currents and on the corresponding micro-level developments (Blackwell et al. 2008). This 'second culture' is methodologically more exploratory than traditional technology roadmapping. The roadmaps are not approached as 'hermetic' plans to achieve definite goals (e.g. new products), but instead they are approached as knowledge umbrellas that depict a large-scale strategy picture of a system. Strategy roadmapping is also about engaging and empowering people. This idea links the strategy roadmapping to organization and strategy studies, especially to strategy crafting (Whittington and Cailluet 2008; Heracleous and Jacobs 2008).

IPRM can be compared to a transition management (TM) framework. TM was developed in the Netherlands in the early 2000s (e.g. Rotmans et al. 2001). The aim of TM is to connect micro-scale technical niches into macro-scale landscape developments through the middle-scale of a socio-technical regime (Geels 2004: 915). It is supposed that transitions result from a multi-layered process of interactions:

- Niche innovations build up internal momentum, through learning processes, price/performance improvements, and support from powerful groups.
- Changes at the landscape level create pressure on the regime.
- Destabilization of the regime creates windows of opportunity for niche innovations (Geels 2002, 2005; Geels and Schot 2007; Eerola and Loikkanen 2009).

Heiskanen et al. (2009: 411–2) have provided a crystallization of the central features of TM. First, TM is based on long-term thinking. In this case, the long-term stands for a period of over 25 years. Secondly, TM accentuates the interrelatedness of societal and technological systems and the multiplicity of actors. Thirdly, TM emphasizes both top-down and bottom-up perspectives. Fourthly, TM puts a specific emphasis on crafting the policy activities according to the long-term systemic targets. This is why transitions in the regime and landscape levels are seen as gradual and slow-paced.

However, there are also crucial differences between IPRM and TM. First, IPRM springs from a roadmapping tradition and thus places significant emphasis on the process and systematic form of information. It means that different parts of the roadmap are formed in a systematic workshop process that includes several stakeholders, iteration and feedback, but the data is also presented in a visual roadmap structure. Secondly, in IPRM the long-term thinking is dependent on the subject under study. With IPRM, one can handle long-term systemic issues, but also more short-term topics with systemic characteristics. Thirdly, because IPRM is more of a process methodology than a generic societal frame, the number of participants is limited. There is a critical lower limit to the number of participants to allow the process overall, but there is also an upper limit that is basically the limit of having a manageable process. However, the process-orientation also creates latitude and makes it adaptable in different contexts. Fourthly, IPRM also combines bottom-up and top-down perspectives. Nonetheless, in the case of IPRM one could talk about a process perspective. Top-down information might be utilized during the process, but the topics highlighted are the outcomes of a systematic process. Fifthly, IPRM also places significant weight on forming policy conclusions in relation to long-term visions. However, in contrast to the long-term emphasis in TM, IPRM adopts a multi-temporal perspective that is dependent on the topics under scrutiny (e.g. the long-term in information and communication technologies (ICT) is very different from the long-term of transport or energy infrastructure), the level of study (e.g. does the study focus on the generic impacts of ICT in society or specific applications in a defined sector) and the nature of the process and its participants.

3.2 Policy rationales of IPRM

A key aspect of IPRM is that it links the results of research and technology development to the systemic frame of policy-making. IPRM can be applied to forward-looking policy design in multiple ways. The first way is through the building of a common vision. The building of a collaborative vision stimulates the commitment and embeddedness of the long-term goals. Therefore organizations that are involved can utilize the vision as a 'beacon' for navigating towards the future. In innovation policies a common vision is required, because, for example, commercialization of innovations is usually dependent on investments and development activities realized by multiple actors. A joint vision can direct these interlinked activities towards joint goals and align their timing. Particularly when development, commercialization and diffusion of innovation takes place in a context with a high degree of systemic characteristics—i.e. strong interdependence between related actions—a joint vision can create a shared point of reference for aligning complementary actions.

The second way to apply a roadmapping approach to policy design is to facilitate systemic change by identifying those societal needs which create a potential demand for new solutions. With regard to a set of pressing 'grand challenges' such as climate change, an aging population, depletion of mineral resources or shortages of food and water, roadmapping can identify latent societal demand, for example, in the context of sustainability. Particularly when large sunk costs have been incurred in existing technologies and infrastructures, the system is often locked into technological solutions which are socially suboptimal and do not transform automatically through market transactions alone. Roadmapping can articulate these needs more explicitly and link them with emerging technological and industrial development. Systemic change can be facilitated through different policies, e.g. regulation and taxes, and through policy instruments that, for example, focus on public procurement, or support for the adoption of new technologies.

The third way is to anticipate how and when the demand could be articulated towards the emergence of a new market. There are several reasons why the existence of a market for new products cannot be taken for granted. In some cases, adopting new technologies is very slow due to high switching costs. In other cases, the market does not develop because a pricing mechanism for the benefits is missing. This is common, for example, in environmental innovation. Social and economic costs created by emissions and pollution are not always easy to allocate to those who generate them. A pricing regime for these externalities has to be established before a market can emerge. When executed well, a roadmap synthesizes and depicts the participants' common understanding of future societal and market needs.

The fourth way to use roadmaps is with visionary strategizing. This refers to a 'cross-over' knowledge that builds on understanding the interfaces between the layers of the roadmap, for example societal drivers, markets, solutions and technologies in a certain timeframe. A roadmap can create an analytic structure for understanding how and when the 'push' created by new technologies and the 'pull' driven by market demand are likely to match, and under which conditions. There are several policies and policy instruments to support visionary strategizing. First, the policies could aim to facilitate the commercialization of public research and technology development. Secondly, policies could be deployed to provide validation and feasibility assessment, and to create demonstration and piloting environments. Thirdly, policies could be about setting product certification and labelling schemes and requirements. Also, the more standard technology policies, such as public funding for R&D and innovation, support for technical standardization, intellectual property rights regulation and the provision of public technical infrastructure, can be applied.

The fifth way is to identify specific innovation targets, either singular technologies or logical temporal sequences, in the roadmap structure. When the business environment follows the systemic logic of a value network rather than the more linear logic of a value chain, it is important to identify all the elements and linkages in a network (Adner and Kapoor 2010). Single or sequential targets could be very important for identifying preferred partners in a value chain or when formulating a sourcing strategy.

3.3. Depiction of IPRM

In principle, there are two levels of inspection in IPRM: the level of systemic transformation (transformation roadmap) and the level of enablers (technology roadmaps). However, it depends on the case whether the particular enabling roadmaps are necessary or whether it is sufficient to map the enablers at the level of a systemic transformation roadmap. In Section 4, for example, we present an example of a more focused sectoral roadmap (the construction industry in the Victoria Technology Roadmap, Australia) in which the enablers are mapped in the transformation roadmap, and a roadmap of environmentally sustainable ICT, in which the enablers are mapped separately as three technology roadmaps.

The structure of the systemic transformation roadmap is presented in Fig. 1. This roadmap depicts the impacts of the objects under scrutiny (e.g. new industrial practice and emerging service business) in an overall systemic level. In a transformation roadmap, the system could refer to an entity consisting of different actors, for example, in the health value network and the regulatory context of this network, as in the case of the health sector, or the

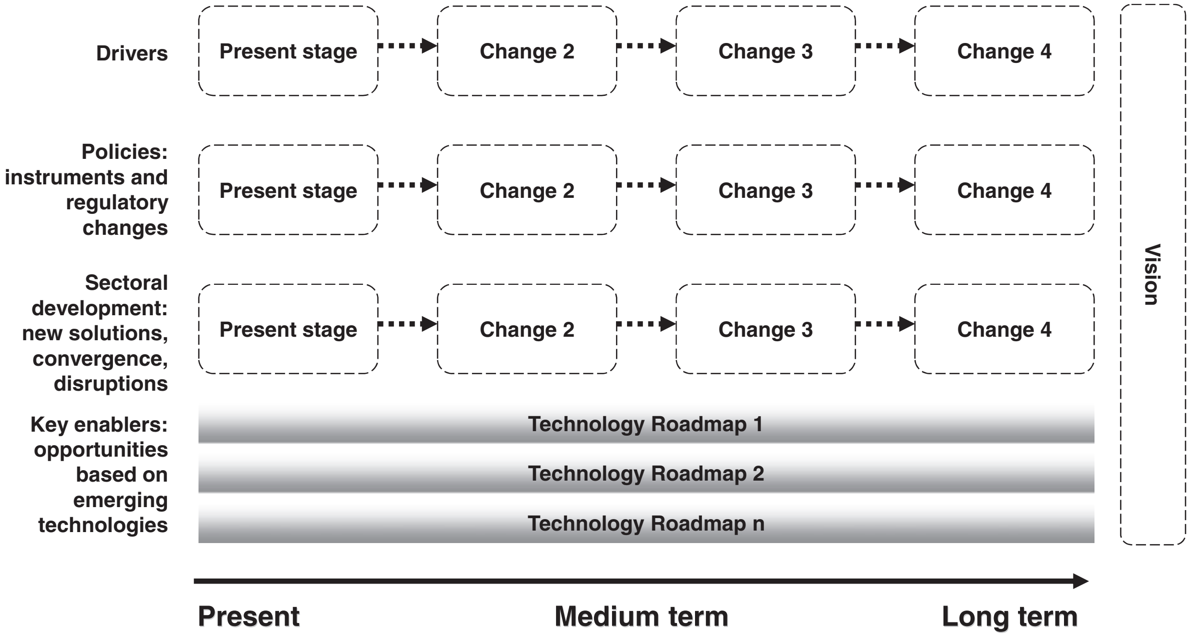

Figure 1. Generic structure of systemic transformation roadmap.

system could also refer to a convergence of sectors, for example in the case of functional foods. The key idea of a transformation roadmap is to connect the development of technologies and innovations to a wider societal sphere. The aim is to endorse the formation of policy conclusions based on an in-depth understanding of the technological developments and their socio-economic frameworks.

The first roadmap level in a transformation roadmap is drivers. This level depicts the key drivers and the so-called 'grand challenges' that are assessed as the most important factors structuring the roadmap topic. In IPRM, the second level of policies, policy instruments and regulatory changes is critical. IPRM endorses the positioning of the policy practices in a dynamic socio-technical context, and weighs the policy practices in relation to the conditioning factors. It also enables one to visualize and communicate the logic of the policy decisions. The third level is sectoral development, with an emphasis particularly on emerging solutions, and on anticipated convergence and disruptions. This level provides critical contextual setting for the policies. The fourth level is key enablers, with a primary focus on technologies that enable the sectoral development.

Fig. 2 presents the subset of a systemic transformation roadmap, the technology roadmap. The critical boundary of the technology roadmap is formed by the long-term vision defined in the systemic transformation roadmap. The technology roadmap has four potential levels. What levels are utilized depends on the topic: in some cases it is enough to map just the enabling technologies, yet in some cases the market development and actors play more important roles. In the first level, technology-based solutions, specific developments of technological solutions are depicted on a level that is assessed as necessary. At the second level the technologies that enable the solutions as well as the potential technological convergence are mapped. Commonly, one focuses on technologies that endorse the development of the solutions, but in some cases it is also possible to map the convergence of enabling technologies. The advantage of this practice is that the enabling technologies are also assessed as evolving constructs, and not as singular 'black boxes'. The third possible roadmap level accentuates needs and market developments—both the market segments and geographical market regions—that are important for the technology-based solutions under scrutiny. The fourth potential level is capabilities, resources and actors. At this level, the technology is set in its immediate societal context. Capabilities refer to the competencies, at the scales of individuals, organizations and geography, required to develop the technology. Resources refer to both material resources and social capital. Actors refer to the individuals, organizations and institutions that are perceived as important in the development of the technology.

There are basically three ways to build roadmaps. The first way is future-oriented, i.e. to define a desired vision and the related future targets, and start to extrapolate steps backwards from the vision towards the present stage. This method is known as backcasting. The second way is present-oriented, i.e. to define the present state and start to build steps, finally reaching the long-term state. The third way is a hybrid between the future-oriented and present-oriented methods. Hybridization allows the roadmapping process to escape process lock-ins that can result from too rigid a process.

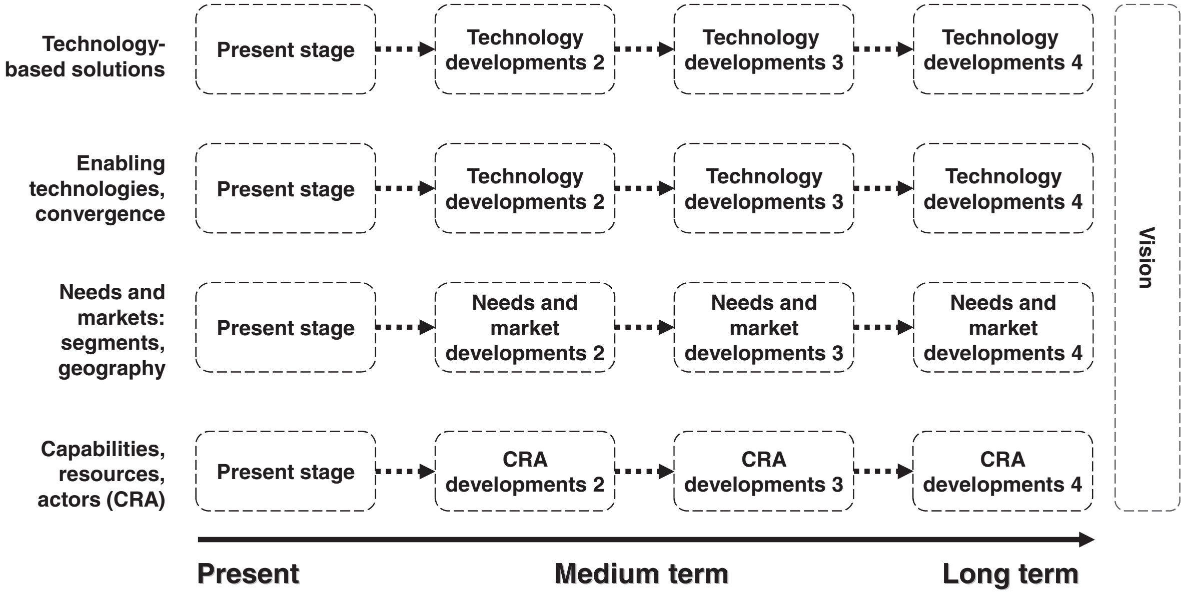

Figure 2. Generic structure of technology roadmap.

The development of the IPRM method, still an on-going process, is an outcome of several projects realized at VTT Technical Research Centre of Finland. In Sections 4 and 5 we reflect on two projects as case studies. The function of these case studies is to demonstrate how the IPRM method can be utilized in the mapping of systemic policy-level trajectories.

4 Case study 1: Roadmap of green and intelligent buildings in Victoria, Australia

4.1 Background

The first case study is a regional-sectoral strategy process, the Victoria Technology Roadmap, made by Intellectual Capital Services (ICS) and VTT, in Victoria, Australia, in 2009. Commissioned by the Victorian government, the purpose of the Victoria Technology Roadmap was to build a synthesizing picture of the effects of emerging technologies and technology convergence in the region of Victoria, Australia, up until the year 2020. Altogether nine economic sectors were analysed and roadmapped in the project. In Fig. 3 we illustrate the outlines of the green and intelligent buildings roadmap in the Victoria Technology Roadmap project. The knowledge required for building the roadmaps was gathered in a systematic process that combined literature scanning, expert interviews and an assessment workshop.

In the context of Victoria's construction industry, the question of strategic intervention is basically motivated by the rather 'conservative' nature of the field. Traditionally, the construction industry has invested relatively little in R&D, and has also been slow to adopt new technologies. The fragmented structure of the industry, its value chains and business models create barriers to the adoption of new innovations. Innovation in the construction sector therefore needs to be framed within the larger context of new business processes, contractual arrangements, organizational culture, and government regulation and incentives. There are also specific systemic bottlenecks in the Victorian construction industry that stimulated the needs for strategic intervention. The first bottleneck is regulation. Construction is subject to a relatively high degree of regulation, including technical building codes and quality standards for energy consumption, safety and health. Because the regulations are not always consistently coordinated between different levels of government, companies that operate across several jurisdictions report high compliance costs due to multiple regulatory frameworks. The second bottleneck is the project-based nature of construction, with little replication at the design level. Project processes usually have non-standard features that do not support systematic repetition (Gann and Salter 2000). The third bottleneck is the fragmentation of building activities. Building activities are characterized by a high fragmentation of responsibilities, processes and resources. New solutions need to be negotiated within a large network of actors and thus risk aversion predominates. The fourth bottleneck is strong business cycles. The cyclical nature of the industry with its expectations of short-term profit discourages innovation, as both demand and profits are subject to strong variation (Squicciarini and Asikainen 2010). The fifth systemic bottleneck is split incentives. Building owners and users do not have the same incentives to improve building performance in relation to, for example, energy efficiency (World Business Council for Sustainable Development 2009).

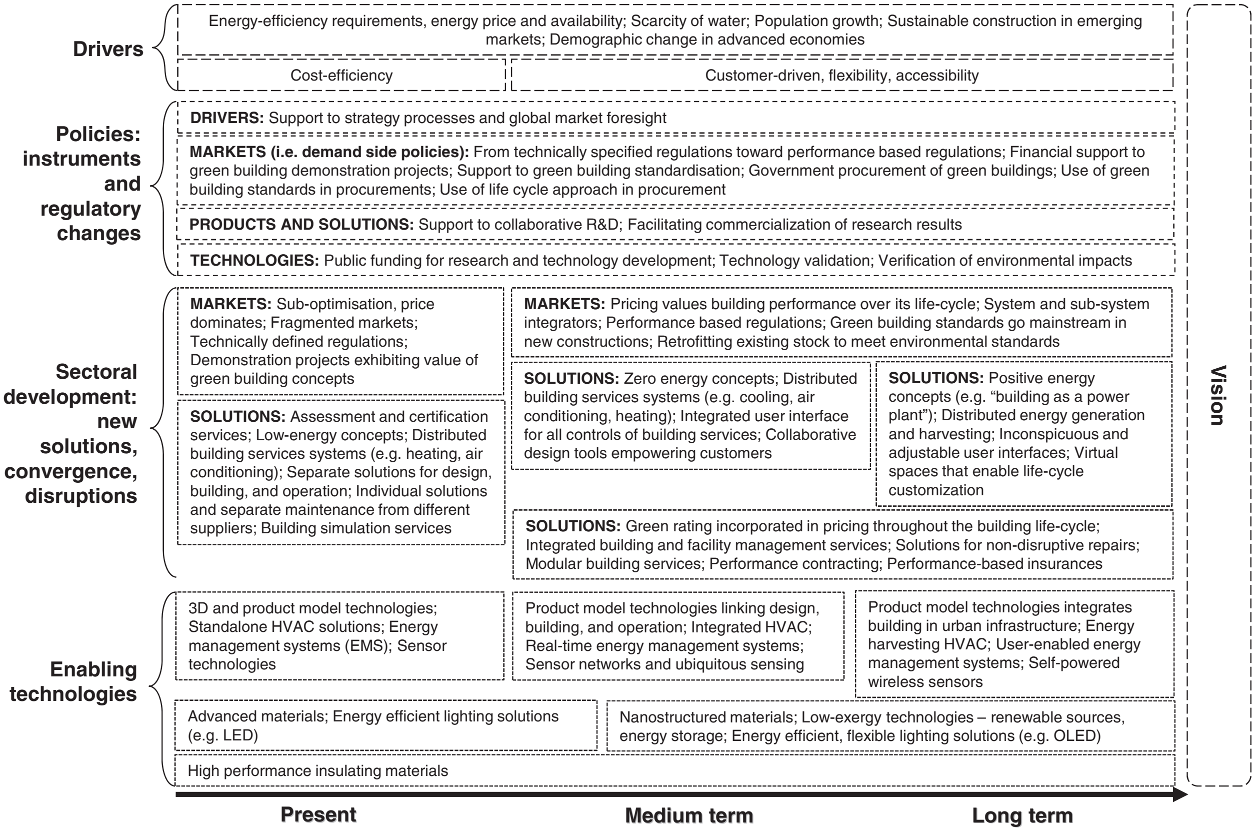

Figure 3. Transformation roadmap of green and intelligent buildings in Victoria, Australia.

4.2 Outline of the transformation roadmap

In this case, the roadmap knowledge was crystallized in a transformation roadmap (Fig. 3). The working vision for the green and intelligent buildings roadmap, targeted towards the year 2020, was the following:

> Victoria is a sophisticated market for green and intelligent buildings. It is among the first to adopt sustainable construction technologies and green business models in building and construction. Victoria is a lead market for solutions suited for buildings in dry and warm climate conditions.

4.2.1 Drivers. At present, the most important driver in the construction sector is cost-efficiency. Short-term pressures for profit dominate over the longer term building performance issues and user needs. In the future, the move is expected to be towards a more customer-driven and flexible approach. There are signals that emerging user requirements highlight energy efficient, convertible and user-friendly buildings. Traditionally, user needs have not been very well translated into building designs. Particularly in the Victoria region there are specific energy-efficiency requirements, focusing on the questions of energy price and availability. The scarcity of water is an important issue, since Victoria suffers from lowering levels of precipitation and a shortage of water storage facilities. Population growth, especially in the form of immigration, sets the critical framework for the construction sector in Victoria. Sustainability, in an integrative sense combining issues of economic growth, social progress, and environmental protection, is a rising topic in the emerging markets of the Victorian construction industry. A further driver is a demographic change in advanced economies that is reflected in the residential housing sector. The aging population requires the adaptation of homes and refurbishments of buildings to allow senior citizens to remain in their homes. The trend towards single-households sets requirements for more households per head of population and smaller dwelling units.

4.2.2 Policies. In the project, it was concluded that a sophisticated mix of policy instruments should be put in place to propel the creation of a more sustainable and user-driven construction industry. The main goal should be double-edged: to create conditions for a more sustainable construction industry to evolve, while simultaneously creating market demand and business opportunities for existing and new players in the business.

The key policies can be categorized into the levels of drivers, markets, products and solutions, and technologies. At the level of drivers, the most important policy would be to support regional strategy processes by executing systematic rounds of global market foresights. The regional strategy processes could be developed towards continuous and cyclical processes, which are updated annually. At the level of markets, referring mainly to the demand-side policies, the first policy proposal was to move from technically specified regulations toward performance-based regulations. Construction regulations have traditionally been based on setting standards for particular technologies or processes. This may have a negative effect on innovation in the industry because legitimate solutions will become associated with particular technologies. The movement towards performance-based regulation sets norms for targeted performance outputs instead of opting for specific technical solutions. The second policy proposal was to provide financial support to both green building standardization and to related demonstration projects. Support for standardization is becoming accepted as a legitimate goal for government innovation policy as part of demand-oriented innovation support. Standardization is a critical prerequisite for innovation because it influences technology development and contributes to innovation through shaping the way in which new technologies are developed. A further policy proposal would be to catalyse government procurement of green buildings, and also to use the green building standards and life-cycle approach in these procurements. The public sector should drive demand for innovative solutions through the early adoption of new solutions. It was assessed that Victoria should ambitiously target the creation of a lead market for green and intelligent buildings that address dry climatic conditions.

At the level of products and solutions, the support for collaborative R&D and facilitation of commercialization of research results were assessed as the main innovation policy practices. Collaboration between the key R&D players and the government would be important especially in the Victorian context, due to the fragmented nature of the construction sector. At the level of technologies, the three most important policy proposals were: public funding for research and technology development, technology validation and the verification of environmental impacts. Financial support for collaborative industrial R&D will provide the basis for an innovation-driven construction industry, but should be offset by demand-oriented innovation policy measures such as smart regulation and public procurement.

4.2.3 Sectoral development. In this roadmap, sectoral development is divided into the themes of market and solutions. The present markets are fragmented and emphasize suboptimization by price. The regulations are mainly defined technically, and some demonstration projects exhibiting the value of green building concepts have already been realized. From the medium- to long-term, the markets are supposedly developing towards pricing that values building performance over its life cycle. Regulations are also developing in a performance-based direction as green building standards are increasingly going mainstream in new constructions. In the market, this trajectory calls for new types of actors, system and subsystem integrators.

The most important present solutions are: assessment and certification services, low-energy concepts and distributed building services systems (e.g. heating and air conditioning). There are also separate solutions for design, building, operation, and individual solutions and separate maintenance from different suppliers. Building simulation services are also emerging. Solutions in the medium term include: zero energy concepts, distributed building services systems (e.g. for cooling, air conditioning and heating), integrated user interface for all controls of building services, and different types of collaborative design tools to empower customers. In the medium- to long-term the key solutions included, for example: green rating incorporated in pricing throughout the building's life cycle, performance contracting and performance-based insurances. In the long-term the more emergent solutions are positive energy concepts, e.g. 'building as a power plant', distributed energy generation and harvesting, adjustable user interfaces and virtual spaces that enable life-cycle customization.

4.2.4 Key enablers. At present, one of the most important enabling technologies is 3D and product model technologies, like building information models. Another important enabler is stand-alone heating, ventilation and air conditioning (HVAC) solutions. Current R&D on HVAC accentuates the connection of separate systems into a larger building automation system through ICT protocols. A further enabler is energy management systems (EMS) that are also being integrated into the overall building design. One key enabler is sensor technologies. In particular, micro-electrical mechanical systems sensors, and in the future nano-electrical mechanical systems sensors and ubiquitous sensing systems are, and will be, used in construction to monitor and control the environmental condition and the materials performance. In the medium term, development of ICTs will focus on product model technologies linking design, building, operation and real-time EMS. In materials, a key present enabling technology is advanced materials and energy efficient lighting solutions (e.g. LED). In the long term, the use of low-energy technologies and energy efficient, flexible lighting solutions (e.g. OLED) will continue to increase. In addition, important emergent enablers are product model technologies that integrate buildings in urban infrastructure, energy harvesting HVACs and user-enabled EMS.

5. Case study 2: Roadmap of environmentally sustainable ICT, Finland

5.1 Background

The second case study is a roadmap of an emerging systemic field: environmentally sustainable ICT. It was completed as a strategic process at VTT Technical Research Centre of Finland in 2010, with two aims: first, to outline an increasingly pivotal nexus of ICT, environmental sustainability and human actions; and secondly, to provide an assessment of this nexus in the context of VTT's strategy. The aim of the roadmap is to form a perspective on the issue based on VTT's technological expertise and to offer an outlook of the potential developments of green ICT based on VTT's technological competence. In the roadmap, ICT for environmental sustainability is defined as the use of ICT for optimising societal activities in order to improve environmental sustainability (Ahola et al. 2010).

The case example consists of a transformation roadmap (see Fig. 4) and a technology roadmap (see Fig. 5). The roadmapping process was completed in three working phases. Phase I was a landscaping phase that was realized in three steps. The first step was desktop research. The second step was a discussion workshop on the core themes of the process. The third step was the selection of the relevant themes for the actual roadmapping process. Phase II was the roadmapping. First, a specific roadmapping core group was set up. Secondly, an expert workshop with 16 technology experts was organized. Phase III involved the elaboration of the roadmap. The first step was a round of comments in which selected technology experts iterated the results of the roadmapping workshop. The second step was the updating of the roadmap document. The third step was an extensive round of commenting on the document. The roadmap was then finalized.

5.2 Outline of the transformation and technology roadmaps

This example of environmentally sustainable ICT demonstrates an innovation policy roadmap that is constructed of a systemic transformation roadmap and a technology roadmap which is a subset of the transformation roadmap. The long-term vision, targeted towards the year 2025, for the roadmap of environmentally sustainable ICT was the following:

> ICT will increasingly be present in our everyday private and business life. It has contributed to decreasing the resource consumption and resource-intensive lifestyles in many ways. ICT offers achievable data and easy-to-use tools for the people to decrease their ecological footprint and to select more environmentally sustainable products and services. Smart production and recycling technologies have resulted in

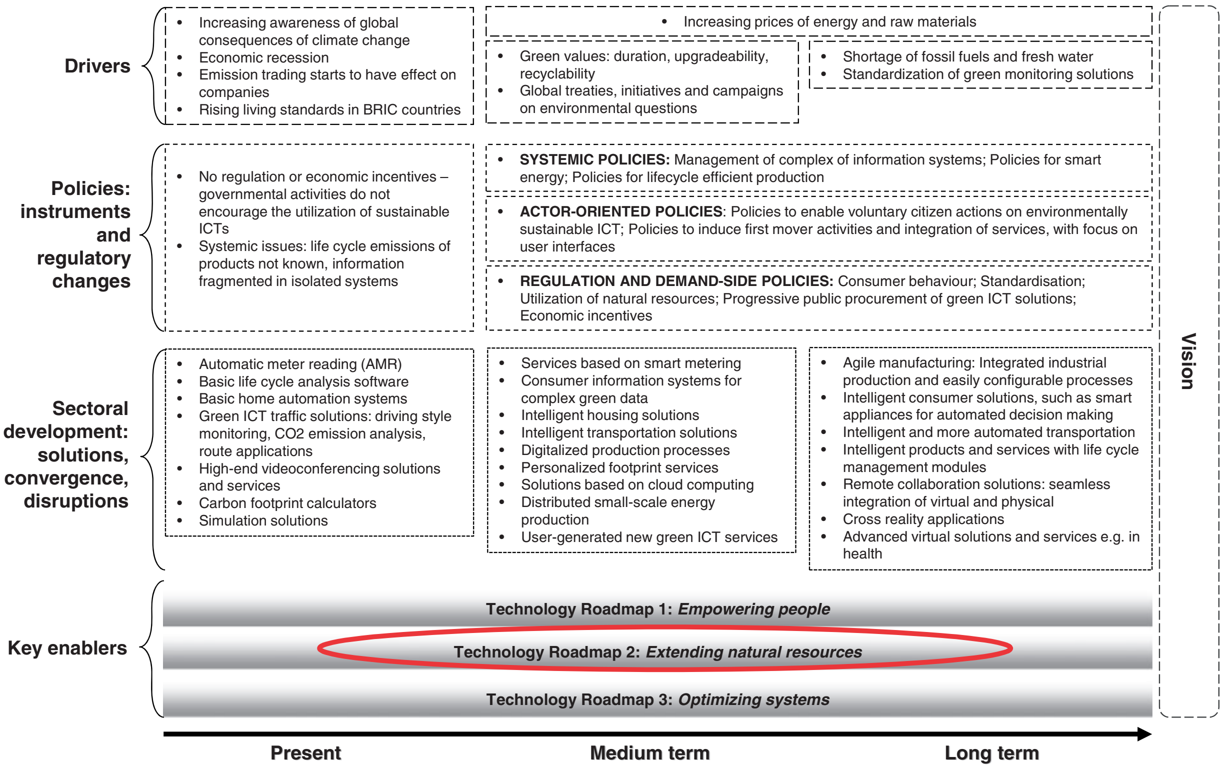

Figure 4. Transformation roadmap of environmentally sustainable ICT, Finland.

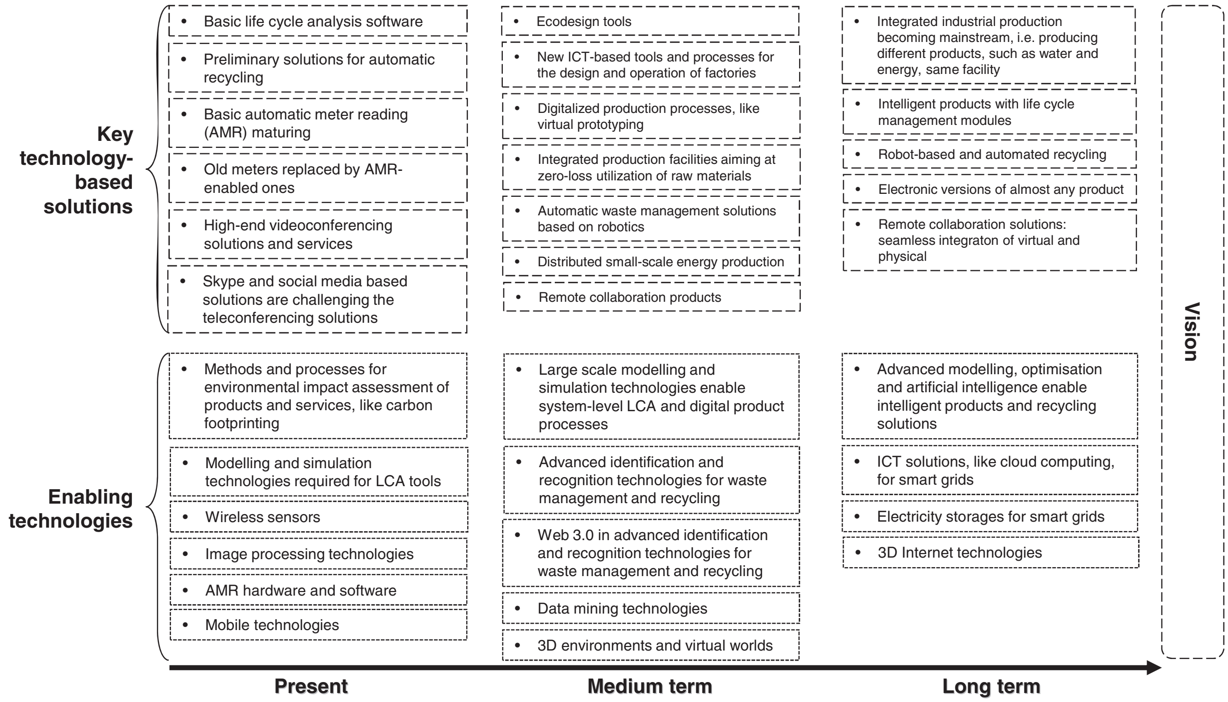

Figure 5. Technology roadmap on 'extending natural resources' as a subset of a transformation roadmap of environmentally sustainable ICT.

optimised products, processes and systems that consume as few resources as possible at every stage of their life cycle. Smart metering and grid technologies have enabled flexible, accessible and economical energy generation (using renewables), distribution and consumption both in households and business/industry. Intelligent transportation systems and remote collaboration technologies have reduced unnecessary traffic and minimised the energy usage of transportation in general. ICT devices and networks themselves will be highly optimised. Sustainable decisions are also supported by governmental regulation and other incentives.

5.3. Transformation roadmap

5.3.1 Drivers. At present, there are four important drivers for environmentally sustainable ICT. The first is increasing awareness of the global consequences of climate change. The second is the economic recession. Recession is empathetically a double-edged phenomenon: it can be a driver for environmental solutions by focusing on issues such as the reduction of materials or the streamlining of production lines, but it can also be a bottleneck, especially if firms and organizations modify their environmental agendas and deem investments in this area to be unnecessary. The third driver is emission trading, which is currently starting to have an effect on companies. The fourth driver is the rising living standards in the BRIC countries (Brazil, Russia, India and China). In the medium term, global warming is expected to be the major driver at the global level. Consequently, more concrete regulation and incentives for both citizens and companies will be utilized. The increasing price of energy and raw materials is also a significant driver. In the long term, drivers other than just climate change will play a larger role globally. The scarcity of some critical resources, such as fresh water and rare earth metals, will have major effects. Consumption fees, taxes and regulation can be used to control user behaviour.

5.3.2 Policies. The strategic policy issues in environmentally sustainable ICT start from the present zero position, in which there is basically no regulation or incentives to utilize sustainable ICTs. Also, the systemic effects of ICTs, such as life-cycle emissions, are not known. Most of the information is fragmented in isolated systems. Basically, the strategic policy issues depicted here aim to affect this zero state of affairs.

The first, and in this case the most fundamental, level is the systemic policies. The first of the systemic policies emphasizes the management of a complex of information systems, with a special emphasis on information transparency and security. The core task is the coordination of an integrated information system, and managing the complex interactions within it. This sets specific demands for interoperability. The interfaces should also be designed in such a way that they do not lead to a build-up of information overload. The second type of systemic policy concerns smart energy. In this, smart metering and sensor network-based subutility energy measurements play a key role. The utilization of smart metering and sensor technologies could result in more elaborate energy consumption information, from both temporal and load profile perspectives. The new energy consumption information could enable novel business models and the provision of new digital services for diverse stakeholders, such as: demand forecasting for energy companies, energy performance benchmarking for building operators, dynamic pricing and energy consumption monitoring for individual residents. In the future, systems will be integrated towards a smart grid concept that enables distributed, small-scale energy generation. This also requires new energy market players that take the responsibility for aggregating the distributed energy resources to the grids. The third type of systemic policies is policies for life-cycle efficient production, for example factory facilities to produce several different types of products and the adoption of digitalized production processes. The emergence of life-cycle oriented policies is linked to the policies on information disclosure, transparency and security.

The second set of policies is actor-oriented policies. The first of these is to enable voluntary citizen actions on environmentally sustainable ICT, and thus to foster citizen participation. The second policy would focus on inducing first-mover activities and integration of services, with a specific focus on interfaces. This policy could be realized by demand-side interventions, like endorsing public procurements with a certain ICT standard, or by different financial activities to back up new public and private actors in the field.

The third set of policies focus on the regulation and demand-side, and refer to more 'standard' types of practices, like regulation that affects consumer behaviour, standardization and the utilization of natural resources. Furthermore, basic demand-side policies, like public procurement, can be utilized in the context of green ICT as well as economic incentives.

5.3.3 Sectoral development. At present, there are a number of separate products and services available (e.g. carbon footprint calculators, car navigators and ecodriving instructors) for private citizens. The basic versions of home automation systems are currently utilized, for example in heating and ventilation. Automatic meter reading (AMR) is currently one of the key solutions. Basic life-cycle assessment (LCA) software is already used in industrial production. In the medium term, there will be different types of services that utilize data from ICT embedded in our everyday environment. For consumers, personalized information services that integrate diverse activities (housing, transportation, nutrition etc.) and handle complex data on environmental sustainability (automatically) are entering the market. In industry, new manufacturing paradigms are evolving and new ICT-based tools and processes are available for the whole production life-cycle. Remote collaboration services provide a sense of telepresence over the internet, resulting in a more extensive use of teleworking and virtual conferencing. In the long term, the small-scale environmental sustainability services offered to individual consumers can be scaled up to large-scale systems. Telepresence and other virtual services have expanded from the company level to the consumer level. The manufacturing industry is efficient and agile in terms of life cycles, leading to integrated industrial production and easily configurable processes. A considerable portion of the energy is generated and distributed in buildings or at the neighbourhood level. New ecomobility solutions, such as hybrid and electrical vehicles, are common and their performance has been optimized.

5.4 Example of enablers: technology roadmap on 'extending natural resources'

In the final part of the case study section we present an example of a technology roadmap constructed as a subset of the transformation roadmap (see Fig. 5). The topic of the exemplary roadmap is 'extending natural resources'. The roadmap has two levels: technology-enabled solutions and enabling technologies.

5.4.1 Technology-enabled solutions. At present, LCA is a standardized method and many types of LCA software are available. The basic AMR services are maturing. Digital communication channels are challenging the solutions dedicated solely to teleconferencing. On the other hand, high-end videoconferencing solutions and services are gaining ground within larger companies and organizations, which use them as a substitute for travel. In the medium term, ecodesign tools are widely used to minimize the environmental impacts of products over their life cycle. New ICT-based tools and processes are available for the design and operation of factories. The production processes are mainly digitalized, including solutions such as virtual prototyping. More integrated production facilities are emerging, with a goal of zero-loss utilization of the most scarce and valuable raw materials. Distributed small-scale energy production based on renewables is emerging. Remote collaboration services utilize virtual and augmented reality. In the long term, integrated industrial production will become mainstream. That means that different types of products will be produced in the same facilities to ensure a maximal use of resources. Intelligent products and services are emerging with embedded life-cycle management modules. A considerable portion of the energy is generated in a distributed manner in buildings or at the neighbourhood level, using mainly renewable energy sources. Remote collaboration solutions provide a virtual presence, integrating physical and virtual worlds into a single seamless user experience.

5.4.2 Enabling technologies. At present, much emphasis is placed on developing methods and processes for the environmental impact assessment of products and services, including carbon footprinting. The modelling and simulation technologies required for LCA methods are also available. Wireless sensors as well as image processing technologies help in the object recognition needed for automatic waste recycling. AMR hardware and software are available commercially, off-the-shelf. In the medium term, large-scale modelling and simulation technologies will enable system-level LCA, digital product processes, and a smart energy supply. There are advanced identification and recognition technologies for waste management and recycling. Web technologies (web 3.0) are utilized in both energy consumption monitoring and remote collaboration solutions. In the long term, advanced modelling, optimization and artificial intelligence methods will enable intelligent products, recycling and energy grid solutions. Smart grids with controllable distributed energy resources will enable high penetrations of intermittent or non-controllable renewable generation and distributed generation. They benefit from diverse ICT solutions, varying from cloud computing to communication technologies. 3D internet technologies will enable novel remote collaboration solutions and virtual products.

6. Conclusions

This paper has depicted an IPRM methodology in the context of forward-looking policy design. It exemplified IPRM with two case studies from Australia and Finland. The aim of the case studies was to reflect on how the policy perspectives can be constructed in a dynamic context of societal drivers, solution and market development, and enabling technologies. We discussed how the roadmapping approach can create strategic guidance for identifying the type of steps required for transformation towards a shared vision to take place. It can also provide a more nuanced perspective of the temporal sequencing of the evolution of technology and innovation, and related policy instruments. The roadmapping approach represents a form of foresight which can contribute to dealing with the web of future dependencies. The first case study (green and intelligent buildings in Victoria, Australia) was an example of a transformation roadmap that was completed as part of a wider regional strategy for industrial renewal. The second case study (environmentally sustainable ICT in Finland) was an example of a more focused exercise that envisaged the outlines of an emerging systemic and strategic field.

We conclude this paper by emphasising two related contributions that the roadmapping approach can bring to innovation policy and forward-looking policy design. First, innovation policy roadmapping contributes to enhancing the systemic benefits of foresight. Our conclusions support the views of Georghiou and Keenan (2006) who emphasize the systemic rationale of foresight. Foresight enables the connection between multiple stakeholders, with diverging perspectives and limited information, and enables them to align their actions towards shared long-term visions. Foresight processes can produce outcomes that spring from interactions between multiple stakeholders. The success of the systemic foresight process could be evaluated, for example, by the ideas it has created that could be potentially important for multiple stakeholders or by the amount of new linkages among the stakeholders formed during the process.

Secondly, as we have discussed in this paper, the roadmapping approach can combine issues of strategic intervention with potential lock-ins and systemic interdependencies. In addition, diffusion of innovations often depends on changes in infrastructure, information systems, organizational practices and social institutions. Identification of these complementary elements and associated interdependencies is an important contribution that a roadmapping approach can illuminate. Furthermore, large-scale diffusion of commercial innovations also requires the emergence of a specific market for new products. However, when subject to systemic lock-ins the emergence of such markets often depends on the formation of associated institutions. These institutions can be formal, such as regulations and standards, or informal, such as new inter-organizational partnerships. These societal elements can also be grasped in a systematic roadmapping process.

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