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Integrating sustainable value thinking into technology forecasting: a configurable toolset for early stage technology assessment

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ABSTRACT

There is an urgent need for technology development to make a sustainable or restorative contribution to the environment, with its inherent links to society and societal welfare. Forward-looking activities, such as firm level technology forecasting and technology intelligence, are increasingly important in providing positive impact that is complementary to policy level interventions. However, selecting and implementing appropriate approaches to conduct these activities and quantifying their value contribution is still difficult. This article seeks to demonstrate how technology opportunities may be explored more effectively by combining existing methods for assessing new technology and identifying sustainable value, in an approach for industry that is both configurable and practical while delivering tangible benefits. It details the two-year university-industry collaboration and testing of a configurable toolset, based on four templates used in a workshop setting. Results indicate that the toolset has successfully probed technological, environmental and social capabilities, promoted the selection and implementation of an appropriate approach and led to the quantification of value through the inclusive, transparent and documented assessment of technology opportunities and the tangible actions identified. In summary, the toolset supports company employees in realising a measure of prospective sensemaking, which is a key deliverable from forward-looking activities.

Keywords (6): sustainable value; management tools; technology assessment; prospective sensemaking; corporate foresight; technology forecasting.

1. INTRODUCTION

Corporate technology investments affect firms and their performance as well as their supply chains, the environment and society in a broader sense. Given their long-term effects, introducing sustainability thinking at early stages of the technology assessment seems not only relevant but also imperative. Technology and business contexts have a strong influence on a firm's economic, environmental and social impacts (Taticchi et al., 2013); thus, early consideration of the long-term impact on environmental and social aspects needs to be integrated into innovation processes for new technology development so that companies are able to look forward and plan more effectively. This aligns with the call for a sustainability vision that provides a roadmap and forward-looking guidance - in terms of organisational priorities, technology development, resource allocation and business model design - to identify business strategies and practices contributing to the creation of sustainable value for the firm (Hart and Milstein, 2003).

The Technology Futures Analysis (TFA) field involves technology intelligence, technology forecasting, roadmapping, technology assessment and technology foresight (Porter et al., 2004). Technology foresight and technology assessment are widely understood as public sector activities, while technology forecasting and technology intelligence are seen as private sector activities. However, roadmapping (Phaal et al., 2004) is well accepted in both arenas and recent literature suggests that company level technology assessment (Tram and Daim, 2008) and corporate foresight (Rohrbeck et al., 2015) are terms that are gaining wider acceptance. Forward looking activities using corporate level methods can perhaps influence sustainable value creation more directly by changing viewpoints within companies and thus affecting the innovation process.

This article proposes a light-weighted, flexible and non-quantitative approach to integrate sustainability thinking at early stages of technology development to support more effective forward looking activities within the firm. This aligns with researchers' calls for practical support in technology commercialisation (Evans and Nichols, 2010; Huang et al., 2016) and for approaches that make a clear contribution to long term industrial sustainability (Smart et al., 2017; Evans et al., 2017a). It illustrates how technology exploitation opportunities can be explored in greater depth by bringing together existing methods for the identification of sustainable value and the assessment of new technology into a practical and configurable forward-thinking toolset developed with and for industry. The toolset is flexible in nature and allows navigation of the technology assessment from either technology pull or marketing push perspectives. The challenges in the adoption and use of management tools and the significance of university-industry collaborations in developing and applying them are also addressed.

This article first describes the research context and background. It then presents the research design and methods, and the findings illustrated by industry engagement and collaborations. The article concludes with a discussion of findings, including organisational impact and process learning, along with implications for improving technology innovation processes to include environment and social elements at the early stages, and further implications derived from this research.

2. RESEARCH CONTEXT

2.1. Forward-looking activities in the firm

Research is increasingly recognising that forward-looking activities such as roadmapping, technology foresight and technology assessment are often carried out within companies as well as at policy level (Phaal et al., 2004; Rohrbeck and Germunden, 2011; Tram and Daim, 2008). Roadmapping activities in companies have evolved from early applications in Motorola (Willyard and McClees, 1987) and Philips (Groenveld, 1997) which inspired later work. Fast-start methods for product-technology roadmapping (Phaal et al., 2001) and strategic roadmapping landscapes (Phaal et al., 2007; Savoiz and Blum, 2002) soon developed, supported by activities such as technology intelligence. Variants such as value roadmapping for exploring early stage value opportunities (Dissel et al., 2009) and scenario roadmapping as technological foresight (Hussain et al., 2017) have also been proposed.

Corporate foresight builds on existing management research in three main areas – managerial cognition, forward-looking search and prospective sensemaking (Rohrbeck et al., 2015). Quantification of the value contribution of the corporate foresight process remains an issue as explored by Boe-Lillegraven and Monterde (2015) who reviewed the cognitive value of a technology

radar process. They emphasise looking at process measures rather than more traditional outcomes and found value in terms of connections made externally and across functions or departments as a mechanism to change mindsets. Discrepancy between individuals' expectations and experiences (Maitlis and Christianson, 2014) and exposure to technology features (Griffins, 1999) are key triggers for sensemaking. Sensemaking is important for learning in organisations and is accomplished by enabling other organisational processes and outcomes, e.g. strategic change (Maitlis and Christianson, 2014). Prospective sensemaking underlies activities associated with planning and initiating change in organizations, reinforcing fundamental organizational processes (Stigliani and Ravasi, 2012).

Technology assessment within companies is sometimes termed inverted technology assessment (Coates and Fabian, 1982) to contrast it to policy level activities and can include cost benefit analysis, information monitoring, surveying, decision analysis, technology measurement, roadmapping, scenario analysis and Delphi, mathematical models, synthesis methods, technological attribute–application tables and patent reviews (Tram and Daim, 2008; Lee et al., 2014). Practical guidelines are also available. For example, Lindsay (1999) takes the technology audit angle and proposes assessing and evaluating the market significance or potential of different technologies, to compare to the organisation's competitive position in these technologies using linked grids. In contrast, Liao and Witsil (2008) suggest reviewing the opportunity in terms of the technology itself (early stage or later stage, i.e. basic or applied R&D), the technical or management team, the market and the financial opportunity before selecting from a range of appropriate tools.

This work suggests that while aggregate level TFA activities can set the broader national or sectoral context, corporate level activities can complement these by their more direct influence on organisational behaviour and innovation processes.

2.2 Sustainability integration issues

Industrial sustainability advocates for a generative, restorative and net positive economy to advance environmental and societal well-being (Smart et al., 2017). A sole company in isolation cannot accomplish system-level sustainability. Individual companies can achieve firm-level sustainability through their own internal capabilities, while contributing to make sustainable the whole system they are part of through stakeholder collaboration (Stubbs and Cocklin, 2008). There is unanimity among scholars across disciplines on the importance of taking a holistic approach to address sustainability in businesses. Van Marrewijk (2003) proposes synergistic and holistic interpretations of corporate sustainability based on well-balanced, functional solutions creating value in economic, environmental and social dimensions in a win-together approach with relevant stakeholders, and based on embedding sustainability in every aspect of business operations, respectively. Evans et al. (2017a) delineate a systemic view of sustainable value flows among multiple stakeholders which hold interests and responsibilities for mutual value creation. Taticchi et al. (2013) outline the need for sustainability initiatives that extend along the product and service lifecycles and to all business functions including R&D, product development and procurement. From a social sustainability perspective, a wide-ranging evaluation should consider four dimensions at firm and system levels, i.e. internal human resources, external population, stakeholders' participation, and macro-social issues (Hervani et al., 2017).

According to Paramanathan et al. (2004), technology management practice can potentially support sustainability in several areas e.g. sustainability strategy and long-range planning, environmentally sensitive design and product development processes, and technological knowledge sharing. They also see scope for embedding sustainability into different technology management processes. The study done by Calabrese et al. (2019) provides empirical evidence of the relevance of technology management activities for sustainability integration in strategic decision-making and planning.

Incorporating sustainable value thinking into technology assessments seems relevant to work towards overcoming current negative impacts of industrial activities. Although several studies address the assessment of cleaner or more sustainable technologies (e.g. Söderholm et al., 2019; Daim et al., 2009), there are limited works on technology evaluations for sustainability. These works are mostly based on Life Cycle Assessment (LCA) methods and focused on the environmental impacts of introducing a specific, already developed, technology into companies' products or processes (Cerdas et al., 2017; Gavankar et al., 2015; Dewulf and Van Langenhove, 2005). However, innovations often involve the application or development of new technologies whose impacts are not well known. Prospective LCA methods have been used once the technologies are in early stages of development, e.g. small scale-production, thus, a future scenario can be modelled (Arvidsson et al., 2018). At early stages of looking at technology opportunities, there may be a lack of quantitative measures as well as a lack of knowledge on what environmental and social impact categories would be affected, and on who may have a stake in the technology. These limitations could be addressed by more adaptable methods, easy to use by practitioners and based on qualitative assessments rather than quantitative. Therefore, to answer these questions, a multi-stakeholder, practice-oriented and qualitative approach needs to be taken.

2.3. Development, adoption and integration of management tools

In this article, we address the collaborative development of a configurable set of management tools appropriate to forward thinking activities with limited data in uncertain circumstances. These tools are made up of templates and structured prompts to help companies brainstorm, cluster and select ideas and activities to help clarify the way forward. Stigliani and Ravasi (2012) suggest that prospective collective sensemaking builds on cycles of cognitive work performed by groups of individuals going back and forth through selected material artefacts, categorising and interpreting information, and engaging in retrospective reflection of emerging narratives.

There are several issues related to this type of tools, including their development, integration and successful adoption and use. Their adoption and use have been reviewed by Hidalgo and Albers (2008), who state that there is no one-to-one correlation between a firm's specific business problem and the methodology that solves it. Due to the deeply context specific situation presented by engagement in real industrial circumstances, Mortara et al. (2014) hold that, if seeking classify tools in any way, it is necessary to consider instances of 'tools-in-action'. They discuss the iterative dynamic between specific tool application in one situation and generic tool abstraction to support diffusion of learning to a new situation.

Combining such tools into toolkits involves an even wider range of issues. Kerr et al. (2013) discuss operationalised principles for deciding the form, function and features of potential tools to aid decision-making and state that *"a core set of powerful, flexible, scalable and modular tools should*

suffice to allow generation, exploration, shaping and implementation of possible solutions, that are configurable and implemented in a light-weight manner". In addition, Phaal et al. (2006) describe the process of developing useful tools and toolkits through *"active collaboration with industry, working together on live management problems and challenges"*. This collaborative approach has been illustrated in two publications which use roadmapping as a platform for developing innovation toolkits, one in a multi-company setting (Farrukh et al., 2014) and one in a single company setting (Kerr et al., 2017). One way to avoid tools and toolkit proliferation is to work towards an integrated toolkit (Phaal et al 2006; Foden and Berends, 2010) and then use sub-sets of these tools, or toolsets, selected from the cohesive whole. For example, with a core of roadmapping, portfolio matrix and linking grids (Phaal et al 2006; Oliveira and Rosenfeld, 2010; Kerr and Phaal, 2015) further tools can be seen as populating key related aspects while maintaining consistent levels of analysis and integrity of information flows.

3. EXISTING TOOLS USED AS A BASELINE

Quantitative approaches are useful in answering questions about exploitation potential when data is available; however, more qualitative approaches are useful when data is scarce or unreliable, especially at early stages of technology development (Goffin and Mitchell, 2017). Therefore, the focus for the initial baseline tools was on qualitative tools. This excluded LCA-based tools as they rely on quantitative data availability, even for streamlined LCA (Bocken et al., 2012). Four existing tools were selected on the basis of the nature of the tools themselves and whether they would combine well into an appropriate toolset:

- Nature of the tools – supporting the broad evaluation of in-company assessments of sustainable technology opportunities by using visual, exploratory and participatory methods in the form of templates (Phaal et al., 2016); and individually powerful (Kerr et al 2013).
- Complying with principles for developing strategic technology and innovation management toolkits - human centric, workshop based, neutrally facilitated, lightly processed, modular, scalable and visual (Kerr et al., 2013).

Marketing, innovation, and technology management fields provide strong foundations for research on sensemaking activities due to their relations to technology features and technology understanding (Griffins, 1999). Template-based tools within these fields provided a good basis for the toolset, which was complemented with a template-based tool from the sustainability field. Other qualitative tools for sustainability assessment include checklists and directional tools based on product life cycles (Bocken et al., 2012). We identified a sustainability template-based tool bringing together multi-stakeholder and sustainable value perspectives. The tools selected as potentially complementary candidates are briefly discussed below.

3.1. Marketing Process for Technology

Three tool templates were combined in a Marketing Process for Technology (Farrukh and Athanassopoulou, 2014) and the development and use of these is described below.

a) Benefits Mapping template – linking technology/marketing opportunities

A key step in identifying potential opportunities is to find the overlap between what the technology can do and what problems (or needs) can be solved (Probert et al., 2013). One approach to do this takes the form of a detailed technology function mapping process as proposed by Felkl (2013) who draws upon previous work by Evans and Nichols (2010) to propose an approach to support commercialization before or in the early stages of the new product development process. Higher level benefits mapping is discussed in consultancy websites (<http://realisor.com/>) and project management literature (Jenner, 2018) as part of successful change management projects, and benefit maps are described in detail by a number of authors (Thorp 1998; Bradley 2016; Ward and Murray 1997). They are often based on 'how-why' question logic with 'a left to right flow', from enablers, to business change, to benefits, with headings that cover Technology, Changes, Outcomes, Benefits, Investment Objectives and Drivers (e.g. <http://www.772consulting.com/>). These approaches informed the development, and testing in industry workshops, of a Benefits Mapping template to support commercial and technical discussion around a technology opportunity.

b) Structure of the Industry Mapping template

Research in emerging industries (Routley et al., 2011) and markets for new technologies (Maine and Ashby, 2002) suggests that the structural and historical development of current industries can guide where a new technology can find either a short term niche or a disruption point in an industry value chain. However, without considering the full range of possible initiation points it is difficult to decide which might be the most advantageous place to start. The industry structure analysis developed from work with manufacturing start-ups (Dworschak et al., 2011; Lubik et al., 2011) breaks down an industry supply chain into its constituent parts and spells out what this means at each stage in terms of key players and the potential value added by the new technology. Through later use in a project with an SME looking to develop markets for a new technology, an additional layer was added, prompting specific consideration of the route to market. Subsequent use of the revised template with a large organisation resulted in a breakthrough in how to approach a new market with an existing technology.

c) Performance Dimensions Mapping template

Breaking down a technology offering into several parts and considering how the importance of these parts may change for differing markets and/or applications is a useful exercise for structuring further development actions. In linking the technology to market drivers the push-pull dynamics were first considered in terms of linking layers in a product technology roadmap (Phaal et al., 2001) and in a more general sense within innovation overall (Herstatt and Lettl 2000). The search for solutions is facilitated by considering what 'performance dimensions' a technology can enable within an application space before becoming concrete about a particular product, process or service. A practical tool for plotting such factors was found in Quality Management related work (e.g. Basu 2004) where spider web plots are used to compare levels of achievement before and after operational interventions. Hence, the plots can be used to compare the performance of a new technology against existing technologies or their applications in defined markets, to see where the new technology has strengths and weaknesses. This template can also be used in roadmapping workshops to prioritise technology development (Farrukh et al., 2017).

3.2. Roadmap-Portfolio Toolkit

Three tool templates were combined in the Roadmap-Portfolio Toolkit (Farrukh et al., 2014). A number of practical tools to help align technology investment with business objectives exist, although useful and effective tools such as roadmapping and portfolio matrices are often not used outside major strategic initiatives or in smaller companies. They are seen as being difficult to select, configure and combine, and as resource consuming. The Roadmap-Portfolio Toolkit is an effective and light-weighted intuitive approach that supports the development and implementation of innovation strategy by selecting and exploring innovation opportunities. Drawing on literature and practice, the workshop was developed around three key templates and run in eight companies (four small companies and four units of larger companies) and the approach was refined using learning from each application. The key workshop templates were the Opportunity Definition template, the Portfolio Matrix template and the Opportunity Exploration template. The toolkit delivered valuable insights to companies, many of whom planned to use or adapt it for themselves in further workshops. Learning highlighted that advance framing of the workshop with the participants is very important. From a practical perspective, companies can obtain value from light-weighted interactions if prepared correctly, however one workshop does not create a whole innovation strategy. It demonstrated that efficient, pre-configured toolkits are usable, useful and functional when packaged as a template-based workshop process and to support, not replace, wider strategic discussions and decision-making (Farrukh et al., 2014).

3.3. Value Mapping Tool

The Value Mapping tool was developed to *“elicit failed value exchanges among multiple stakeholders in the network of the firm and uncover new value opportunities through a structured and visual approach”* (Evans et al., 2017b). The combination of firm-level and system-level views within this tool supports the development of internal capabilities and the identification of sustainability-oriented collaborations with key stakeholders, which are fundamental for sustainable organisations (Stubbs and Cocklin, 2008). This tool has been designed to stimulate innovation of business models to create sustainable value, through a systematic assessment of value (Rana et al., 2017). During its development process, which took around 6 years, several versions were devised, e.g., the simplified version, adequate for shorter workshop sessions, proposed by Bocken et al. (2013). The tool was initially thought to help companies to develop an improved understanding of their value proposition (Rana et al., 2013; Bocken et al., 2013). Its potential to support broader business model innovations arose during the development process. The template supports the understanding of the business purpose and potential stakeholders in the value network, of positive and negative aspects of the value proposition, and the identification of opportunities for sustainable value creation (Rana et al., 2017). Within the sustainable business modelling process, it was used together with the sustainable business model archetypes, the business model canvas and the strategic roadmapping tool (Rana et al., 2017). Since then, it has been applied in different settings, outside the original intend to support business model development. Applications in conjunction with other tools were reported within workshop processes related to eco-innovation, eco-design, light-weighted innovation strategy, and design thinking (Bocken et al., 2015a; Bocken et al., 2015b; Geissdoerfer et al., 2016). This proves the high versatility of this tool and suggests that it may be also adequate to be combined with others for the assessment of early stage of technology opportunities.

4. METHODOLOGY

This research was carried out within the collaborative environment of the Strategic Technology and Innovation Management (STIM) consortium. The consortium enables participating firms to engage with one or more proposed projects with different level of involvement, as it fits their interests. This environment nurtures a wide range of research co-creation opportunities with methods including action research, focus groups and participatory research. Based on early discussions of STIM companies' needs, it was identified that companies were interested in methods for integrating sustainability thinking into their business activities and technology development processes. In response to this, we conducted this collaborative research around the topic of sustainability in conjunction with methods to assess technological innovation.

4.1 Approach for toolset design process

We adopted a collaborative approach with industry for the toolset configuration process (Mortara et al., 2014). This took the form of an exploratory and iterative design process (c.f. Kolb, 1984), including probe and learn activities (Lynn et al. 1996), and drew upon aspects of process research (Platts, 1993; Neely et al., 2000), procedural action research (Maslen and Lewis 1994) and engaged scholarship (Van de Ven, 2007). As such the configurable toolset and workshop process were developed by drawing upon literature and practice, and then piloted in working organisations in two phases – development and testing. The workshop design has, as a fundamental principle, the implicit assumption that information flow takes place through templates, activities and the involvement of people and is of paramount importance in assessing value and prospective sensemaking activities.

Measurement of process success is an important element of this approach and the process is refined until stable and then tested more widely. Process success was judged in response to a set of criteria: usability, usefulness and functionality. Usability indicates whether the process was easy to implement for both facilitator and participants. Functionality shows whether the process does what it was designed to do. Usefulness is evaluated by looking at organisational impact. Organisational impact can be evaluated immediately from post workshop questionnaires and from the actions decided upon following the application of the toolset. Further impact can be assessed by following up sometime after the workshop to see whether those actions have come to fruition, i.e. has the technology development been completed and the application successfully commercialised.

4.2 Research design

This work established a participatory research approach as primary research method, with a clear intervention goal and strong involvement of some industry participants in the whole research process (Louis and Bartunek, 1992). The research involved firm managers throughout the research process in a co-learning environment with frequent interactions and briefing points. The work was carried out in two linked and evolutionary phases: the first being toolset development during 2015/2016 and the second being toolset testing during 2017/2018 as shown in Fig. 1 below. Throughout the work, STIM companies were encouraged to provide ongoing feedback during poster exhibitions, by attending pilot workshops and contributing to and commenting on the guidance format. Interactions and dialogue with the STIM companies have been fundamental elements of this academic-industry research project (Bartunek and McKenzie, 2017).

The research design built on the structure and timeline provided by the STIM consortium events, but additional meetings and workshops were planned between STIM events to maximise engagement with the industrial participants and to adapt the interaction needs according to the advancement of the research. Thus, more in-company activities were planned during the testing phase. This approach helped the researchers to create an environment of generous reciprocity, in which opportunities to engage with industry participants are frequently sought, and used to look together at data and the interpretations made, during the research process (Rhodes and Carlsen, 2018). These engagements, together with key project milestones, are illustrated in Fig. 1. More details are provided in next subsections.

Fig. 1 Research design overview

4.2.1 Research Design Part 1: toolset and workshop development

The initial interactive poster sessions and small group discussion sessions resulted in comments from 7 companies, and we used this input to select the preliminary toolset to be used (M1) and to shape the multi-company workshop process (M2). The **multi-company pilot workshop** was held with 3 companies. Participants were asked to review in advance the technology opportunity to be considered using a structured question set, and to bring along 2-5 commercial and technical people per company for the workshop. The 3-hour workshop included plenary briefing and feedback time as well as individual company small group work. This was followed by a **single in-company workshop** (WS1) that further shaped the application of the toolset. A briefing meeting with this company helped advancing the toolset definition and workshop design (M3).

4.2.2 Research Design Part 2: tool and workshop testing

The second part of the research design built on the development findings and focused on testing a configurable approach in group discussions and single company workshops. Three small group discussions were held as part of ongoing STIM consortium interactions. The revised toolset was displayed to 11 STIM companies, including a webinar to one company, and received comments and feedback from 7 of them. Four in-company workshops were conducted in June and July 2018 with two companies (WS2-5). The protocol to conduct these workshops included a preparation phase and a post-workshop phase. The preparation phase consists of detailed discussion on the workshop steps

and a walk-through the templates focused on the identified initial technology opportunity with lead participants from the companies. Generic examples to illustrate the use of the templates were provided and the discussions resulted in the narrowing down of ideas to use for the workshops and selection of the template combination to be used. Refinements to workshop design were done based on feedback obtained from briefing meetings with companies afterwards (M4).

5. FINDINGS

In this section, the results and findings are described, including reflections on emerging themes from the analysis such as the nature of the organisational impact, the process of learning and integrating sustainable value thinking, and the implications for improving and further testing of the method.

5.1 Building the initial toolset and workshop process

The first interaction session with the STIM companies was used to understand their requirements and level of interest in this research. The research theme was presented as “*Mapping Sustainable Value for New Technology Opportunities*”. This session attracted interest and comments from 5 STIM companies. This provided reassurance on the practice need for including environmental and social aspects into the assessments of new technologies. The breadth of potential different uses suggested in the comments and the range of sectors initially interested in the project (e.g. bioscience, electronics, machinery) indicated that highly adaptable templates were preferable at this early stage of the research. This influenced the initial selection of component tools for the toolkit.

The Value Mapping tool was adopted as a base component of the toolset due to its fundamental roots in sustainability and its wide exploration of value in line with the industrial comments received. This starting point guided choice of the further complementary tools. The Value Mapping approach is based on the consideration of a single unit of analysis rather than a portfolio view, so we decided to focus on a single new technology opportunity as the input to the overall assessment. Due to this, it was decided that the Marketing Process for Technology templates would be a better match than the Roadmap-Portfolio templates. In particular, the exploratory templates (Benefits Mapping and Industry Structure Mapping) were seen as more useful to open out the potential technology-commercial opportunities than the more focused Performance Dimension Mapping template. The initial workshop framework for technology assessment was defined on these premises (Fig. 2).

Fig. 2 Initial framework: technology opportunity based assessment

The initial selection of component tools was presented at the next poster and small group session. This resulted in expressions of interest from 5 STIM companies including 4 out of 5 of those originally interested. This strengthened the case for proceeding with the selected tools and developing the workshop process. The next step was to design the workshop objectives and process structure. The workshop objectives were defined as:

- To integrate a wider view of environmental and social value, including a multi-stakeholder perspective, into the assessment of a new technology;
- To provide a structured workshop process and prompts for idea generation around the topic of sustainable value in the context of technology assessment by considering the combined use of existing tools.

The workshop process was then designed drawing upon the Marketing Process for Technology templates and the Value Mapping tool (Fig. 3). The decision was made to focus on the input being a technology. The first template (1) was Benefits Mapping, looking at technology/market opportunities for solutions or benefits that the technology could provide, by means of bringing together commercial and technical people to discuss possible value opportunities. The second template (2) was the Industry Structure analysis to contextualise the selected opportunities in market terms, but split into two parts (2a & 2b). Thus, the third template (3), Value Mapping, would be carried out between identification of the key links in the value chain and the definition of the value achievable, so that the final output is enriched by the detailed value mapping step.

The workshop agenda was designed for a two-hour multi-company workshop in the first instance, to allow researchers to gather multiple perspectives at the same time as well as cross company sharing of learning. During the workshop, each company could work separately on a technology opportunity of their choice by using the templates in the pre-selected order, a 30-minute slot was allocated to each template. The researchers acted as facilitators of the workshop process and provided individual

support to participants when needed. The workshop was planned to provide time and space for cross company interactions between templates and for a final plenary session for immediate reflection as a group. Individual feedback questionnaires were distributed afterwards.

Fig. 3 Initial toolset and workshop structure (draft process)

5.2. Obtaining feedback on workshop flow and tools integration.

Feedback from the multi-company workshop

Detailed feedback on the first toolset and workshop design was gathered during the multi-company workshop, all participants completed the feedback forms. It was run with two STIM companies and one non-STIM start-up (see Table 1), with interest from two further STIM companies who could not attend. This multi-company approach increased the generalisability of the learning and findings regarding the workshop process. Companies' activities, sector, and size, as well as the type of technology opportunity considered by each company were very different. This variety provided insights into potential benefits and problems of this approach for different types of companies and technology opportunity.

Workshop results are summarised in Table 1. Overall, the templates were found useful to focus company thinking and support a structured discussion. The Value Mapping (template 3) was seen as the most useful by two of the three companies and some difficulties were found in the flow from one template to another. There was seen to be a need to have the right people involved, especially important for new technology, i.e. cross disciplinary representation involving both commercial and technical, and especially with Value Mapping (template 3) as some commercial insight is needed. Splitting the Industry Structure tool into two parts (template 2) did not appear to help the final assessment output. It was difficult to go back to the partial template after Value Mapping (template 3) and for the technology application case there was a lack of tangible assessment output.

Table 1 Findings from multi-company workshop

Company	Type of technology opportunity	Template 1: Benefits Mapping	Template 2a: Industry structure	Template 3: Value Mapping	Template 2b: Industry structure
Hi-tech start-up (1 technical participant – university researcher)	New technology concept under development	This template was very helpful in terms of focusing thinking on what the technology can offer	This challenged where best to target the technology	Useful.	Route to market was useful in this second part
Domestic appliances (2 technical participants – R&D manager and senior industrial researcher)	New technology to be installed in product	The technology is already embedded in a product so not so useful at this late stage	It was difficult to know what industry to analyse, we looked at our own company value chain but perhaps should have looked at the one related to consumer need for the product	This was very interesting and would have been even more useful at an earlier stage in the product development and with commercial people present	Didn't see how to combine with 2a or translate the findings from template 3 into more insight
Machinery (2 technical participants – R&D manager and technology scout)	New technology developed recently	The technology application was well defined technically but the market is very uncertain. We did not find this template helpful	This template was useful to summarise key players and possibilities in market offering	This was a useful discussion although only technical people present	Did not find going back to this useful

Feedback from poster and small group discussion

Further exposure of the toolset and workshop during the third poster and small group discussion (session III in Fig. 2) provided insights from 4 STIM companies, in addition to those involved in the multi-company workshop. During the poster session, discussions with companies extracted their reaction to the research so far. They appeared to relate strongly to the way the templates framed and structured what can be fuzzy discussions about commercialisation potential. In particular, it became clear that the workshop helped companies to define more clearly what the technology can offer and the options for application, to understand better the current market knowledge and where the information gaps are, and to appreciate more fully the broader impact of the technology application (e.g. on environment, society, suppliers, etc.).

Feedback from single company workshop and subsequent debrief sessions

A further workshop was held with one STIM company at their request in order to explore a specific technology development opportunity. The workshop process was adapted for single company use and included a dedicated preparation phase with the lead company participant. The tool templates and workshop design were the same as in the multi-company workshop. There were four company participants mainly from technological backgrounds, as the marketing team that had been invited could not attend. Feedback forms were distributed and completed after the workshop session.

Most participants considered that the workshop process worked well to support technology assessment in an accessible format and that it helped to widen the consideration of technology contribution to environmental and social aspects. The value mapping (template 3) was found useful to consider all aspects of the technology, provide a much broader idea of potential project impact and promote critical thinking. Areas that could be improved were identified:

- The structure of the industry mapping (template 2) did not seem well understood by all participants or as effective as the other templates during the workshop session.
- More preparation work and sharing information in advance would have been welcomed.
- More facilitation was necessary on template 1 to make it easier to understand by technology focused participants.

References to missing the presence and inputs of the company marketing team members were made during the workshop and in the feedback forms. Participants expressed their willingness to repeat the workshop session together with the marketing team to gain further insights on the market and customers.

A later debrief meeting between the researchers and the lead company participant confirmed the above and additionally indicated a missing step to reflect on the results of the discussion and to support the development of an action plan to follow-up the workshop session. Based on this discussion, the performance dimensions mapping (template 4) was included in the toolset to serve this explicit need for a reflection and comparison step.

Another key area of discussion during the debrief meetings concerned the need for clarification of the assessment level and unit of analysis in terms of the opportunity that the company wishes to consider. It was realised that the templates proposed could be used and combined in slightly different ways to explore either a generic technology opportunity or a particular application of the technology. This workshop and related discussions crystallised the need to have a more configurable approach to assessing technology along different stages in technology development.

5.3. Refinement and creating the configurable toolset

The range of assessment needs identified, from generic potential technology opportunity to specific technology application opportunity in a particular product, led to discussions on how best to define or partition the opportunity space, perhaps as several discrete elements. Being more specific in describing the type of technology opportunity under consideration should allow selection of the tool combination that will give most help to a company, providing a more configurable assessment approach. Thus, companies might be able to use this toolset and workshop process over a wider range of technology maturity stages than first thought. A typology of decisions about technology opportunities was required, that could be applied to delineate the decision space further. Having reviewed different technology assessment approaches (e.g. Lindsay, 1999; Liao and Witsil, 2008; Tran and Daim, 2008), it was decided to look at the technology opportunities as presented by the companies. Adopting their own definition of what was new technology to them irrespective of whether the technology would be classified as early or later stage, or had been developed in house or sourced externally. Reflection on the workshops held to date and the discussions with STIM companies in this regard led to the identification of three types of technology assessment. An overview is provided in a revised framework in Fig. 4 and can be described as follows:

Technology prospect: the company has a new technology but it has not decided on an application yet, it could be in its current markets or new ones and the decision will determine the direction of ongoing development. At this stage, the objective of the technology assessment is to evaluate the use of this technology in company's processes, products or services, and the integration of sustainable value thinking provides alignment with company sustainability vision and principles.

Technology application: the company has a new technology application idea but does not know how much value it will give the business and how to focus further development. At this stage, the objective of the technology assessment is to evaluate one or more possible applications of this technology in the company's processes, products or services, and the integration of sustainable value thinking provides understanding on opportunities for higher value applications.

Technology-enhanced offering: the company has a new technology that will improve an existing commercial offering but want to explore how to maximise the benefits to all stakeholders. At this stage, the objective of the technology assessment is to evaluate this technology-enhanced offering, and the integration of sustainable value provides insights on improvements to maximise its value.

Fig. 4 Revised framework: evolution of technology assessments at different stages of technology opportunity development

Once the three types of technology assessment had been defined it was possible to see a more configurable toolset approach emerging, depending on what aspect of a technology was being considered and what level of sustainable questions needed answering (Fig. 5). The Benefits Mapping (template 1) was revealed to be the key to introducing flexibility into the workshop process. Due to its versatility to initiate the discussion from a technology pull, market push or, even, solution driven perspective, it was retained as the starting point for both the technology prospect and technology application assessments. Following this comes the Industry Structure mapping (template 2) for technology prospects, or the Value Mapping (template 3) for technology applications. The Industry Structure mapping (template 2) seems more beneficial when discussing a generic use of a new technology along the value chain opportunities, while the Value Mapping (template 3) brings more benefits when applied to more specific applications. According to our observations, and previous experience using template 3, outputs from the value mapping exercise become less meaningful when the unit of analysis is not accurately defined, as is normally the case for technology prospects as defined above. Therefore, for the technology prospect assessment, it is proposed to prompt the

brainstorming process in the Benefits Mapping (template 1) with preliminary ideas for sustainable value thinking obtained from a reflection of the company's own sustainability vision and principles. These prompts could be obtained from using the Value Mapping (template 3) as a pre-workshop discussion, as well as from other sustainable value frameworks (e.g. Hart and Milstein, 2003) which provide insights focused on building capabilities and markets. The Performance Dimensions (template 4) is introduced as final step for reflection and comparison, with performance dimensions derived from previous templates. This template is considered useful to focus action plans and very effective to capture key performance requirements necessary for the adoption of any technology by a particular application and market sector (Farrukh et al., 2017). In the case of technology-enhanced offerings, the technology is already developed and its application selected. Thus, the exploratory templates would not be adequate and the recommendation is to use solely the Value Mapping tool (template 3) to analyse ways to enhance sustainable value creation for a wider range of stakeholders. This single template situation was not part of our research project. The new multiple template toolset was taken forward for more testing in further company workshops.

Fig. 5 Toolset and suggested tool usage for different technology assessment stages (revised process)

5.4. Applying the configurable toolset

This new configurable approach was presented during the poster and small group discussions (sessions IV-VI in Fig.2). Engagements and comments confirmed interest and led to conducting four workshops in two STIM companies (WS2-5 in Fig.2). Although other two companies were interested in the workshop, they did not manage to arrange it within the STIM program timeframe.

The workshops were each 3 hours long and they all started with a 15-min introduction and workshop overview, followed by 45-min slots for each template. They all finalised with a 30-min discussion and feedback session. The agenda for each workshop was customised with company language during planning sessions. Several workshops (WS2-4) were carried out using different units of analysis for the same company; this helped to remove barriers of non-familiarity with the toolset and to reduce limitations in the analysis based on particular company situations. All four workshops fell into the technology application area, hence using templates 1, 3 and 4, however in each case template 2 was reviewed with a small set of leading participants during the pre-workshop discussions to ensure that

the technology application was well enough defined. Workshop 4 (WS4) was considered for the technology prospect route, as the specific technology was not fully defined by the company; however, it was finally decided to explore a particular application during the workshop. Although all four workshops were considered technology application focused, two were technology leading and two were customer need leading. This is seen as an important distinction.

Table 2 shows a summary of the workshops conducted, including key outputs and follow-up actions. The company workshops resulted in extensive feedback from the participants, who confirmed that the choice of templates fitted their assessment needs overall, and provided helpful comments and significant learning points. All participants completed the feedback forms and workshop size ranged from 5-8 people (see Table 2). Qualitative and quantitative feedback (i.e. participants' ratings) on the process success criteria are presented in Table 3 and Table 4, respectively.

Table 2 Overview of testing workshops

Workshop	Type of technology assessment	Participants background and templates used	Template 1 focus	Outputs / actions
WS2	Technology application – customer need leading	6 Technical 1 Manufacturing 1 Marketing Templates: 1, 3 (twice), 4	Customer need leading with one proposed technical solution (2 solutions assessed)	Prepare a proposal to take technology solution forwards. Plan to use template 3 again
WS3	Technology application – technology leading, seeking definitions of new offerings	5 Technical 1 Commercial Templates: 1,3,4	Technology leading, focused application area	Collect technical data. Plan to explore wider uses. May build a physical mock-up as a demonstrator
WS4	Technology application / prospect – technology leading, widely perceived future customer needs	6 Technical 1 Commercial 1 Psychologist Templates: 1,3,4	Customer need leading, very wide remit	Agreed that should have narrowed focus before workshop. Ongoing discussions in this area
WS5	Technology application – technology leading, better process technology so internal customers	2 Manufacturing technologists 2 Scientists, 1 Tech translator Templates: 1,3,4	Technology leading, looking for validation of need	Shared knowledge and understanding, while uncovering several possible uses for technology

The comments received highlight the difficulties of short timescales, wide ranging topics and a new workshop process. We extract three main process-related learning points from this testing phase:

- i. **Nature of assessment:** There were more assessments of technology applications presented for consideration than new technology prospects. This meant that structure of the industry mapping (template 2), which is about rethinking the business model, seemed less relevant to workshops in these better-defined situations. However, for wide-open technology opportunities, it would work well as a good discussion starter, for example to frame workshops up-front in technology application situations. In some instances, the companies thought their technology application was well defined, however, the workshop process uncovered uncertainties. At this point the facilitators realised that the process would have benefited from using the technology prospect route first to define the application in more detail.
- ii. **Nature of tools:** Different parts of the toolset play different roles. Benefits mapping (template 1) is very useful for technology push if there are commercial people present, as enables a wider view of the possibilities. However, there is a need to structure the brainstorming process better through facilitator prompting and template redesign to make

the process more intuitive for both possible starting points (technology or customer need driven). Value mapping (template 3) consistently gave value by means of prompting stakeholder views and in depth discussions. However, it relies on an agreed definition of the unit of analysis, which with a wider number of participants needs some support (from template 1 or elsewhere). Template 3 needs familiarisation time, and it was particularly helpful to run this template for two options (in WS2) and then compare them using the performance dimensions mapping (template 4). Template 4 drives the next steps but relies upon a good basis for comparison. More examples are needed here, so that participants understand that independence of dimensions is needed to allow good scoring. Also, it was worth discussing early ideas for performance dimensions at end of Template 1.

- iii. **Nature of participants:** The stakeholder most often mentioned as relevant was the customer; indeed, most workshops explored several customer segmentations in the value mapping (template 3) and facilitators realised that R&D teams especially welcomed insights from marketing participants regarding their target customers. Both customers and society were stakeholders that concentrated the discussion and attracted ideas for new value opportunities, together with environmental aspects, as key outputs of using template 3.

Table 3 Summary of feedback and comments from participants in testing workshops

Topics	WS2	WS3	WS4	WS5
<i>Overall:</i> What worked well?	Discussions very useful. Template 1 gave beneficial outputs for technology needs. Template 3 provides a great playground for ideas to become more mature. Working on both value (template 3) and performance mapping (template 4) helped to see the whole picture.	Brainstorming on use cases. Generation of new ideas to apply the new technology. Benefit mapping worked well. Discussion of a 'new technology' instead of an 'add-on technology' was good. Inspiring and teaching. Technical discussion.	Templates 3 & 4 went well and were more enjoyable. Thinking about a variety of topics and values when looking at products.	Bringing together departments and collating key issues. Small group. Simplicity – clarity of tools. Introduction of each step.
<i>Overall:</i> What worked less well?	A more diverse team (larger) needed. Template 3 could be improved in terms of differentiating types of value. Need to make sure the contribution of attendees is maximised. Better structure to brainstorming.	Performance mapping was hard to complete. The assessment of new emerging technologies. On Template 4 it was difficult to know what to compare.	Our company had not prepared topic sufficiently. Needed more tools and collaboration to narrow down the topic initially. Workshop was a bit fast paced.	Better definition of Template 1 needed – significant overlap in areas of template in discussion. Stop discussion going off track (rabbit holes). A bit more time. Space and linking things together.
<i>Specific:</i> Template 1	Wanted a more structured brainstorm but still identified extra solutions to problem.	Identified several plausible new applications of emergent technology.	Struggled due to incredibly wide range of possible technologies and lack of tangible way forward.	Confused by template, but some new potential value opportunities identified.
<i>Specific:</i> Template 2 (used	<i>Not seen as relevant as defined need in existing application space.</i>	<i>Not seen as relevant as very early tech and</i>	<i>Not seen as relevant as very wide application area at present – BUT</i>	<i>Not seen as relevant as in defined processing area not changing BUT</i>

during prep phase, not workshops)		defined business model retained.	may have helped to move thinking forward.	may have reinforced findings from template 1.
Specific: Template 3	Done twice, the second done quickly by exception. Most relevant stakeholders: customers, society, investors.	Went well, good discussion, another one if more time. Most relevant stakeholders: customers, R&D and production facilities, suppliers, partners.	Went well, good discussion, another one if more time. Most relevant stakeholders: customers, society, suppliers, partners, investors.	Done once, another one if more time. Most relevant stakeholders: customers, society, employees, investors, suppliers, partners, environment.
Specific: Template 4	Worked well – mapped benefits for each.	Struggled to find good basis to compare performance.	Compared to competitor, which worked well.	Compared to existing process, went ok but no big surprises.

Table 4 Summary of participants' feedback scores for the process success criteria

Topics	WS2 score	WS3 score	WS4 score	WS5 score	Total score
USABILITY: How well did the process support technology assessment in an accessible format? (0 = difficult to use, 5= very easy to use)	4.0	4.0	3.4	4.2	3.9
FUNCTIONALITY: How well did the process work to select and explore technology opportunities effectively? (0 = not effective, 5 = very effective)	3.8	4.0	3.1	3.8	3.7
FUNCTIONALITY: How well did the process help widening consideration of technology value contribution? (0 = not well, 5 = very well)	4.0	4.2	4.0	4.2	4.1
USEFULNESS: How useful were the following activities? (Usefulness: 0=not useful, 5 = very useful)	4.0	3.8	3.4	4.8	4.0
- Introduction to workshop					
- Benefit Mapping (template 1) - Looking for technology / need combinations	4.1	4.5	3.1	4.2	4.0
- Value Mapping (template 3) – Multi-stakeholders and sustainable value analysis	4.3	3.8	4.2	4.2	4.1
- Performance Dimensions (template 4) - Performance gap to close	4.7	2.8	3.4	4.0	3.7
- Discussions during workshop as a whole	3.9	4.3	3.2	4.6	4.0
- Promotion of a collaborative approach between technical and commercial groups	4.0	4.0	3.0	4.4	3.9
- Outputs of the workshop	4.2	3.8	3.2	4.2	3.9

Note: Workshop scores obtained by averaging the individual scores given by each workshop participant.

5.4.1 Observations on sustainable value thinking

The Value Mapping (template 3) received high scores for functionality and usefulness in participants' feedback forms and verbal feedback provided at the end of the workshops. It helped widening participants' views on the value of technology beyond economic insights. This template supports a systematic assessment of value for multiple stakeholders based on the concepts of value capture and value uncaptured. Value uncaptured is analysed in terms of value missed, destroyed and wasted in the interactions with stakeholders (Rana et al., 2017). The template includes the environment and

society as primary stakeholders (Stubbs and Cocklin, 2008; Evans et al., 2017a) to prompt discussions specifically on environmental and social value, beyond value uncaptured insights from stakeholders.

The results suggest that there is good understanding among participants on environmental impacts related to energy consumption and efficiency, waste generation, and recyclability potential. In some instances, this seemed to be guided by established certifications and regulations. Specific questions on other positive environmental initiatives, e.g. use of alternative input materials or alternative end-of-life strategies based on remanufacturing or refurbishment, could be added in the future during the facilitation process, to ensure discussions extend beyond the scope of current regulations and certifications. It was noted that participants particularly appreciated the discussions around contributions to society, community building and customer value. In this sense, opportunities to support conscious consumption patterns and to improve working relations with other business functions were identified in one of the workshops. Additional value opportunities emerged from revisiting current value chains or establishing partnerships to enhance product effectiveness.

5.4.2 Observations on process success (workshop and toolset)

In total, the four testing workshops involved 27 participants, who were experienced in terms of technology development, although less experienced in the use of management tools and templates. In all cases the specific tools used were unfamiliar to them, however the lead company participants, for the single company workshops, had been introduced to the templates in pre-workshop discussions. This enabled workshop planning, by means of walk-throughs, to allow the facilitators to identify the suitability of each aspect of the process for the technologies to be assessed.

In summing up the information about the overall workshop performance, we need to review both the workshop process and the toolset based on the data collected. This provides a consolidated result based on all the workshops carried out in terms of the defined success criteria - usability, functionality and usefulness.

The main shortcomings and the best activities in the view of the participants are revealed in Tables 3 and 4 by the questionnaire scores and the questionnaire comments. These were as follows:

- Usability – for three workshops this scored well, but for workshop 4 significantly less so. This was possibly due to the wide topic under consideration and less preparation time with lead participant.
- Functionality – this was split into two parts, the first considered the selection and exploration aspects of the process and the second the widening of value consideration. The first scored along the same lines as Usability above, the second reflected sustained appreciation of the Value Mapping template 3.
- Usefulness – the scores mostly reflected the differences observed above in Functionality and Usability, with workshop 4 running lower scores for all sections of the workshop except template 3, which again scored highly throughout. In workshop 3, the Performance Dimensions template 4 also scored lower, due to difficulties finding a good basis of comparison for the technology.

5.5. Perceived future applications, issues and concerns

Briefing meetings and a poster and small group discussion (session VII in Fig 2) provided further evidence on the adequacy of the proposed configurable toolset to help companies build a business case for technology acquisition or for continuing the technology development process. During follow-up meetings, workshop participants specifically reported that workshop outputs supported R&D teams in specific ways. These included (1) to push a technology development forward, (2) to gain insights to make a new idea feel real that led to obtaining company back-up for creating a demonstrator and obtaining further market insights, (3) to identify an unexpected higher value-adding technology application. An additional use was identified regarding (4) looking into entering an unknown industry with a proprietary technology, for the technology prospect assessment.

Due to the nature of the testing regime, the workshops were fast-paced. This served to test workshop feasibility for a light-weighted (concise and lower resource) implementation, which was confirmed. Future workshops could be carried out in more depth, which would require dedicating 2-3 hours to each template, ideally on different days to give space for reflection and for gathering information on identified knowledge gaps before the next session. Each session would then start with a brief recap from previous one and providing any additional information needed to move forward and use the next template.

Identified issues and concerns that need to be taken into consideration for future applications regard the importance of narrowing down the topic for discussion before or during the workshops, the selection of assessment route to bring most value to each company situation and the current strong dependency on facilitation to use the templates. More guidelines could be provided during the preparation phase to help companies address these issues, including a set of prompt questions that can be used along the workshop sessions to reduce dependency on facilitators' guidance.

Participants' feedback reflect that the workshop process was helpful to widen their considerations of technology value towards customers, society as a whole and the environment. These do not seem often promoted within R&D activities. The toolset could be used for training innovation and technology managers on ways to address these aspects within their forward-looking activities. Indeed, the toolset could be used in higher education programmes covering teaching and learning on innovation and technology management. It could help training future managers in widening their views towards environmental and social aspects in technology forecasting and technology intelligence activities.

6. DISCUSSION

This discussion first addresses two key challenges identified in the literature concerning: (i) obtaining value from forward-looking activities, and (ii) balancing technology and market while integrating sustainability thinking in technology assessment. Then, it describes the key learnings from the workshop and toolkit development and testing process.

6.1. Forward-looking activities and sustainability thinking

The first challenge was obtaining value from forward looking activities, which require effective implementation in order to result in the best outcomes for organisations. Our toolset supports a

broader assessment of future technology opportunities in several ways. Overall, it brings together a range of stakeholder perspectives through the workshop-based approach, resulting in 'prospective sensemaking' (Rohrbeck et al., 2015; Boe-Lillegraven and Monterde, 2015) and allowing shared realisation of the sustainable advantages possible. In particular, the toolset gathers information and insights that fulfil the requirements of effective technology scanning activities in terms of being useful in strategic planning process, improving the technology foresight of senior managers and developing the corporate skill base and learning (Van Wyk, 1997). At a detailed level, the toolset approach supports corporate technology intelligence activities, which include the technology screening and selection process and conveying results to decision makers, and challenges the translation of these intelligence outcomes (screening, solution finding, implementation) in a way that promotes action (Gerybadze, 1994). Both interpretation and action are at the essence of sensemaking (Weick et al., 2005).

The second challenge regards matching technology and market on an ongoing basis while including environmental and social aspects in commercialisation of a technology. The whole process, and particularly the Benefits Mapping (template 1), worked well to bring technical and commercial views together. Thus, enabling shared understanding (Stigliani and Ravasi, 2012). Also, this template exposes workshop participants to technology features, as a stimulus for sensemaking (Griffins, 1999). The multi-stakeholder consideration of the Value Mapping (template 3), that implicitly included environment and society, was very much welcomed at these stages of technology assessment, where it is not currently an established practice. In technology forecasting tools, it is still mostly the case that only shorter term technical and economic aspects are addressed, although the long-term impact of sustainability is usually recognised (Phaal et al., 2006). At policy level, there seem to be inadequate efforts to address the environmental and social problems deeply implicated in many technologies (Schot and Steinmueller, 2018). This detachment from societal expectations and impacts is somehow reflected in forward-looking activities at company level too. Our proposed toolset helps to reconcile this while supporting considerations on the environmental impacts of new technologies and the products, services or processes in which they will be embedded.

Furthermore, the toolset and workshop process create a space for prospective sensemaking, based on technology features and market opportunities as starting points and building a common understanding of stakeholders' value exchanges with the technology opportunity being assessed. This approach provides the perspective of intended users, which is often underexplored (Jacobs et al., 2013), and moves beyond this to provide perspectives of intended stakeholders, including the environment and society. This brings insights of future stakeholders into prospective sensemaking in technology assessments, which is a novel area to be further investigated.

6.2. Key process learning

The application of the evolving process and toolset was documented by the facilitators' records of discussions and noted observations and by participant questionnaires, which reviewed the process success criteria of usability, functionality and usefulness. Our findings suggest that companies benefit from using the toolset to confirm, or find unexpected alternatives to, a developmental path for new technologies, and this implies building a business case to obtain organisational support on the ongoing or subsequent technology development projects (Probert et al 2013). Thus, the toolset

is supporting firms in deriving and implementing technology forecasts and technology strategic planning (Gerybadze, 1994; Tram and Daim, 2008).

Major learning points refer to the nature of the technology assessment, the tools and the participants in the workshop process. The final configurable toolset (Fig. 5) fulfils the toolkit development principles (Kerr et al., 2013) better than the initially selected toolset (Fig. 3). This was partly due to the wide range of 'new technology opportunities' that companies wished to consider. We learned that, in the companies we interacted with, assessment of technology opportunities mainly considers current exploitation opportunities. Earlier stage conversations, involving freewheeling discussions about new technologies, are perhaps carried out at higher levels or seen as too risky to share externally. Therefore, we proposed distinctions for technology opportunity assessments based on the stage of technology development within a company, namely technology prospect, technology application, and technology-enhanced offering. These three contexts defined the combination of tools used in the process. Overall, testing revealed that the tools do work well together when context and configuration are matched. Besides, the ability to vary the unit of analysis and the types of data used in all the templates allows flexibility and scalability. Their combined use shows that they can be modular with either inputs or outputs flowing from one tool to another or presenting complementary perspectives. In addition, the configurability of the toolset chimes with the spirit of Liao and Witsil (2008) who, after reviewing available technology opportunity assessment tools, suggested that multiple analytical views customised to company need was the best way forward. Our participative approach, as required for TFA studies and their methods selection, emphasized practitioner engagement in the process and considered contextual influences, data and resources availability and practitioner preferences (Porter et al., 2004).

We understand from the feedback that the combination of tools added depth. Both Benefits Mapping (template 1) and Value Mapping (template 3) provided the value-focused approach and the multi-actor interactions that are essential for effective technology forecasting activities (Gerybadze, 1994). The Benefits Mapping (template 1) helped focusing on the need for the technology (not solely technology push) and the benefits for the company and its portfolio. Insights from the Value Mapping (template 3) on societal, customer and environmental considerations were very much welcomed by the technology developers and R&D teams. Reframing value in terms of the specific categories and the involvement of a wider range of stakeholder views were key aspects. The prompted stakeholder "society" in the template stretched the thinking of participants towards wider societal implications of technology use and current products. Although challenging during the workshops, this was clearly appreciated by participants and reflected in feedback forms. The Benefits Mapping (template 1) was also seen as a useful scene setter and way of narrowing down what should be considered in the Value Mapping session(s). The Performance Dimension Mapping (template 4) worked well in bringing more focus to the value discussions and enabling sweep-up of actions required. The Structure of the Industry Mapping (template 2) is more useful in earlier discussions when choices are being made about where to focus efforts. The potential for a light-weighted manner of application has also been demonstrated during the testing workshops.

Forward-looking activities such as technology forecasting require involving, communicating and enabling interactions among relevant actors for decision-making (Gerybadze, 1994; Boe-Lillegraven and Monterde, 2015). Our approach aims to facilitate such interactions by bringing together

technical and commercial representatives to workshop discussions. However, in doing so we revealed the difficulty of organising exploratory conversations with multi-functional groups before a formal project plan has been formulated. In many cases, it was hard to involve commercial people in workshop sessions due to time constraints and other priorities. Commercial representatives invited to workshop sessions were mostly handpicked to be 'sympathetic' and even then came with reservations or not at all. This suggests that there is often disjointed communication between R&D teams, technologists and commercial representatives. Taken together with the observed interest in societal implications during the sessions, this could indicate both a barrier to successful technology commercialization activities and a need for R&D activities to be better informed by more in-depth insights from the end-users at early stages of technology development.

6. CONCLUDING REMARKS

Technology is often evaluated very narrowly – just financially or technically – and a more inclusive and holistic view is needed. Besides the imperative to embed sustainability thinking into business strategic planning to address environmental and societal challenges (Calabrese et al., 2019; Smart et al., 2017) at firm and system level, the need for practical support to integrate sustainable value considerations at early stages of technology assessments has been identified and addressed in this research work. Being part of wider forward-looking activities in the firm, technology assessment requires inter-disciplinary and multi-level analyses developed and tested collaboratively with industry to ensure functionality, usability and usefulness to a variety of users (Phaal et al., 2016; Porter et al., 2004; Liao and Witsil, 2008). The development of this technology assessment toolset was indeed carried out in active collaboration with industry as suggested by Phaál et al. (2006). Contextual characteristics of the technology assessment were also considered for tools selection (Mortara et al., 2014; Liao and Witsil, 2008).

This article presents an approach based on mapping templates that are brought together in a practical form for effective use by industry (Kerr et al., 2013). We propose a configurable workshop format, drawing upon four mapping tools: Benefits Mapping (used as technology or market driven), Industry Structure Analysis, Value Mapping and Performance Dimensions Comparison. The toolset aims to support decision-making by assessing potential value in relation to technology benefits, market insights and sustainability thinking, giving depth and breadth, and building on the strengths of the powerful individual tools which have been proven in past applications. The integration of sustainable thinking in this process occurs by making the value mapping the core of the process and the key vehicle for development of action plans for the technology under consideration. The templates are easy to apply, helping to structure and guide discussion, promoting a consensual way forward and leading to practical action plans. This is a tangible example of making concrete the cognitive work in prospective sensemaking by using visual and textual artefacts to define new courses of action (Stigliani and Ravasi, 2012).

We identified different contexts for the technology opportunity assessments based on the companies engaged in the participatory research, and defined three assessment routes according to the development stage of the technology and the relevant analysis level for sustainable value within the company: technology prospect, technology application and technology-enhanced offering. It was necessary to acknowledge these stages and adapt the assessment process accordingly, matching tools to needs, to increase the effectiveness of the workshop process. As part of the collaborative

research environment (involving ongoing consultations with over twenty consortium companies plus in-depth collaboration with four companies and six workshops), each process step has been reviewed and improved by iteration and consultation with industry and contributes towards the practical realisation of value contribution of corporate foresight and forward-looking activities in the firm (Rohrbeck et al., 2015). These activities can be seen as plausible sensing making, reconciling rationality (economics, technological feasibility) and emotion (societal and personal choice and benefits) and promoting both as complementary (Ericson, 2010).

Selecting and implementing appropriate approaches and quantifying their value contribution is difficult. Using this proposed toolset helped companies to take decisions and subsequent actions on the development path for new technologies under consideration, and secure organisational back-up for either advancing the project or taking a different direction. This showed how to enact sense making as a lens to focus technology adoption (Wang et al., 2019). This focus enabled companies to integrate the technology assessment process into their strategic technology planning activities and improve their organisational learning (Van Wyk, 1997; Tapinos and Pyper, 2018). Additionally, participants' feedback reflects that the workshop process was helpful to widen their consideration of technology value towards customers, society as a whole and the environment, which suggest potential future use of the toolset in training and higher education programmes.

Our work demonstrates that the integration of sustainability into technology assessments helps to address the uncovered need for more insights on end-users, society and societal welfare in forward-looking activities in the firm, especially in technology development activities that involve R&D teams and technologists. Moreover, the toolkit and workshop process introduce insights of future stakeholders into prospective sensemaking, which is a novel perspective deserving further investigation. In addition the need for and provision of flexible and customisable toolsets needs to be further explored to help reveal, translate and realise long term value for companies.

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