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A functions approach to improve sectoral technology roadmaps

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ABSTRACT

The roadmap approach has been used to develop future-oriented analysis (FTA) linking technology/innovation, policy, business and social drivers. There has been a growing interest in introducing a systems perspective within the roadmap approach, especially at sectoral level. This paper proposes the use of the 'functions of innovation systems' as drivers/layers within sectoral roadmaps, with the purpose of directing decision-making and policy-making efforts towards the functions. We provide the case study of a sectoral roadmap exercise aiming at establishing a non-existing automotive sector in Santa Catarina State, Brazil (a sector which does not exist at present time in the region) by means of integrating the 'functions approach' with the roadmapping process. We find the 'functions approach' to be a useful approach to support the development of future-oriented analysis by making explicit the current and desired future states of each system's function.

1. Introduction

Future-oriented Technology Analysis is a projection, to the future, of current knowledge and has as main role to assist societies, decision makers and businesses to tackle difficult decisions when it comes to technology and its impact on economic development (Daim and Oliver, 2008; Cagnin et al., 2013). Due to the potential of FTAs in enabling a better understanding of complex problems and in defining more effective policy responses, interest in studying its theoretical and practical implications has grown, see for example the Special Issue in *Technological Forecasting and Social Change*, edited by C. H. Cagnin, A. Havas and O. Saritas in 2013.

Among the many FTA tools, the roadmapping approach has become widely popular during the last decade and has been adopted by companies, governments and other organizations, due to its capability to link technology/innovations, policy and business/social drivers (Garcia and Bray, 1997; Lee and Park, 2005; Daim and Oliver, 2008; Saritas and Aylen, 2010; Carvalho et al., 2013; Moehrle et al., 2013). As it can be verified in the previous literature, there are two main traditions of roadmapping: corporate roadmaps, which relate to the development of temporal and graphical means to explore and communicate the relationship between markets, technologies and products (Phaal et al., 2004a, 2004b; Lee and Park, 2005); and roadmaps at sectoral and national levels, which relate to the development of visual narratives describing multi-layered strategy maps of both, the macro-level currents and the micro-level developments (Blackwell et al., 2008; Phaal and Muller, 2009), in order to identify trends (Lee and Park, 2005) and forward-looking policy design (Ahlqvist et al., 2012).

In recent years, there has been a growing interest in introducing a systems perspective within the roadmap approach, especially at sectoral level (see for example, Ahlqvist et al. (2012) and Saritas and Oner (2004)). Following this line of practice, the paper introduces the concept of 'innovation systems' and more specifically, the 'functions of innovation systems' into the roadmapping process (Alkemade et al., 2006; Hekkert et al., 2007; Bergek et al., 2008). In this sense, each system function serves as one dimension of analysis for the roadmap (i.e. the drivers). In order to demonstrate the usefulness of this proposal, we provide the case study of a sectoral roadmap exercise aiming at establishing a novel automotive sector in Southern Brazil (a sector which does not exist at present time in the region).

Our main argument is that the system functions serve to map the current state of the sector and the desired future state of the sector, providing policy makers with a richer set of guidelines to draw on, in order to build the roadmap from the current to the future state. Similar work can be found in Andersen and Andersen (2014), Andersen et al. (2014) and Alkemade et al. (2006).

This paper is structured as follows: in Section 2 we briefly review the previous literature on sectoral technology roadmaps. In Section 3 we outline the theoretical framework integrating the 'functions approach' with the roadmapping process. In Section 4 we provide a case study in Brazil. The purpose of the case study is to demonstrate how the 'functions approach' can be utilized in the roadmapping process of a yet-to-exist sector. In Section 5 we provide the synthesis of the main contributions as well as the discussion and conclusions. We conclude with the acknowledgments and references sections.

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2. Previous literature on sectoral technology roadmaps

Technology roadmaps (TRM) were originally used in the corporate domain. Probert and Radnor (2003) reported Motorola and Corning as the first companies to use the approach in the late 1970s and early 1980s. Geum and Park (2012) reported many studies developing the field of TRM, by studying its characteristics (Phaal et al., 2004a, 2004b), its types (Kappel, 2001; Phaal et al., 2003; Lee and Park, 2005) and formats (Phaal et al., 2004a, 2004b; Lee and Park, 2005). These exercises were mainly focused at the corporate level, with the purpose of developing strategic, process, product, capacity, integration, and long-term plans as well as between operational units of the company (Probert and Radnor, 2003). Kostoff and Schaller (2001) categorize these roadmaps into four categories: (i) product/portfolio management (ii) Science & Technology; (ii) industry technology; and (iv) corporate or product-technology.

In addition to the corporate roadmaps, there are a variety of other roadmapping exercises found in the literature. For example, Phaal et al. (2004a, 2004b) proposed a variation of the fast-start process, extending beyond the roadmap for product technology planning, called T-Plan to the S-Plan, which involves broader applications. The S-Plan was developed with the aim of Identifying and exploring strategic, innovation and business opportunities (Phaal et al., 2007).

Walsh (2004) based on the traditional TRM approach, proposes a model for disruptive technologies. Geum and Park (2012) explore the state of the art in relation to the development of roadmaps for the public sector, arguing that these are particularly distinct of corporate roadmaps. In this sense, the authors come to four main types of technology roadmaps for the public sector: (i) action-based; (ii) pathway-based; (iii) technology-based; and (iv) vision-based. Yasunaga et al. (2009) illustrate goals, structures and methodologies for roadmapping application for national technology policy, arguing that this approach can assist the preparation of government R&D policies and generate discussions about relevant policy indicators. Rinne (2004) explores how technology roadmaps support virtual innovation and argues roadmaps can be important drivers of innovation, as they allow the convergence of foresight and innovation, represent the co-evolution of technologies and markets, and contribute to technology organization over time. Simonse et al. (2015) built a model for innovation roadmapping and point out the effects on innovation performance of competitive timing and industry sinergy.

On the other hand, another stream of literature sought to combine a 'systems perspective' with the roadmap approach. Morioka et al. (2006) focus on the innovation system of the Research Institute for Sustainability Science (RISS) and propose a technology transition management based on technology push, demand pull and institutional design to develop this system. Komninos et al. (2011) developed an innovation roadmap that combines regimes and new solution niches (technological, industrial, social, and policy change) to support the development of innovative policies and strategies for Smart Cities and the Future of the Internet. Almeida et al. (2015) present the methodological tool used for the creation of the future vision and agenda for a National Innovation Initiative (NII) in three emerging technologies in Brazil. This instrument integrates methods of technology foresight, technology roadmapping and Delphi for the formulation of public policies, identifying emerging technology areas and prioritizing RD&I efforts.

Ahlqvist et al. (2012) propose the Innovation Policy Roadmapping (IPRM), a methodological framework that connects the results of R&D to the innovation systems context for policy design. Therefore, the IPRM integrates technology and social environment analysis to make future-oriented analysis, listing the results of the survey to policy design in five ways: (i) building a common vision; (ii) facilitating systemic change by identifying social needs that require new solutions; (iii) anticipating the emergence of a new market; (iv) understanding the interdependence of the different layers of the roadmap; (v) identifying specific innovation targets.

The IPRM is based on two traditional exercises: technology roadmapping, with respect to the legal instrument of technology identification and its alignment to product planning and action plans, and strategic roadmapping, which involves a dynamic and interactive process.

In structural terms, the authors divide the IPRM on two levels. The first level corresponds to the systemic transformation roadmap, which aims to understand the technological development and its socio-economic frameworks to support policy-making. Its architecture consists of four levels: (i) drivers, (ii) policies, (iii) sectoral development; and (iv) key enablers. The second level corresponds to the technology roadmap, which is a sub level of the key enablers step and is formed by the long-term vision defined in the previous level. The structure of the technology roadmap can have up to four sub-levels, depending on the analyzed topic: (i) technology-based solutions; (ii) enabling technologies, convergence; (iii) needs and markets (segments, geography); and (iv) capabilities, resources, actors (CRA).

To illustrate how the political perspective can be built in the dynamic context, the authors analyzed two case studies: the roadmap of green and intelligent buildings in Australia and the roadmap of environmentally sustainable ICT in Finland. This approach has two main contributions to the use of roadmaps for policy design: (i) the IPRM emphasizes the systemic benefits of foresight, integrating many stakeholders to build a shared long-term vision; (ii) the roadmap identifies gaps and the interdependence of the components of the system (Ahlqvist et al., 2012).

At the sectoral level, specifically, roadmaps have been developed for more than two decades. Among the sectors that applied technology roadmap, we can mention mobile communications, chemicals, automotive, energy, software, nanotechnology, mining, academic services, construction, medicine, hydrogen, telecommunications (Carvalho et al., 2013) and semiconductors.

In the latter sector - semiconductors - as well as studies in different countries (Kostoff and Schaller, 2001; Garcia and Bray, 1997; Allan et al., 2002; Edenfeld et al., 2004; Carballo et al., 2014) there is also a study called the International Technology Roadmap for Semiconductors (ITRS), which is updated every two years, and is one of the most successful and disseminated example of sectoral roadmaps (Kajikawa et al., 2008).

There are other numerous examples of sectorial roadmaps, as the roadmap process in the energy services sector at Bonneville Power Administration (BPA) in the United States (Daim and Oliver, 2008). This was drawn from three main stages: planning, training of those involved in the roadmapping process, and implementation and development of the roadmap. To undertake the construction of the roadmap, they analyzed drivers, desired products features, technology and R&D. Another example is the UK Foresight Vehicle Technology Roadmap (Phaal, 2002), which examined a number of trends and drivers, measure performance and targets, and technology and research to indicate strategies for the road vehicles sector considering a 20 years vision.

We can also mention the South Australian Cellulosic Value Chain Technology Roadmap (Ahlqvist et al., 2013), who used the concepts of path dependence, path creation, and the theories emphasizing evolutionary aspects of economic agglomerations and emergence of clusters to develop a strategic roadmap. Thus, the authors created a model, considering the industrial, cultural, environmental, financial, regulatory and R&D aspects, to renew the forest industry. In addition, the ICT for Environmental Sustainability Roadmap (Ahola et al., 2010), built a meta-roamap considering drivers, bottlenecks, services, products and markers, and enabling technologies. Then, in a second level, they developed three sub-roadmaps, using the same variables: empowering people, natural resources extending and optimizing systems.

Besides these, there are numerous other cases of sectoral roadmaps. The International Energy Agency (IEA, 2016), for example, presents a series of global roadmaps, focused mainly on low-carbon technologies, including bioenergy, biofuels, and so on. The Agency makes an analysis in terms of "technology development, legal/regulatory needs,

Table 1
Synthesis of technology roadmap approaches.

Approaches	Authors	Level	Application purpose
TRM	Various	Corporate, sector and national	Product, service/capability, strategic, long-range, knowledge asset, program, process, and integration planning
T-plan	Phaal et al. (2003) Phaal et al. (2004a, 2004b)	Corporate	Product technology planning
S-plan	Phaal et al. (2007)	Business, corporate, sector and policy	Identify and explore strategic, innovation and business opportunities
Public-sector roadmaps	Geum and Park (2012)	Public sector	Public-sector planning
METI's Strategic technology roadmap	Yasunaga et al. (2009)	Public sector	Governmental innovation policy for promoting technology convergence
Techology roadmap for the innovation game	Rinne (2004)	Corporate	Explore how technology roadmaps support virtual innovation and innovation factories
Innovation roadmap	Simonse et al. (2015)	Systemic	Propose a framework for innovation roadmapping
Smart cities innovation roadmap	Komninos et al. (2011)	Systemic	Propose a smart cities innovation roadmap framework and recommendations for urban development enabled by future Internet technologies
Innovation policy roadmapping	Ahlqvist et al. (2012)	Systemic	Link R&D results to systemic policy contexts and to forward-looking policy design

investment requirements, public engagement/outreach and international collaboration". Table 1 summarizes TRM various approaches.

3. The functions of innovation systems and sectoral roadmaps

The innovation systems approach has been pointed out as a suitable framework to study the relationship between technological change and economic development (Lundvall et al., 2002). Drawing on Schumpeterian and Evolutionary Economics, the innovation systems approach was initially conceived at the national level, in an effort to understand how actors, networks and institutions shape a national economy (Lundvall et al., 2002). Over the decades, other levels of the economy were proposed as suitable ones to understand the systemic nature of innovation: the regional level (Cooke, 2001), the sectoral level (Malerba, 2002) and the technological level (Carlsson and Stankiewicz, 1991).

In the early 2000s, scholars within the innovation systems community began to call for a more theoretical basis for the approach, see for example: Liu and White (2001), Edquist (2005) and Jacobsson and Bergek (2006). Their main argument was although the innovation systems approach had been successfully introduced into policy-making debates, it did so but in a very broad fashion, without formalizing empirically or theoretically what an innovation system actually was and how it could be measured and/or managed.

In this line, Edquist (2005) argues the innovation system is, primarily, a 'system' with a purpose, components, relationships and activities (i.e. key processes within the system aiming at fulfilling the system's main aim or purpose). In the words of Edquist (2005), activities are the factors or determinants "that influence the development, diffusion and use of innovations".

More recently, scholars such as Hekkert et al. (2007) and Bergek et al. (2008) propose a similar approach than the one from Edquist (2005). They propose a set of 'functions' (i.e. a set of key processes the explain the functioning of the system as the emergence of the functioning of each key process) to explain how an innovation system may evolve over time.

From our point-of-view, activities and functions are different[1]: activities refer to processes being performed within the system and they have been used to compare countries and regions (see for instance, Edquist and Hommen (2008) and Edquist (2011)); functions, on the other hand, refer to 'system functioning' and to system performance (Hekkert et al., 2007), constructs, not necessarily related with concrete processes. The 'functional approach' has been used mainly to analyze technologies within a technological innovation system perspective, but also within geographical boundaries (see for instance, Alkemade et al. (2006) and Gabaldon-Estevan and Hekkert (2013)), an argument we will later use to integrate the functions approach with roadmapping.

Among the authors within the "functions approach", there has been as well, ample discussion as to which set of activities should comprise - yet synthetically represent - an innovation system. Even though the set of proposed functions differs from scholar to scholar, there is, relatively, more consensus on which functions should compose a whole set, Bergek et al. (2008) offer, for instance, a comparative analysis showing the main similarities and differences of the set of functions proposed in the literature. We base our analysis on the set of seven functions proposed by Hekkert et al. (2007), shown in Table 2:

Despite the set of functions chosen, broadly speaking the 'functions approach' offers a clean perspective of:

- Performance: as stated by scholars within the 'functions' tradition, it provides performance measures for each function, and overall system performance emerges out of individual system performance;
- System dynamics: the innovation system functionality changes over time as their individual functions change (or evolve) over time, offering a dynamic perspective on how a particular innovation system should or could change (evolve); and
- Forecasting and backcasting: by understanding how each system function may have a better performance over time, leads to a clearer understanding of future-oriented technology analysis, i.e. how to reach a 'desired' future state for each system function and therefore, for the system as a whole.

Functions, in this sense, may be seen as key drivers or enablers – i.e. determinants in the words of Edquist (2005) – of a technological innovation system (i.e. an innovation system where technology is the key object of interest). The notion of functions as inducing and blocking mechanisms has been previously used within the 'functions approach' (see for instance, Bergek et al. (2008) and Hoppmann et al. (2014)). When – and if – well managed, they serve – or function – as inducing factors for the growth or improved performance of the system. Alternatively, when poorly managed, the serve – or function – as blocking factors for the growth or improved performance of the system (Bergek et al., 2008).

Moreover, the perspective of technological innovation systems might be useful for roadmapping exercices as well. Technology is the key object of interest even at the most traditional business-oriented roadmapping approaches. In fact, for approaches such as the one from

[1] In fact, there is no consensus as to whether activities and functions are the same or different constructs. In Bergek et al. (2008) for instance, functions and activities are compared as if they were the same construct. Edquist, on the other hand, has mentioned both constructs are essentially different in several publications (Edquist and Hommen, 2008).

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Table 2
Set of functions of innovation systems with typical indicators.

Function	Description	Typical Indicators
F1 - entrepreneurial activities	It can be either new entrants, who see a new business opportunity, or incumbent companies established in the market looking for diversifying their businesses. F1 is analyzed by considering the number of new entrants, diversification activities of incumbent companies and experiments with the new technology	Number of new entrants; Number of diversification activities; Number of new experiments with a new technology.
F2 – knowledge Development	It encompasses "learning by searching" or "learning by doing" and is analyzed by the number of R&D projects, patents, and investments in R&D	R&D projects over time; Patents; Investments in R&D.
F3 - knowledge diffusion through networks	It is the exchange of information between agents of the innovation system. This function is analyzed by mapping: the number of workshops and conferences on the subject and the network size	Number of workshops and conferences on a particular technology The network size and intensity over time.
F4 - guidance of the search	It refers to the activities of the innovation system that can positively affect the visibility of the technological needs. This function is mapped by identifying: the focus of the research carried out by the agents and the number of articles published in journals that are related to the development of new technologies	Specific targets set by governments or industries regarding the use of a specific technology; Number of articles in professional journals that raise expectations about new technological development.
F5 - market formation	It is the creation of protected space for new technology market niches. This function is analyzed by mapping the number of market niches, tax incentives for new technologies and new environmental standards	Number of niche markets that have been introduced; Specific tax regimes for new technologies; New environmental standards that improve the chances for new environmental technologies.
F6 - resources mobilization	It involves the mobilization of financial resources and human capital. The extent to which such resource are available and how fast such resources are redistributed to nurture the system.	Funds made available for long term R&D programs set up by industry or government to develop specific technological knowledge; Funds made available to allow testing of new technologies in niche experiments; Perception of the actors regarding the access to sufficient resources.
F7 - creation of legitimacy/counteract resistance to change	It is the appearance of coalitions defending the entrance of new technologies and minimizing the resistance to change. This function is analyzed by mapping the group or groups defending the legitimacy of these technologies	Rise and growth of interest groups; Lobby actions.

Source: adapted from Hekkert et al. (2007).

Phaal et al. (2004a, 2004b), the main goal of technology roadmaps is technological development over a predefined time horizon. In their words, roadmaps provide means for "exploring and communicating the relationships between evolving and developing markets, products and technologies over time".

Similarly, recent streams, such as innovation-oriented roadmaps, also highlight the importance of technology, with a larger emphasis on the "systemic" nature of roadmaps: "…these system characteristics are, for example: actor assemblages, enabling technologies and related infrastructures, a temporal scope of the system … and spatial scales of the system. (Ahlqvist et al., 2012)". For instance, the IPRM connects the development of technologies and innovations with a wider societal sphere, based on drivers, policies, sectoral developments and key enablers (Ahlqvist et al., 2012) which could be re-written as an innovation system.

Sectoral roadmaps could also benefit from the innovation systems perspective, since sectoral roadmaps have, as main goal, the development of industrial sectors within a predefined time horizon. The technological innovation systems perspective highlights the creation and diffusion of technologies within specific industrial sectors (Carlsson and Stankiewicz, 1991). Also, the sectoral innovation systems perspective highlights the importance of sectoral characteristics for the creation and diffusion of innovations (Malerba, 2002). In this sense, one could infer that – in essence – the main purpose of sectoral roadmaps and innovation-oriented roadmaps is the development of technological innovation systems within a geographical boundary. If we depart from this premise, the drivers of a technological innovation system (i.e. the system functions) could be of use for technology roadmaps by delivering a future-oriented vision of how each function should be developed. The structure of the proposed functions-based roadmap is presented in Fig. 1. This roadmap depicts how to combine the functions approach with the roadmap approach.

In such functions-based roadmap, the functions serve as drivers (enablers) for the development of the technological innovation system at hand. Especially, it could prove very useful when developing 'emerging' technological innovation systems, that is, cases where the sector, technology or both are new to the market, such as environmental innovations or inexistent sectors in a region (in Section 5 we provide a case study from Brazil, which aim is to demonstrate how the functions-based roadmap can be utilized for developing a future-oriented analysis in order to incentivize the creation of an industrial sector within a region). Similar use of the 'functions approach' in sectors can be found in Gabaldon-Estevan and Hekkert (2013).

The functions of innovation systems offer a systemic perspective in relation to previous roadmaps structures. In this sense, entrepreneurial activities (F1) for instance, integrates elements from technology and market; while knowledge development (F2) is more focused on technology and R&D. Other functions, such as guidance of the search (*F*4) and resource mobilization (F6) offer an integrative view of policy instruments, regulatory changes and human and financial resource allocation.

By integrating the system functions as drivers of technology roadmaps, the analyst is capable of tracing individual function-by-function dynamics over time (i.e. how each function evolves over time, and therefore how the system evolves over time), enabling enhanced future-oriented analytical capability. Moreover, the functions-based roadmap addresses local and global interdependencies between the functions and throughout the time span (i.e. the evolution of a specific function influences the evolution of other functions across the time horizon).

On a broader perspective, the integration of innovation system functions into foresight studies and policy analysis has already been proposed. In this stream of research, Alkemade et al. (2006) shows the use of functions helps bringing insights about the patterns of success and failure related to emerging technologies. More recently, Andersen

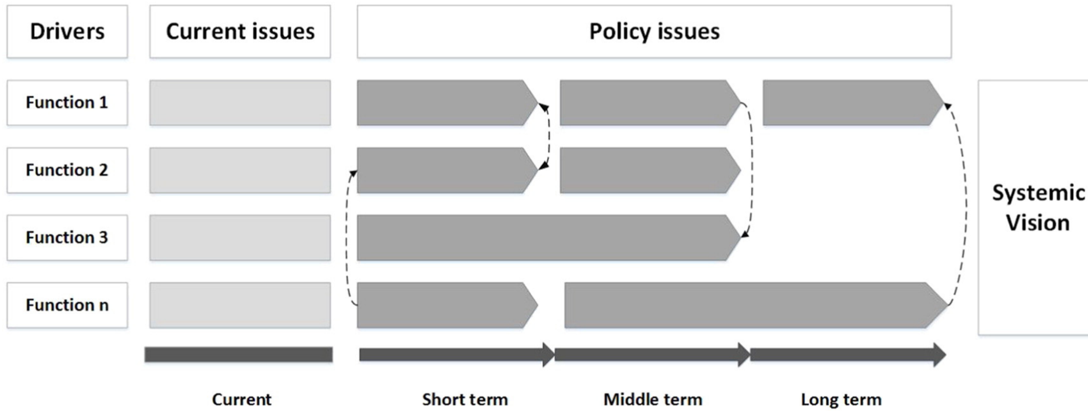

Fig. 1. Generic structure of a functions-based roadmap.

and Andersen (2014) have suggested the use of the 'functions approach' as means to operationalize the concept of 'innovation system foresight', a theoretically-based integration between the innovation systems framework and foresight. According to them, functional analysis can help in identifying weaknesses in the system that, in turn, can inform the foresight process for normative measures (Andersen and Andersen, 2014). The details of how to integrate the 'functions approach' with 'innovation system foresight' are beyond the scope of this article and are left for future work.

In this sense, the development of integrating the 'functions approach' with foresight in general, and roadmapping in particular is still an on-going process, an outcome of several research projects realized at the Federal University of Santa Catarina in Brazil. In Section 5 we introduce a case study which aim is to demonstrate the usefulness of integrating the 'functions approach' with the roadmapping approach.

4. Overview of the functions-based sectoral roadmap process

The process to design a functions-based sectoral roadmap has four main stages: (i) planning; (ii) functional analysis; (iii) workshops; and (iv) roadmap (see Fig. 2).

4.1. Planning

In this stage the roadmap purpose is defined, including its scope, participants and schedule, as well as the roadmap architecture and time frame (as explained before, in our case, the dimensions of analysis are the functions of the system – i.e. the horizontal layers of the roadmap).

4.2. System functioning

In this second stage, we map the current "functionality" of the system under analysis as well as the key actors, networks and institutions (i.e. the structural components of the system). We used bibliographical sources of interest as well as in-depth interviews with eight experts from industry and academia. In this sense, this stage serves as an initial assessment of the current performance or state of the sector.

4.3. Workshops

The workshops serve to go beyond what the initial set of experts and our literature review identified. In this stage, we gathered a pool of 60 plus experts from industry and academia and worked with them in small groups throughout four workshops. The main aim of this stage was to 1) validate our functions analysis of the current state; 2) build likely paths for each function in order to achieve the future (desired) state of the sector and 3) identify mega-trends that should serve as inducing or blocking mechanisms for the evolution of each system function. The detail of each workshop can be found next:

- Workshop 1: the results of our functions analysis were shown to the experts with the aim to validate them and to begin the future-oriented analysis from that point.

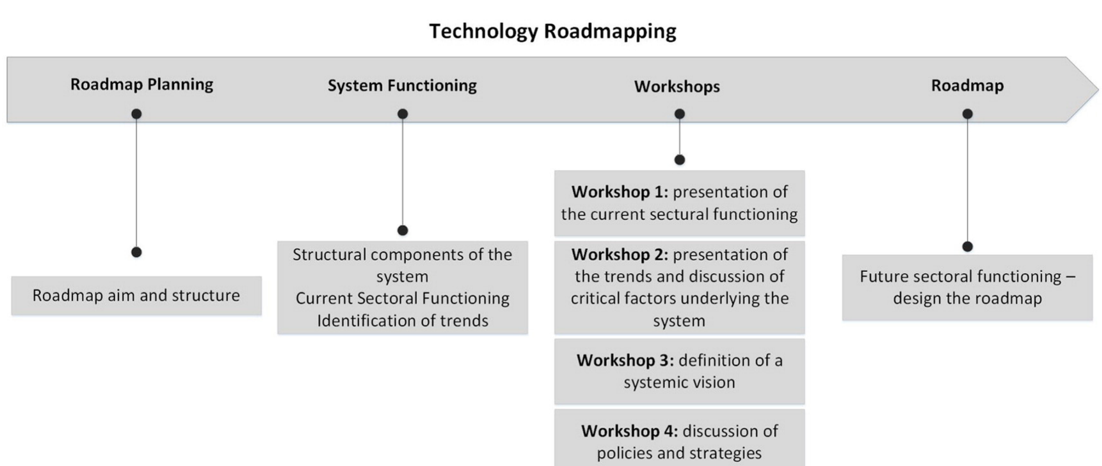

Fig. 2. Outline of the roadmapping process.

- Workshop 2: The mega-trends were identified and then the experts were invited to point out the critical issues concerning the sector under analysis. In this sense, these workshops offers an opportunity for reflection about the current and future opportunities and threats that may influence the sector.
- Workshop 3: Experts, through a brainstorming, defined the working vision for the roadmap: "An integrated, developed and technologically sustainable automotive sector value chain".
- Workshop 4: in order to mitigate the weaknesses and enhance the strengths to achieve the desired working vision – defined in the previous workshop – the last workshop involved all experts into a deep reflective process in which key strategies and policies were proposed.

4.4. Future sectoral functioning – the roadmap towards 2022

In this final stage, the team gathered to summarize the main findings of the four workshops, in order to aggregate and synthesize them on the roadmap. The roadmap depicts the current functioning but also shows the evolving paths identified by the experts for each function and in doing so, it defines the main tasks and actions needed towards the timeframe to achieve the working vision for 2022.

5. Case study: roadmap of the automotive sector in Santa Catarina, Brazil

5.1. Background and current sectoral functioning

The case study aims to demonstrate the usefulness of integrating the 'functions approach' with the roadmapping approach. It depicts the experience in developing a roadmap for the automotive sector in Santa Catarina, Brazil. Commissioned by the Industry Federation of Santa Catarina (FIESC), the purpose of the Automotive Roadmap was to build a planning tool for establishing an automotive sector in Santa Catarina until 2022 but more importantly, to identify the key tasks needed to make it possible along the way. As of 2014, when the project was carried out, Santa Catarina accounted for a very little share of industrial activity in this sector, mainly through manufacturing firms supplying auto parts and other byproducts to auto manufacturers outside Santa Catarina (FIESC, 2013).

In this sense, the roadmap had to account for all key dimensions needed for the sector to grow: firms and suppliers, government support, R&D labs, infrastructure, skilled human resource availability, legislation and other institutions and so on. As previously stated, we used the system functions as the key determinants to map the current state of the sector, using data from relevant literature and expert interviews, the functions mapped were:

- F1 – Entrepreneurial activities
- F2 – Knowledge Development
- F3 - Knowledge diffusion through networks
- F4 - Guidance of the search
- F5 - Market formation
- F6 - Resources mobilization
- F7 - Creation of legitimacy

In the following paragraphs we will address each of the functions above.

5.1.1. F1 – entrepreneurial activities

This function looks upon new entrants and/or incumbents interested in diversifying their businesses. Currently, Santa Catarina is experiencing the entry of world manufacturing leaders, mainly GM, BMW, Sinotruk, LS Mtron and Pezzaioli. The new plant of BMW is the first one in South America and received much attention from local press. The setting up of BMW was in part a strategic move from the Government of Santa Catarina which offered several incentives to attract the German Auto Manufacturer.

On the other hand, only a handful of incumbents are moving towards diversification in the sector. A case example is WEG Inc. which initiated a new R&D program to prototype traction technologies as alternative to mass transit and energy sources.

Moreover, the largest share of original equipment manufacturers (OEM) is absent. For instance, there are no cold forming technology competencies, nor electric traction and other byproducts. Overall, there is a lack of incentives, excluding cases such as BMW; high installation costs and poor road infrastructure, issues that are discouraging for new entrants, as pointed out by the experts interviewed.

This assessment lead us to qualify this function's performance as poor.

5.1.2. F2 – knowledge development

Our study encompassed only R&D activities, since no data on patents was available at the time. This function's performance is also poor, since there were only a few relevant R&D projects going on by WEG, related to electric traction technologies and alternative sources of energy and funded by Federal Agencies (FINEP and BNDES). Experts signaled the lack of research funding and incentives to develop R&D in key fields such as emissions control, embedded sensors and cold forming.

5.1.3. F3 – knowledge diffusion through networks

The way firms have found to collaborate with other agents is through joint projects. However, regulation and legislation barriers hinder collaboration and are current issues affecting this function. Despite this, some important networks do exist, such as the one between SENAI[2] and MIT which aims at developing technology and products focused on embedded systems (FIESC, 2014). Another important network in Santa Catarina is SAE Brazil,[3] a non-profit association of engineers, executives and technicians with the purpose of disseminating knowledge and techniques in mobility. The regional chapter of SAE Brazil Parana and Santa Catarina organizes competitions, symposiums and forums about mobility.

Also, much of knowledge diffusion, not only in Santa Catarina but also in Brazil, comes through benchmarking. Many state companies seek to exchange information with companies from North America and Europe, in order to adapt their products to the Brazilian market. Moreover, since some fields are small, such as cold forming technology, Brazilian firms are obliged to seek partners abroad.

5.1.4. F4 – guidance of the search

The sector is guided through its institutional set-up, mainly international and national standard certification programs. The main barrier here is to increase the speed at which firms comply with such standards. Some important international standards are: ISO 9001 (quality), ISO 14001 (environmental management), ISO 16949 (quality management for the automotive industry) and the EURO 5 (environmental legislation focused on trucks and buses to reduce the impact of emissions of pollutants). As standards evolve so does the pressure on renewing compliance, for instance, the new standards EURO 6 and the Labor Safety Standard NR-12 for local firms. The key issue here is the lack of certain certifications and certification institutes in Santa Catarina, which hinder the potential capacity of producing competitive automotive products at the international level.

5.1.5. F5 – market formation

The increasing pressure of national and international environmental legislation, like EURO 6 and ISO family of standards, cited in F4, improves the chances of the development of new environmental

[2] National Industrial Training Service (SENAI) is one of the branches of FIESC

[3] http://www.saebrasil.org.br

technologies. Some firms have been researching how to adapt their products to meet the new environmental standards. However, most of them use private resources due to the lack of incentives and excessive bureaucracy to get public funding.

The government has developed some programs focusing on the development of innovation and tax incentives. A highlight is the Incentive Program for Innovate-Auto (2012), which aims to increase the competitiveness of the automotive sector by investing in the supply chain, R&D and production of more fuel-efficient and safest vehicles. The incentive is valid until 2017.

Another initiative of specific tax regimes for new technology is the Law 11.196/2005, known as the “Goods Law”. Some manufacturers in the sector in Santa Catarina have been benefiting from it to incorporate new technology in their products.

Although there are incentive programs that could leverage the automotive industry, bureaucracy discourages firms to use these incentive programs. Consequently, it undermines the formation of a niche market for the sector in Santa Catarina.

5.1.6. F6 – Resources mobilization

There are a number of Federal Programs to fund R&D activities in the automotive sector: the “Greater Brazil” Program, which aims to support capacity building projects and development of suppliers in the auto parts sector in several Brazilian states, including Santa Catarina; BNDES, the Brazilian Development Bank, which offers special loans programs for auto manufacturers, such as ‘urban mobility’. And FINEP (the Brazilian Innovation Agency) also offers funding for R&D activities. However, most procedures are bureaucratic and this, in part, has discouraged most firms in the sector to use these resources.

In terms of human capital resources, there is a lack of qualified personnel in the automotive sector. Very recent initiatives have lead to open up a new engineering program specifically designed towards automotive manufacturing at UFSC in 2014. Other agents such as SENAI and UDESC have developed technical courses aimed at building capacity in the sector but still it's low.

5.1.7. F7 – creation of legitimacy

At the moment the study was made, there were no relevant legitimacy efforts. It's safe to say the study commissioned by FIESC (out of which this article was elaborated) is perhaps the most important legitimacy action in recent times. Although, at the national level, unions such as Sindipecas and Abipecas have been very active in lobbying about the importance of the sector and the threats of new entrants such as manufacturers from China and Korea.

5.2. Future sectoral functioning – the roadmap towards 2022

Considering the working vision for the roadmap, targeted towards the year 2022 was “An integrated, developed and technologically sustainable automotive sector value chain”, the development of the future or desired state of the sector was driven by actions leading towards a ‘better’ functioning of the system as a whole. In this sense, the roadmap depicts how the functions should evolve in the long term.

By taken into account the current functionality and mega trends, experts identified the current issues for each function (as of 2014). For each issue, the roadmap develops possible paths in order to achieve the ‘desired’ future state of the system. The roadmap is shown in Fig. 3: the gray pentagons represent actions to-be developed, whereas white dotted pentagons represent actions affecting two or more functions, showing the interdependence between them.

In addition, the expert panels lead to identify mega-trends for each system function for the coming years. They served to drive the evolving paths for each function towards the challenges the sector will face in the mid to long term. The mega-trends are shown in Table 3.

In the following paragraphs, we briefly describe how each function should evolve in the near future (time horizon 2022), based on our field work.

5.2.1. F1 – entrepreneurial activities

The main current issues related to entrepreneurial activities, have to do with a lack of suppliers, OEMs and auto manufacturers on the one hand, and infrastructure on the other.

In terms of firms, the roadmap points out to the need to increase, both the number of new entrants in the sector as well as the technological competencies and capabilities of incumbents. One key policy instrument is to offer tax incentives to encourage a higher intensity of entrepreneurial activities, mainly to address some of the mega-trends in the sector, namely, cold forming technologies, traction technologies and electric engine technologies. This path also influences F5 (market formation) and F6 (resource mobilization) functions.

In addition, a higher number of incumbents in the sector may lead to creation of stronger clusters and other types of agglomerations, increasing the functioning of F3 (knowledge diffusion through networks) and the lobby power of the sector in F7 (creation of legitimacy).

5.2.2. F2 – knowledge development

Actions within the functions should direct an increase in R&D activities, mainly through tax incentives (F6) in the fields of embedded sensors, cold forming and greenhouse gas emissions reduction. In the long term, such new investments and incentives should increase the rate of R&D projects and patenting, leading to the creation of specialized labs and R&D centers in Santa Catarina.

5.2.3. F3 – knowledge diffusion through networks

This function was the most discussed in terms of actions and policies. Most actions referred to establishing a stronger network with national and international partners in different settings. First, to increase technology transfer from abroad, in order to reduce the technology gap which is present nowadays. Second, to increase knowledge transfer, through courses, training and other competence building efforts. Third, to strengthen the relationship with public organizations in order to develop public-private partnerships in different issues such as road infrastructure, alternative energy sources or other ones relevant for the sector. All these actions in the long term will lead towards higher interaction between industry, academia and government in R&D, competence building and public-private partnerships.

5.2.4. F4 – guidance of the search

The main concerns within this function were related to developing stronger institutions within the standard and compliance setting. Experts identified as critical the need for firms and public organizations delivering specialized services related to quality, noise and other certifications. Also, the need for larger number of specialized labs for testing, as an example of the current technical infrastructure in Santa Catarina in metrology.

In addition, agreements with international organizations are needed, in order to increase certification services in Santa Catarina. Experts recalled recent noise reduction and emissions control certifications and the lack of expertise in offering such services in Santa Catarina.

5.2.5. F5 – market formation

The approach taken to increase the performance of this function was to look for the means to increase a number of market mechanisms, mainly through tax incentives. These mechanisms should, in the long term offer better market conditions for producers, but also for consumers as it is expected to increase technological competencies in environmental technologies, such as electric engine vehicles, noise reduction technologies and GHG emissions reduction.

In this sense, more attention should be given to the creation of partnerships with universities and research labs in order to develop such

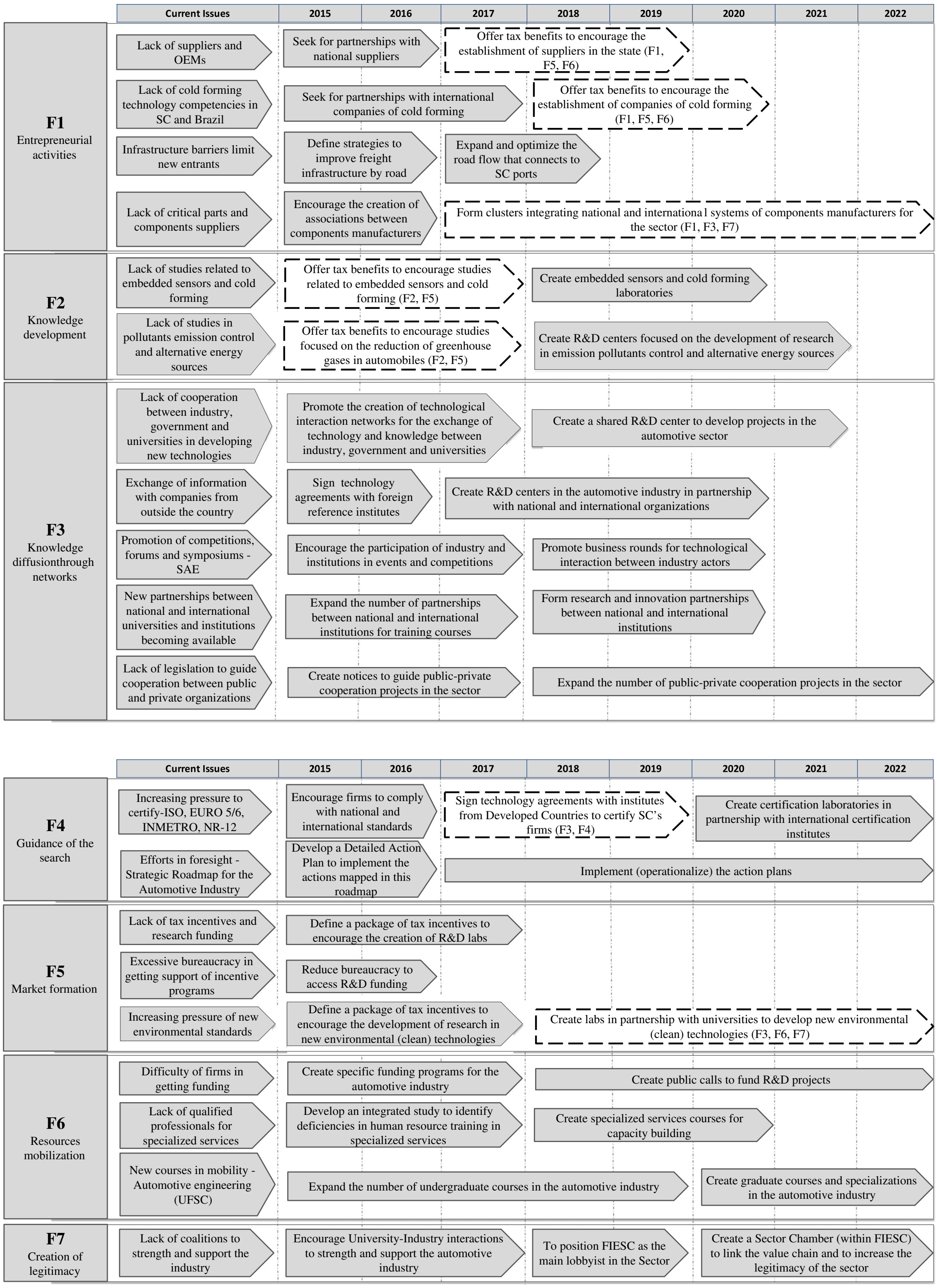

Fig. 3. The functions-based roadmap for the automotive sector in Santa Catarina.

technologies. Such policies will increase as well the 'functioning' of knowledge diffusion (F3), resource mobilization (F6) and creation of legitimacy (F7) as such 'clean' technologies should change the overall image of the automotive sector for consumers.

5.2.6. F6 – resources mobilization

Resource mobilization will clearly depend on the policies defined in previous functions. For instance: 1) the need for tax and other incentives for incumbents and entrants; 2) efforts towards increasing

Table 3
Mega-trends for the automotive sector of Santa Catarina per function.

	Mass transit
	Autonomous systems
	Variety of combinations and attributes offered to customers
	Compact, efficient, safe and silent vehicles
	Interior design
	Electric and hybrid vehicles
	Electric traction in mass transit
*F*1	Enhancement of infrastructure and service standards
Entrepreneurial activities	Automated infrastructure
	Rigorous emission control
	Alternative energy sources
	Noise reduction
	Recycling of parts and reverse logistics
	Energy sources applied to hybrid or exclusive propulsion technologies
	Advanced systems for vehicle safety
F2	Integrated electronics
Knowledge development	Energy recovery systems
F3	
Knowledge	
Diffusion	University-Industry Interactions
*F*4	
Guidance of the search	Certification services for compliance with new and evolving standards
	Reduction of greenhouse gas emissions
	Green Design
	Rigorous regulatory policies and legislation
F5	Taxation systems to streamline high congestion periods
Market formation	Legislation focused on the reduction of environmental impact
	Increased need of technicians and engineers
F6	Opportunities related to professional training
Resources Mobilization	Qualified human resources with communication skills and team playing skills
F7	
Creation of legitimacy	Entry of new auto manufacturers may lead towards higher lobby power

technical and managerial competencies of human resources and 3) tax incentives and other sources of funding to develop technological capabilities through new R&D labs in fields of interest (noise reduction, GHG emissions control, alternative sources of energy and others). But also, according to experts, State and Federal Governments will need to understand and support such policies, in joint effort with firms through public-private partnerships and through specific funding sources for the sector.

5.2.7. F7 – creation of legitimacy

Last but not least, legitimacy should be nurtured through the collective action of many key actors, such as unions and FIESC – the Industry Federation of Santa Catarina. More specifically, FIESC plans to continue lobbying with State and Federal Agencies about the strategic importance of the Automotive Sector for Santa Catarina. In the long term, a Chamber for the Auto Sector will be created, with the aim to keep developing projects and actions to develop the sector.

The roadmap outreach event took place with the participation of multiple **actors** of the automotive industry. This event included the presentation of the final report and its validation.

6. Discussion and conclusions

As mentioned at the beginning of the paper, our aim was to introduce the 'functions of innovation systems' as drivers within the roadmapping process (i.e. as layers of the roadmap). The rationale behind the use of the 'functions approach' lies in i) the notion of functions as 'drivers' of innovation systems, as pointed out by previous literature; and ii) in the notion of sectoral roadmaps as being visual representations of how a sector evolves – or should evolve – over time, with a main focus on the generation and diffusion of technologies and innovations (i.e. sectoral roadmaps depict essentially technological innovation systems). Furthermore, the need for a 'systems perspective' has been recently discussed within the roadmapping literature (see for example, Ahlqvist et al. (2012) and Saritas and Oner (2004)) leading to the need for contributions in this stream of research.

The paper exemplified the use of the 'functions approach' as drivers of a technology roadmap by presenting a case study in Southern Brazil. The case study served to show how each function should change/evolve over time, in order to reach the long-term vision of the roadmapping exercise.

Our findings can be split into two groups, findings about our overall proposal, i.e. to integrate the 'functions approach' to sectoral roadmaps; and findings specific to our case study.

In terms of the first group, the use of the 'functions approach' as focusing device, led to a better understanding of how actors are related and how they should be related, for example, the need to provide tier-1 and tier-2 suppliers for the emerging auto sector, besides the already existent tier-3 suppliers.

The systems view also helped in identifying the key technologies that will be important in the future, and how the actors should prepare to acquire - externally - or to develop - internally - such technologies. It also helped in identifying the institutional set-up of the sector, i.e. current technical and economic regulations that shape and steer technology and innovation efforts in the sector. Moreover, the 'functions approach' helped in identifying key actors, technologies and the institutional set-up and in grasping the dynamic character of the sector by looking at how they relate to each other.

In terms of the second group of findings, assessing the current functioning of the automotive sector in Santa Catarina led to identify its weak state, due to the lack of original equipment manufacturers (OEMs), suppliers, networks and institutions. It also helped in building a shared vision by key stakeholders, i.e. a shared understanding by experts and industry representatives concerning the path the auto sector should follow in the long term.

By assessing how each function should evolve/change over time, key stakeholders were able to identify both strengths and weaknesses.

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Strengths served to deliver insights on how to benefit from them in the long term; weaknesses, on the other hand, served to develop specific short, medium and long-term work plans that will be implemented throughout the roadmap time span. In addition, the roadmap's visual nature helped in showing clearly how and when each work plan should begin and end, enabling easier individual project management.

Furthermore, the integration of FTA techniques, such as sectoral roadmaps with the innovation systems approach opens up possibilities for further studies seeking to discuss novel streams of literature, such as the so-called 'innovation system foresight'.

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