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**Overcoming Challenges of Sustainable  
Innovations: a Participatory System Dynamics  
Approach  
to Value Co-creation**

Dissertação para obtenção do Grau de Mestrado Europeu em Dinâmica  
de Sistemas

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**July, 2016**



## ACKNOWLEDGMENTS

This research was elaborated thanks to the collaboration with Cleopa GmbH, an energy innovation research SME in Germany in which I spent a 6 months' internship applying the system dynamics methodology to different projects related to multi-stakeholder and cross-organizational initiatives under the cooperative framework of the European Commission. I would particularly like to thank Detlef Olschewski, manager of Cleopa GmbH for his total support and advice, but especially for being open and giving me the opportunity to explore new applications of the methodology to real life problems that required immediate solutions. The present thesis should be read bearing in mind that the analysis described, was developed as a process of discussion where different possibilities to address the issue were presented to the problem-owners. In this way they were free to decide whether or not to apply system dynamics to their case given the methodological evidence provided and making a connection to their aims. Without having Cleopa GmbH to support me, this research would not have been possible.

I am also deeply grateful to Prof. Nuno Videira for accepting to supervise the thesis, for his patient guidance, support and advice provided throughout the research development as well as during the time I was his student. Thanks to him I discovered new collaborative paths, opened my vision towards sustainability issues and recognized the importance of integration. That was my inspiration to write this thesis and I am sure that this vision will continue to motivate me and help me to develop future research.

I would also like to thank all professors and fellow students at the University of Bergen in Norway, the New University of Lisbon in Portugal and the Radboud University of Nijmegen in the Netherlands, for making of my days at each institution a great personal and learning experience. The quality education I received is with no doubts, the result of the commitment and interest of professors to the students and to the European Master Programme in System Dynamics. I am grateful for their passion which encourages me to work hard to spread the use of system dynamics. I will always be thankful for it.

On a different note I would like to thank the Consejo Nacional de Ciencia y Tecnologia (CONACYT) for its financial support throughout the past two years without which I would not be able to finish this master program. Thank you for giving Mexicans the opportunity to study and contribute to construct a brighter future. I profoundly believe that education is the path to understanding and wellbeing and I hope that applying new knowledge and bringing science closer to Mexicans makes of our country a better place.

Finally, I would like to thank my parents Jorge Lopez, Venancia Guerrero, my brother and sister Jorge and Yali Lopez, as well as to Adrien Cano for being always there despite the distance, for encouraging me, for their love and care.





## ABSTRACT

We live in a complex and dynamic world with multiple challenges to be addressed. Given the increased interconnection of the financial system and social interaction across borders, problems seem to be even more chaotic and policy makers are often confused when it comes to developing long lasting solutions.

In this context, sustainability has become one of the major concerns of our time where agreements have to be made at the policy level as to deploy effective solutions to the operational level. Sustainable innovations represent efforts which aims are recognized at the policy level and have the quality to be operational; bringing promising and practical solutions that can escalate and have an impact on society and the planet at large. A systemic and holistic perspective appears to be a good approach to coping with concerns and uncertainty surrounding sustainable innovation implementation, as well as to support environmental, social and economic development goals.

Hence, exploring new possibilities to enhance the successful development of sustainable innovations is necessary to find effective solutions that contribute alleviating major social concerns. The present research created and tested a participatory modelling framework to develop a quantified system dynamics model for value perception to produce a value co-creation platform. This is expected to improve the quality and proficiency of the innovations, as well as to reduce uncertainty for a successful implementation of sustainable innovations.

The framework was applied and tested to an energy efficiency innovation case at the core of a project developed by Nitra's University of Agriculture in Slovakia. Results show that participatory modelling settings effectively enable direct interaction among innovation developers and end-users. Interaction enables dialogue and develops understanding that is likely to improve the way innovations are designed. This can potentially benefit policy makers to allow for deep innovation to occur and thus, to enhance systemic transformation, particularly when applied to large-scale projects.

On the other hand, the use of a quantified system dynamics model to assess value perception exposed the limitations of linear models in terms of value assessment and policy making. The dynamic model reveals insights that contribute to reduce uncertainty at planning level and to assist innovation implementation by learning to better manage sacrifices, focusing efforts to relevant benefits and adapting efforts and strategies to the variety of end-users' groups that benefit from the solution.

**Key words:** sustainable innovation, system dynamics, participatory modelling, value co-creation, perceived value assessment.



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# **1. INTRODUCTION**

## **1.1 BACKGROUND**

All what is new, atypical and unexpected is, by definition, an innovation. In a linguistic scene, the word innovation is used to describe either ideas or objects. Innovation as an idea contributes to improve methods and processes to better address a specific situation. To be able to typify ideas as innovations, it must be demonstrated how a new idea can change the way things are done or interpreted; innovation as an idea does not involve product development. Referring to ideas as a type of innovation is usually supported by management literature (i.e. Trout and Rivkin, 2000; Kotler et al., 2005). A different definition considers innovation as the materialization of an idea into a good or service that creates value to its users. For the purpose of this research, innovation corresponds to the second definition. Therefore, the present research studies innovation described as an invention, the material demonstration of an original idea (Nagy et al., 2013).

Based on this definition, the very volatile nature of innovation comes clear to mind. Materializing ideas into goods involves several iterations during the development process. Even when a product is called ready-to-use, there is still a considerable level of uncertainty around the future interaction between the product and the end-users that might lead to further product transformation. Innovations are highly unstable because of the complexity of the product development process, namely materializing ideas, and the unpredictability of end-users reaction to it. At the moment a product is mature enough in terms of functionality (performs according to inventors' expectations) and adoption (end-users are familiar to its employment) it is not an innovation anymore. Hence, innovations must be unstable to remain considered as such.

Given its instability, understanding innovation is inherently a complex task and seemingly unpredictable. Interests to improve such understanding come from multiple stakes. From the science perspective, introducing innovation is a common aspiration as to improve technology qualifications towards universal scientific progress. From a social perspective, understanding innovations contributes to enhance technology development to efficiently tackle humankind concerns and improve welfare (Stermann, 2013). From the managerial perspective, innovation leads to exploit business opportunities, optimize operations and build-up competitiveness (Trout and Rivkin, 2000).

Beyond the different interests and ambitions around innovation, there is the risk of innovation failure, which is a substantial reason to take this subject in hand for proper and detail study. Records in innovation and management practices literature are filled out with failed market-uptake cases; accordingly the likelihood of an innovation to fail once it gets to the market varies between 50% and 90% depending on the cultural, economic and industrial context (Gourville, 2005). Understanding and

having a certain degree of predictability in innovations could have profound implications to reduce failure probability and thus, to allow innovations to effectively produce the benefits they were meant to achieve.

Based on a legit aspiration to improve humankind conditions while reducing global ecological footprint, achieving sustainability goals is one of the main motivations to better understand and efficiently develop innovation from the social perspective. Giving the relevance of the issue, research towards reducing innovation failure recently took a close look to the sustainability case. Here, analysis suggests that sustainability initiatives directed at cost, quality and productivity frequently fail. For instance, studies indicate that innovative products communicating win-win opportunities in terms of profit and environmental wins, are a sign that innovation is likely to fail because such opportunities either ignore other costs or exaggerate benefits, taking innovation out of a realistic ground. The opposite problem associated to failure arises when providers do not credibly communicate long-term or intangible benefits to end-users (Stermann, 2013). Poor understanding and inadequate communication settings take end-users to undervalue and developers to overvalue innovations relative to their perception, which systematically increases the likelihood of failure (Gourville, 2005; Repenning, 2012).

As suggested by existing theory, creating a bridge for a better understanding between developers and end-users has plenty to offer to make a difference for innovations to succeed in the market place. Such proposal seems to be coherent with the concept of value co-creation that has gained relevance due to the positive effects observed on its applications. The approach refers to end-users active and collaborative interaction with product developers as innovation shapers, particularly through direct interaction (Grönroos and Voima, 2013). By doing so, initial innovators benefit from user-developed innovative ideas that are likely to broaden developers' views and thus, improve the standing of the innovation. Collaborative user innovation is a promising practice, to the point that it is expected to become a product creation norm in a future where social welfare benefits of collaborative user innovations are anticipated to enhance the development of innovations of general societal value (i.e. de Jong et al., 2015; Janeschek et al., 2013).

As it was illustrated, innovation under the product development concept is the center of attention of technological and social progress. However, innovations typically face a challenging scenario full of uncertainties where poor understanding of both product and end-users puts in danger the possibility of an innovation to actually provide the benefits their inventors had in mind when developing the idea.

These challenges are of particular interest for innovations concerning sustainability issues that are growing in attention and interest together with the environmental awareness increase of the last

decades. Since they present well-defined characteristics and address issues that require of urgent attention, sustainability related innovations demand for a particular and separate analysis from other types of innovations (Sterman, 2013).

Perhaps the major challenge of sustainable innovations is to find, and if possible, to create the circumstances and scenarios not only for a smooth adoption but also for a rapid and large scale dissemination. The first suggestion before addressing such an ambitious goal is to reduce innovation uncertainty by improving innovation understanding for developers and end-users in equal bases. Based on improved knowledge and informed decisions, decision-makers will count with tools contributing to proper planning and implementation proficiency.

## **1.2 DYNAMIC PROBLEM**

As advised by researchers, sustainable innovations call for special effort in terms of communication and interaction among developer and end-users. Depending on the degree to which developer and end-users cooperate to solution development, different dynamics characterize the innovation development process and thus, different quality outcomes can be accomplished (i.e. Alves et al., 2016; de Jong et al., 2015; Grönroos and Voima, 2013; Janeschek et al., 2013; Sterman, 2013).

On this matter, Kotler et al. (2005) and Hair et al. (2003) identify two paths followed by product developers when an idea is judged to be potentially successful. The first is to focus on the novelty of the idea and develop a product to latter identify the end-users that will get the most benefits from it. Here, end-user adapts to product possibilities. The second is to identify a need and look for end-users involvement to construct solutions that satisfy such need. Here, the product adapts to end-user needs. Such consideration constitutes the base of value co-creation proposition.

Building up inferences from the background of sustainable innovations into the two general approaches to product development, several interconnections and causalities are identified among actors and elements influencing the way innovations can be improved. Aiming to spot the different possibilities of innovation deployment, Figure 1.1 compares the dynamics of innovation development when value co-creation is pursued against product-focused vision.

Concerning innovation development based on product-focused vision, the course to develop and improve the innovation is an iterative process that depends on innovation idea and compliance with inventor's settled expectations. Hence, the innovation idea serves as a goal to define whether or not the invention is ready for market up-take. Once the invention gets to a readiness level that matches inventor's vision, no more improvements are made and the innovation is taken to the market place.



As soon as end-users interact with the innovation, they evaluate to which degree it complies with their needs and with that, end-users define the value that the invention represents. When innovation effectively complies with such needs, innovation failure likelihood is low. However, if the innovation does not successfully meet with end-user's needs, perceived value is low, indicating that failure possibilities are high. Accordingly, inventors react to failure signs (i.e. direct negative feed-back, difficulty to achieve sales) and when such signs appear, inventors react to improve the innovation. Nonetheless, the delay between acknowledging failure likelihood signs and effectively reacting to improve the innovation can come too late to sustain innovation's implementation.

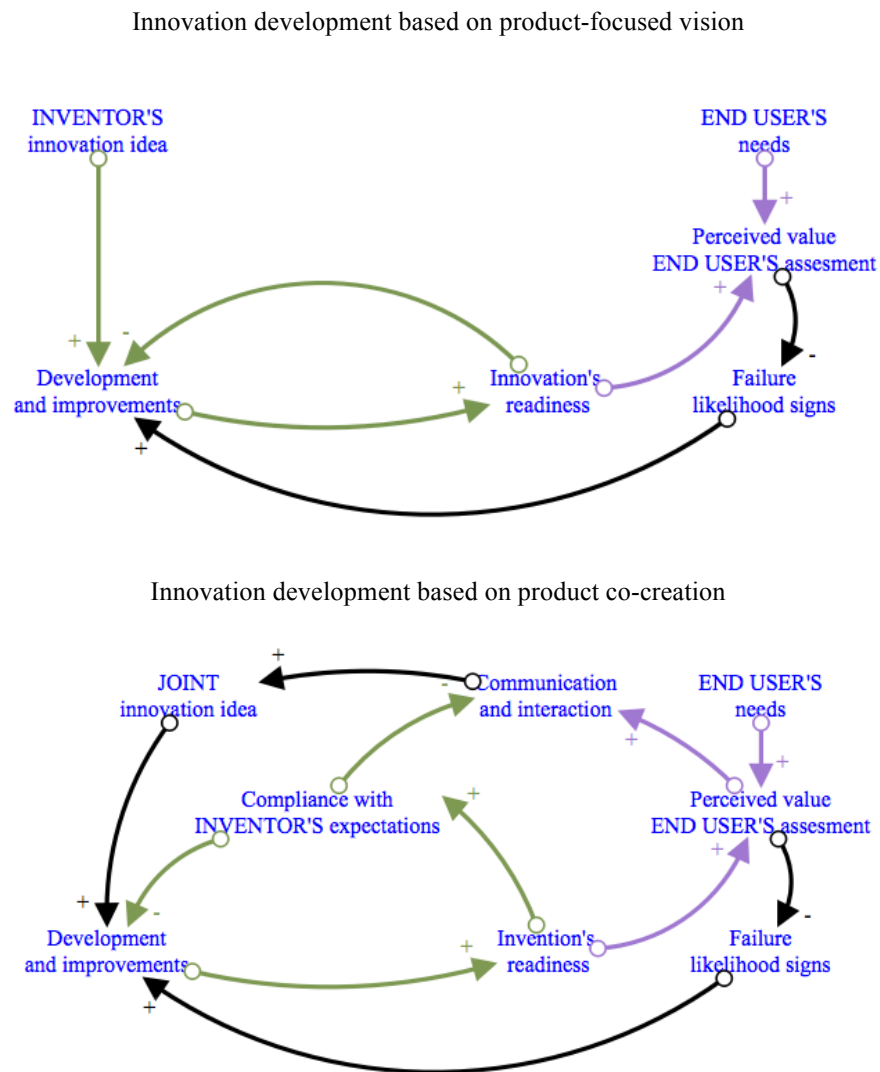


Figure 1.1 Two dynamic perspectives from different innovation development approaches

Observing innovation development based on value co-creation, an iterative process is also recognized. Yet, this time the goal to innovation readiness is not based on inventor's idea but in a joint innovation

idea that evolves with the intervention of end-users. Introducing value co-creation facilitates communication and interaction between developers and end-users, mediating between inventor's expectations and end-user's needs. On one side, inventors acknowledge critical end-users' requests and on the other side, end-users recognize the capabilities of inventor's to ease their needs via innovation development. Additionally, dialogue is expected to increase the quality of the innovation idea by bringing together multiple stakeholders' inputs as explained by Yang and Sung (2016).

The variability of actors involved as well as the uncertainty surrounding end-users reaction to innovation implementation, are key elements that increase the complexity of understanding innovation's potential (Hair et al., 2003; Kotler, 2005; Yang and Sung, 2016). Accordingly, sustainable innovations, demand for problem structuring and impact assessment tools capable to cope with multiple interactions, circular causality and time delays to better manage the uncertainty and complexity that characterizing innovations' development for which system dynamics appears to be a suitable methodology to properly address the problem at hand, as it is further explore in the following chapters.

### **1.3 RESEARCH OBJECTIVE AND QUESTIONS**

Throughout a case study development, this research aims to contribute to structuring and improving knowledge available in an international, cross-organizational and multidisciplinary initiative of Nitra's University of Agriculture Slovakia, by integrating stakeholders' interests and goals to better face challenges related to the development of an energy efficiency device to go from demonstration to market-uptake.

Accordingly, by combining the knowledge and perceptions of end-users and developers, system dynamics will offer a platform for stakeholder communication and joint decision-making regarding sustainable innovation development. Therefore, the specific objective is to reduce implementation failure likelihood and innovation development uncertainty by introducing a value co-creation platform via participatory system dynamics modelling. Hereby, exploring the role of the methodology as a framework to treat uncertainty and contribute to better design sustainable innovations.

According to stakeholder integration and uncertainty management goals, the following research questions will be addressed:

1. What are the implications of eliciting and integrating end-users and developers' standpoints concerning sustainable innovations perceived value?
2. What are the effects of adopting a dynamic view of perceived value to potentially improve the understanding of sustainable innovation development?

3. What are the potential contributions of system dynamics methodology to improve the design of sustainable innovations when using a participatory modelling approach?

The proposed approach aims at testing the role of adopting participatory system dynamics modelling as a methodology to support dialog and improve mutual stakeholder's understanding to deploy value co-creation and with this, better address sustainable innovation's challenges.

As it can be inferred from the research questions, perceived value serves to conceptualize the gap between developers and end-users understanding, since it represents a typical zone of misperception regarding innovation's features. Additionally, perceive value's definition helps to better handle uncertainty by improving knowledge about the state of the innovation (strengths and weaknesses), which in turn allows for better planning in terms of invention improvement.

Then, the expected contribution of the present research to existing literature does not claim to develop a new perceived value model but it aims at finding new extensions to the existing frameworks to manage uncertainty and deploy value co-creation; and with this, to support innovation development especially in the of sustainability field.

#### **1.4 ORGANIZATION OF THE DISSERTATION**

The second chapter of the thesis provides a theoretical context to better understand the state of the art when it comes to sustainable innovation planning. Correspondingly, transition and adaptive management are analyzed as managerial methodologies that focus in multi-stakeholder integration that support the development of deep innovation and progressive social drive. Here value co-creation is explored as a promising approach for stakeholder involvement to innovation design and finally, it refers to value perception assessment as a tool to improve the understanding of products and services, including innovations, to better explain the sources of value that are likely reduce innovation failure.

The third chapter is a compilation of relevant literature to practical approaches useful to deal with sustainable innovation's challenges mainly referring to uncertainty and stakeholder integration. For that, a formal framework of uncertainty is provided and then scenarios and models are described as uncertainty management tools. Also, system dynamic's features are described to emphasize how the methodology is suitable for learning and uncertainty management, throughout model building and scenario analysis. Finally, participatory modelling is described as methodology that responds to both stakeholders' integration and uncertainty management aims.

The forth chapter is a step-by-step guide through the research process.

The fifth chapter reports the results of the participatory system dynamics modelling process in terms of the model, scenario analysis and policy making to reduce uncertainty in sustainable innovation implementation. Also, a process perspective is relevant to evaluate the convenience of the framework to enhancing sustainable innovation design. For this, formal assessment of the participatory process is provided.

The sixth chapter makes a short review of the research and underlines significant results from the system dynamics model and the development of a participatory methodology, as they are relevant for the sustainable innovation cases.

Additional relevant information is provided in the annexes including the scripts used for the participatory modelling process, questioner for process assessment and an explanation of model's equations and parameters including assumptions and limitations.

## **2. APPROACHES FOR MANAGING SUSTAINABLE INNOVATIONS**

### **2.1 TRANSITION AND ADAPTIVE MANAGEMENT**

#### **2.1.1. Transition and adaptive management definitions**

Innovations are meant to alleviate problematic situations and hence, contributing to an ultimate systemic goal beyond commercialization. In this scene, enhancing innovation development is recognized as a means to support progressive social drive. Then, a comprehensive vision in terms of innovation management must be adopted in order to contribute tackling social concerns. Correspondingly, it is necessary to acknowledge managerial approaches that allow for cooperative solutions to emerge. Moreover, taking a close look to the management approaches available helps to identify the significance of value co-creation for the given framework.

In this context, Kemp et al. (2007) refer to transition management as an operative approach that prompts system co-evolution using visions, scenarios and learning by involving different governance figures at a multilevel. A relevant feature of the approach, as argued by the authors, is that it enables systems to test, understand and adapt to new discoveries across stakeholders and organizations. This is possible given the nature of transition management, which is the result of combining principles of complex systems theory, social theory, democratic forms of governance and management translated into an operational model. For these reasons, the comprehensiveness level of the approach is evident.

Aiming for profound innovation, transition management pays special attention to problem structuring, long-term goals and learning by combining the capacity to adapt to change, with the goal to achieve positive social transformation. In this regards, Carey and Harris (2016) describe adaptive management as a platform to operationalize the tasks required to cope with problematic situations where learning

and adaptation are key to progress by focusing on understanding feedback between learning and decision-making processes. Thus, adaptive management becomes a problem structuring method suitable and required to comply with transition management requirements.

From an adaptive management perspective change is not only desirable, but becomes the goal of project management. Interventions on procedures and switching between perspectives are part of a learning process. So that decisions are assumed to adjust according to learning achieved during the course of a project. As a result, management is an open, dynamic, interactive process that allows for communication an adjustment across governance levels. In this sense Bonner et al. (2002) suggest that following the principles of adaptive management contributes to achieve higher, long-term goals by being flexible to new ideas and voicing a larger group of stakeholders.

The concept of social ecological co-evolution is at the core of both approaches. This refers to the mutual evolution of social and natural systems where evolution in the social system inevitable transforms the ecosystems, which in turn affects the way the social system evolves (i.e. Kallis and Norgaard, 2009; Kemp et al., 2007). In this manner, co-evolution suits transition's management proposal of mutual adaption while prioritizing a long-term planning perspective.

So that transition management is related to adaptive management in the scene that both practices consider change unavoidable, yet desirable occurrences. This drives to the understanding of social systems as dynamic systems that just as natural systems, continuously struggle for adaptation in order to achieve better states (Kallis and Norgaard, 2009). Thereby, transition and adaptive management are envisioned as coherent and useful practices to support the natural social evolution process.

Unlike linear management aiming to set conductive strategies based on direct control, fixed goals and predictability, transition an adaptive management put together capabilities, needs and aspirations of individuals and organizations to define and accomplished ultimate societal goals. With this, transition and adaptive management are expected to bring durable results and deeper transformation compared by enlarging problems' structuring perspective in terms of time and stakeholder integration.

### **2.1.2. Means for social inclusion**

As can be appreciated, both approaches aim to be comprehensive in the appreciation of society involvement in decision-making and implementation processes which becomes relevant given the impact of the evolution of cooperative norms and institutions to manage commons resources and to redistribute inequalities, as well as to break down barriers for innovation and the development of more socially responsible corporations (i.e. Kallis and Norgaard, 2009; Porter and Kramer, 2006).

This aims are recognized by post-normal science that explicitly encourages social involvement to participate in the solution of important issues, since social commitment is expected to improve the significance of the debate and problem solving propositions (i.e., Bankes, 1993; Bryson, 2004; CEECEC, 2010). Integrating stakeholders outside the policy-making is urged giving their legit and democratic based right to take part of societal changes in addition to being “competent” to trigger public acceptance of a project (Mitchell et al., 1997; Reed, 2008).

Such aims, allow transition and adaptive management to be relevant to practically any kind of problem structuring an implementation context; but particularly to those simultaneously dealing with social and ecological sustainability goals involving multi-dimensions and complex dynamics (de Gooyert, 2016; Kempt, 2007). The decision of whether or not adopting such practices depends on a few factors. First the resources available, mainly time and money to develop a widely inclusive participatory project and the relevance of including stakeholders at different governance levels. The last one depends on the judgment of the actors triggering a project’s initiative and is closely related to their political will to make the process inclusive. In a number of management cases, limiting the participation of certain stakeholders has been seen as a desirable objective when conflicting points arise among participant, or when some actors look to protect the particular interests of the group (Mitchell et al., 1997).

Additionally, transition management claims to be in an intermediate point between top-down and bottom-up approaches. That is because transition management looks to engage stakeholder at all possible levels to share information and knowledge expecting to gain mutual understanding, commitment to implementation and improve solution making. Transition management tries to utilize innovative bottom-up developments in a more strategic way by coordinating different levels of governance and fostering self-organization through new types of interaction and cycles of learning and action for innovations offering sustainability benefits (Kemp et al., 2007).

Here, adaptive management becomes a tool to put the principles of transition management into practice at each governance level. In this sense, management becomes more open and learning oriented. Then the solution at each level corresponds to adaptive management implementation, mostly in developing response capabilities. When the different levels of governance implement adaptive management, the individual systems they influence contribute to shape the overall system, coevolving to achieve ultimate societal goals. Adopting transition management, co-evolutionary relationships develop from a cooperative perspective and not from the competitive and dominate aims; with this, transition management contributes to co-evolution as a value-free process of change (Kallis and Norgaard, 2009). Under such perspective hierarchy is not seen as authoritarian power segmentation, but as a structure to define relevant tasks and responsibilities at each level.

Under the understanding of transition management and adaptive management potential benefits, it seems appropriate to apply such framework to the innovation case and its social drive goal. Nonetheless, before embracing a methodology because of its features, it is important to recognize its drawbacks.

In this case, authors in project management and problem structuring methodologies point out that despite the benefits of social inclusive approaches to potentially improve results and to respond to social justice principles, the dynamic nature of these management practices creates additional challenges. For instance, the more people participating, the harder to manage the process and allocate tasks, the more resources have to be employed and the more difficult to achieve consensus and prompt equal participation, among others (i.e. Bryson, 2004; Carey and Harris, 2016; Davies and Brady, 2016). Hence, methodologies designed to manage and integrate stakeholders for learning and supporting decision making process have to be implemented and customized to fit the particular aim of change (Vennix, 1999; Yang and Sung, 2016).

In addition to planning challenges, de Gooyert et al. (2016) point out that policy developed throughout transition management approaches often meet significant policy resistance during implementation, which occurs when problem intervention does not reach the desired goals or produces unintended effects because of a poor understanding of feedback effects among actors and system's components interaction (Sterman, 2000). In this regards, Gooyert et al. (2016) suggest that system dynamics can positively contribute to diminish policy resistance by formally mapping the system at the problem structuring phase and thus, acknowledge causalities, identify potential policy resistance sources and plan accordingly.

Stressing the trade-offs of transition management does not intend to discourage the implementation of inclusive practices, but aspires to encourage practitioners on introducing additional tools and designing practices to successfully accomplish the desired aims.

### **2.1.3. Operationalization of transition management**

Transition management involves three levels of planning and analysis, which despite having a hierarchical order are continuously influenced and adjusted according to inputs and results shown at each level. This responds to the co-evolution principle that applies to planning when promoting cause-effect-cause loop analysis throughout levels (i.e. Kallis and Norgaard, 2009; Kemp et al., 2009). In a practical scene, co-evolution embraces interdependency across governance levels. Each level shows relative self-governance in practical decision-making processes and, at the same time each level influences the others because of their constant interaction. These levels as described by Loorbach (2004) are:

- Strategic: vision development, strategic discussions, long-term goal formulation.
- Tactical: agenda building, negotiating, networking, coalition building.
- Operational: experimenting, project building, implementation.

And so, transition management is about organizing a multilayer process where stakeholders, resources, priorities and beliefs are managed in a cyclical way responding to the willingness of actors to cooperate in solving a joint problem. In spite of having common interest in problem solving, each level represents individuals and organizations that are independent of each other in the sense that they cooperate and get together only to pursue the ultimate goal of a system. Otherwise, there is no common agenda among them.

Specific stakeholders with different capabilities, expertise and priorities participate at each level, employing distinctive tools to achieve particular goals associated to the ultimate goal of the system in transition. On account of this, adaptive management is applied to enable a particular level to function, communicate and respond to changes in other levels. As expected, the outputs at each level differ and when they change from what is expected, make the other levels to adjust their goals and planning as well (co-evolution). Here, adaptive planning is key for monitoring and evaluation at each level as to influence the operative process in order to achieve the ultimate goal, aligning stakeholder's standpoints so they support each other through a social learning process expected to produce profound innovation and improve current system's status.

From a transition management long-term perspective, the social development aim of sustainable innovations corresponds to action planning at the strategic level by creating the circumstances to develop nurturing bottom-up solutions at the former levels of governance. At the tactical level, innovative ideas can emerge and transform into material solutions expecting to bring benefits that respond to the societal challenges related to environmental sustainability topics. Lastly, the operational level can be related to action taken to overcome the uncertainties that obscure tactical level planning, which can be interpreted as to tackle the challenges for implementation of sustainable innovations.

Figure 2.1 exemplifies transition management approach as a plausible application to sustainable innovations, aiming to capture the relationships and interdependences described in the previous paragraphs. As it is suggested in Figure 2.1, to implement such framework it is critical to define the means for end-users' integration and to do so, it is desirable to formally acknowledge end-users right to participate in societal change initiatives, plus considering the relevance of their intervention to build up on innovation's development, for which a value co-creation approach appears to be a suitable solution to be followed.



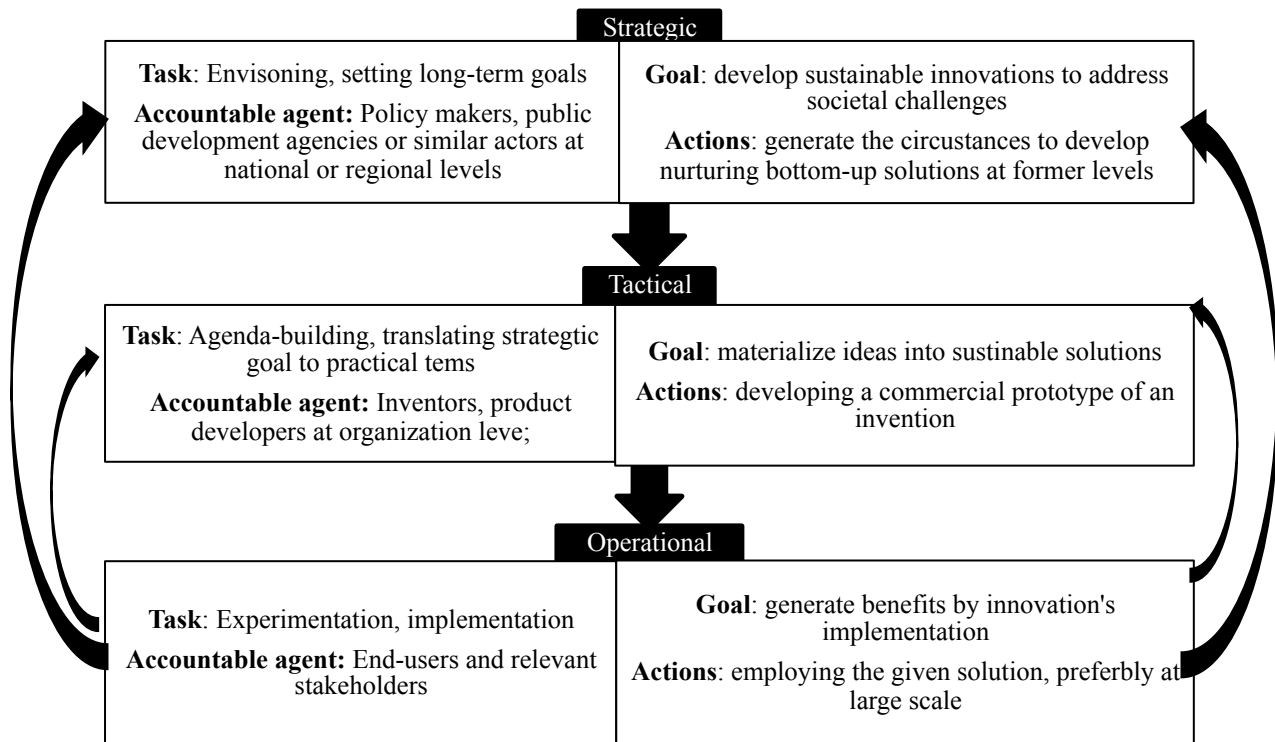


Figure 2.1 Transition management approach example to the innovation case

## 2.2 VALUE CO-CREATION

### 2.2.1 Definition of value co-creation

To recall, research shows that sustainable innovation initiatives emphasizing advantages such as cost reduction, quality or productivity improvement are likely to fail (Sterman, 2013). When innovations are justified and communicated as “a way to help the world” other relevant features of interest to end-users might appear unclear. Lack of comprehensible product advantage has a potential negative impact on product credibility despite of product performance efficiency (i.e. Kotler et al., 2005; Trout and Rivkin, 2000). To overcome the issue of miscommunication and even a more prejudicial one, to avoid developing products that bring low value to end-users, literature suggests involving end-users in a value co-creation platform. Such practice is believed to improve understanding between developers and end-users to make product improvements as well as to allow for product’s perceived value assessment. And with this, find product features that are valued by users and do not prioritize the ones that developers have on high stand (i.e. de Jong et al., 2015; Grönroos and Voima, 2013; Janeschek et al., 2013).

Despite the relative novelty of value co-creation approach, a particular evolution of post-modern marketing perspective focuses on end-users’ interventionist rights, where end-users are characterized as prosumers and not merely customers. Hence, value co-creation entails a “production by consumers”

process aiming to increase involvement on the construction of end-users own well-being. Under this perspective, it is possible to recognize value co-creation as function of interaction, which aims go beyond management purposes (Alves et al., 2016; Grönroos and Voima, 2013).

As described by the literature, value co-creation can be defined as a holistic management initiative that exploits innovation and change opportunities through the development of networks of trust and cooperation, bringing different stakeholders together to produce valued outcomes, intending to create meaning for the long-term adoption and diffusion of social innovation (i.e. Alves et al., 2016; Martinez-Canas et al., 2016; Yang and Sung, 2016).

In co-creation environments, end-users acquire a different stand. They are not seen as potential customers helpful to product improvement studies, but they are warrant of a power position based on their right to directly intervene on creating what they consume. This is somehow a sign of respect for individuals' position where the social role takes over the economic role that reduces end-users to product buyers only (de Jong et al., 2015).

Hence, value co-creation explains how end-user participation in innovation development initiatives is essential for creating more value, such that relevant stakeholders take part of the creation process. Participation is seen as a way to support stakeholder's empowerment and engagement that contributes to strengthening stakeholders' self-determination and self-efficacy by learning and doing. Accordingly, to successfully accomplish the goals of value co-creation in terms of stakeholder empowerment and engagement, the process to be followed should facilitate access to all interested parts, be transparent, enhance dialog and enable for risk-benefit analysis. By creating such circumstances a smooth and active flow of the process can generate positive outcomes through participatory action (Martinez-Canas et al., 2016).

Regarding the process Yang and Sung (2016) warn about the complexity related to integrating multidisciplinary-stakeholder given that different point of views, interests and backgrounds represent challenges to communication and consensus goals. This is because the more diverse the participants group is, the more difficult it is to achieve the same understanding of a given product/solution. In this terms, value co-creation aims to facilitate the alignment of mental models among key stakeholders for the effective progress of social innovation. Here, a more effective approach is needed to enhance dialog, collaboration and learning, particularly when aiming to contribute to high social purposes.

### **2.2.2 Operationalization of value co-creation**

Different approaches to value co-creation arise in various fields. Alves et al. (2016) identified three general categories, a first perspective gives more relevance to organization's interests particularly regarding commercial aims; a second one underlines the study and development of tactics that enhance

value development process; and a third one focuses on end-users' significance in the sense that it recognizes their rights to guarantee that their values and interest are part of the value creation process, and thus of the resulted product.

Consequently, an approach that supports a shift in considering organization not as a value definer but as an inclusive and participative agent is desired to comply with the second and third value co-creation perspectives defined by Alves et al. (2016). Thus, operational practices to value co-creation process should be coherent to the organizations' collaborative goal to construct value throughout different layers by including end-users in the process.

Aiming for multiple ideas and stakeholder integration, Gaurav (2010) argues that co-creation has to follow an organized and facilitated process, ideally via face-to-face interaction. In this regard, Yang and Sung (2016) developed a value co-creation guideline based on innovation's challenges perspective, which includes the following challenges:

1. Enhancing willingness for participation: recruiting interdisciplinary members and adopting a holistic design thinking;
2. Finding appropriate solutions: diving into the issue, defining a facilitation method and presenting conclusions;
3. Solution prototyping: solution monitoring and implementation assessment.

While the first challenge refers to the decision of deploy value co-creation opportunities and the third challenge is related to materialization of the solution, the second challenge is identified as the core of value development (Yang and Sung, 2016). Hence, in order to find appropriate solutions, agents triggering initiatives need of resources and tools to convert concerns and ideas into well-defined value. Depending on the circumstances of each case, different tools can be applied to this challenge.

In cases where time and/or financial resources are limited, software applications are conceived as adequate. For instance, Internet platforms provide participants with easily accessible tools to voice their ideas, opinions and understanding about product/service characteristics and to share knowledge with other stakeholders in meaningful innovation development topics. Another relatively new approach is to employ simulation as an instrumental innovation form to materialize the potential of a given idea. Throughout virtual environments, end-users can explain their reactions to product employment and make suggestions on how products can be improved (Gaurav, 2010; Martinez-Canas et al., 2016).

When possible, direct interaction provides collaborative opportunities that might lead to increase stakeholder engagement through the implementation of face-to-face applications. Here, facilitated sessions can involve material interaction where participants are asked to manipulate physical

components (i.e. prototypes or tool kits) with featured technologies of the solution to later provide feedback and make suggestions. The advantage of employing these types of tools is related to creating a close experience to the innovation's form of use (Gaurav, 2010).

Other facilitated sessions do not involve interacting material. In these cases, discussion and analysis turns around topics and ideas using tools such as storyboards, focus groups, peer-to-peer networks and brainstorming among others. The advantage of these types of tools is associated to allow opening perspectives and increase the number of ideas shared (i.e. Hair et al., 2003; Kotler, 2005).

Either through software interactions or personal encounters, participants improve learning and knowledge by allowing direct communication with one another. Also, combining the referred tools might lead to define personalized interactions means to create well-customized process that become the seed of social change driven from citizens themselves.

### **2.3 VALUE PERCEPTION ASSESMENT**

Value is an indicator of the degree to which an unmet need is satisfied. Because of this, value is closely related to desirability and functionality (i.e. Heetae et al., 2016; Porter, 1998). Although a solution has a unique functionality, the point to which performance is valued depends on end-user's judgement of its usefulness. Such appreciation changes among end-users according to a number of factors mainly related to (i) the context of the problematic situation the solution is meant to tackle and to (ii) the very unique standards and expectations of individuals assessing the solution (i.e. Kotler et al., 2005; Porter, 1998). In this manner, it is evident that perception is an ambiguous concept; criteria has to be defined to construct metrics that enable to understand and quantify perceived value to be used as an indicator to innovation's assessment (Zeithaml, 1988).

Intending to contribute to innovation development, managerial research describes a wide range of methods to sketch implementation feasibility. Such methods are typically related to defining the value of a solution as perceived by end-users. Here, value perception represents how much end-users appreciate the employment of a product or service. Depending on the level and quality of the interaction, either products get discarded for future use or end-users engaged to the product for continuous employment (i.e. Kotler et al., 2005; Porter, 1998).

Moreover, given the social implications of value assessment and its utility to product planning, the concept of perceived value has been discussed from diverse perspectives. From an economic perspective, value is seen as a quantitative concept materialized in the price that end-users are willing to pay for a determined offering (i.e. Goodwin and Wright, 2014; Kotler et al., 2005; Fleith de Madeiros et al. 2016). For example, when using a product or service, users associate certain value in

relation to the quality and the features of the solution and such value can be translated into monetary terms.

Value can also be analysed from a psychological perspective in relation to cognitive and affective topics affecting product perception (Kotler et al., 2005). In this case, the utility of a product appeals to personal characteristics such as values, culture and concerns. This reveals a vision of consumption as an action beyond individual satisfaction, performed towards more meaningful interest. In this manner, Porter and Kramer (2006) suggest that the increased awareness regarding environmental issues takes organizations to pay particular attention to the development of green categories, referring to products produced in a sustainable way or products which use contributes to alleviate environmental related issues. Hence, Kotler et al. (2005), Porter (1998) and Trout and Rivkin (2000) among others, developed a series of strategies to reinforce the environmental and sustainable attributes of green categories to appeal to the qualitative features of value perception.

As suggested by Zeithaml (1988), both economic and social perspectives are fundamental to jointly evaluate quantitative and qualitative elements to define value perception in a comprehensive manner. According to this perspective, Fleith de Madeiros et al. (2016) explain perceived value as the difference between what is gained from using a product (bonus) and the risks to obtain such benefits (onus). In this manner, perceived value is represented and quantified in form of a benefit-sacrifice ratio associated to the acquisition and use of a given solution.

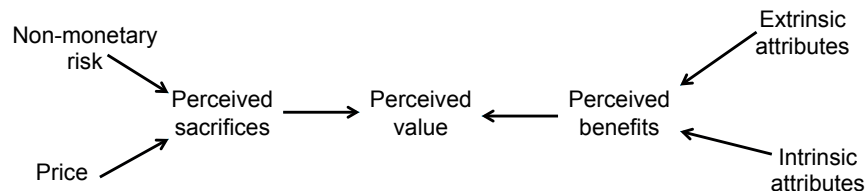


Figure 2.2 Perceived value components

Source: Adapted from Fleith de Madeiros et al. (2016), Heetae et al. (2016) and Zeithaml (1988)

Figure 2.2 shows perceived value components and portrays the relationships among them as described in the literature. Probably because of the understanding of value as a sum of components, literature is full with perceived value models based on linear and static analysis. This is also the case for perceived value assessment applied to sustainable solutions where perceived value is often analysed as a linear price-green attribute valuation relation (i.e. Fleith de Madeiros et al. 2016; Heetae et al., 2016). Consequently, Figure 2.2 describes a general linear model for value assessment where value is build up from the joint evaluation of sacrifices and benefits as perceived by end-users.

On the sacrifice side, two main elements can be identified price and non-monetary risk. Price is related to monetary risk assuming rational-economic thinking of end-users (Goodwin and Wright, 2014). Non-monetary risks are all costs around the solution (other than price), and all potential threats related to solution acquisition and implementation. This includes concepts such as time spending to implement the solution, psychological distress regarding solution's proficiency, as well as other indirect cost such as product replacement or substitution to solution's implementation (Zeithaml, 1988).

On the benefits side, extrinsic and intrinsic attributes categories are described. Intrinsic attributes are features directly related to product or service functionality. In other words, they are the components at the core of the solution. While extrinsic attributes refer to features developed to complement or improve the way intrinsic attributes are used. For instance, thinking of a car an intrinsic attribute is mobility and an extrinsic one could be related to fuel consumption efficiency as explained by Fleith de Madeiros et al. (2016).

To recap, the perceived value of a product depends of the risk end-users are willing to face for the acquisition of the benefits they expect (Goodwin and Wright, 2014). Therefore, end-users are entitled to perform an assessment of value based on comparing the utility they are promised and that they effectively gain when implementing the solution as to determine if the solution satisfies its needs according to expectations (Kotler et al., 2005).

Consequently, defining perceived value appears to be useful when used as mediator between product developers and end-users. Simultaneously assessing perceived value in terms of sacrifices and benefits becomes constructive for the successful implementation of sustainable innovations. In this sense, a holistic value assessment contributes to tackle innovation failure challenges related to miscommunication (i.e. exaggerate or undervalue relevant benefits) and addressing end-users' needs in a wrong way (i.e. ignore costs, focusing in irrelevant problems or adopting a win-win view) as discussed by Gourville (2005), Repenning (2012) and Sterman (2013) among others.



### **3. TOOLS FOR DEVELOPING SUSTAINABLE INNOVATIONS**

#### **3.1 NEW TOOLS FOR PARTIALLY ADDRESSED PROBLEMS**

There are many aspects surrounding innovations' development that make it virtually impossible to predict whether an innovation will make it through implementation. Since prediction is not an option, a better understanding of innovation's development is already good to improve the perspective and define whether implementation is feasible or not (Nagy et al., 2013).

Since this is already a problematic situation for new products, it can be recognized as an even bigger defy for innovations. Kotler et al. (2005) explain how typical market research approaches combine qualitative and quantitative tools as a mean to compare new products with similar products in a mature life cycle stage. Following this reasoning, Trout and Rivkin (2000) advise that a special approach should be followed in the case of innovations where product comparison seems to be a practical but only partially worthy solution. This is particularly evident when considering that innovations contain unexpected characters, for which it is not very reasonable to compare them with existing solutions.

Given that current innovation development approaches in managerial research have not demonstrated superior performance, other methods are worth to be explored to support and improve the standing of the sustainable innovations.

In this regard Mingers and Rosenhead (2004) advise that when adopting methodologies to new uses, a problem perspective must be adopted as to avoid methodological bias. The authors suggest starting by distinguishing well-structured problems from ill-structured ones. Well-structured problems are generally easy to recognize. This type of problems describe consensual information with clear constraints and well-defined cause-consequence relations for which, performance measures are easy to spot. Whereas ill-structured problem, representing blurry, messy and conflicting situations in which even agreeing on problem definition is controversial therefore, problem definition is a critical issue to tackle (Pidd, 2009).

The use of problem structuring methods recognizes the issue of problem definition as being a problem on its own. It is argued that different methods have their own limitations and strengths shaping problem understanding and thus, defining particular policy conclusions. On this matter, problem-solving literature suggests that problem definition is often the result of the selected problem structuring method itself (i.e. Andersen, 1976; Sterman, 2000).

Attempting to avoid methodology bias when exploring new applications to existing methods, academics suggest to first structure the different aspects or dimensions of a problematic situation rather than attempting to provide a straightforward problem treatment (i.e. Andersen, 1976; Kelly et al., 2013; Meadows, 1976; Mingers and Rosenhead, 2004; Rosenhead and Mingers, 2001).



Accordingly (i) formal uncertainty treatment, (ii) scenarios, (iii) models, (iv) system dynamics and (v) integrated assessment, are explored as potential tools to structure and address sustainable innovations challenges, expecting to cover the main dimensions concerning sustainable innovation development.

## **3.2 FORMAL TREATMENT OF UNCERTAINTY**

### **3.2.1 Definition of uncertainty**

To properly treat uncertainty, it is vital to first understand what uncertainty is about and how it is conceptualized throughout different disciplines and problem solving perspectives. In this regards, it is important to recognize that there is not only one type of uncertainty, but a full range of uncertain circumstances for each problem faced. Hence, uncertainty is understood with some variation depending on the field, the level of uncertainty, the source of uncertainty and the outcome or element to which it is associated. A number of definitions and compilations have been made underlying different properties and consequences of uncertainty. The list below provides a short analysis of relevant concepts and interpretation of uncertainty as found in Walker, et al. (2013) and CEECEC (2010):

1. Shannon (1948): a mathematical theory of communication

Formalizing the relationship between uncertainty and available information, implies that uncertainty is quantifiable and thus it that can be measured and threaded

2. Ravetz (1990): situation of inadequate information, ranging from inexactness, unreliability, and border with ignorance

Considering the idea of inadequate information, implies that uncertainty is likely to remain despite adding new information which highlights the relevance of information reliability

3. Walker et al. (2013): insufficient knowledge about an outcome either in future, past, or current events

Referring to deficient knowledge reveals uncertainty's subjectivity. Since it is not easy to set the border to state when enough is enough, uncertainty is closely related to perception and beliefs of those defining knowledge goals

4. Millennium Ecosystem Assessment (2003, p. 210): "an expression of the degree to which a future condition (i.e., of an ecosystem) is unknown. Uncertainty can result from a lack of information or from a disagreement about what is known or even knowable"

The idea of disagreement reinforces the social and ethical concept of uncertainty where it is substantial to define when efforts will not be made given that information is consider complete

5. Walker et al. (2003, p.8): "any departure from the unachievable ideal of complete determinism"

Suggesting that a completely deterministic knowledge is unachievable implies that uncertainty

co-exist with science, which advocates for an approach to science beyond absolute accuracy. Translated to a practical arena, uncertainty is problematic because whenever there is uncertainty, there are additional barriers to make adequate and satisfactory decisions. Kotler et al. (2005), suggests that under a decision-making perspective, uncertainty is considered unavoidable but manageable. Such approach, as explained by Shannon (1948), is necessary to assume that uncertainty can be assessed and tackled, providing opportunities to improve the current state of the problematic situation.

### **3.2.2 Types of uncertainty**

Walker et al. (2013) argue that in problem solving situations decision-makers have little appreciation for assessing and differentiating uncertainty. The lack of uncertainty understanding makes it difficult to find the right approach to deal with it. Some authors suggest that attitudes such as ignoring or making little effort to identify and classify uncertainty are based on the fact that decision-makers prefer to deal with certainty, using intuition or heuristics to minimize uncertainties and reduce mental effort, falling in the trap of giving them a deterministic treatment (i.e. Goodwin and Wright, 2014; Tversky and Kahneman, 1974; Vennix, 1996).


Nevertheless, for some cases the scale of uncertainty is so large that decision-makers feel unconfident about applying simple heuristics to make a decision. This is the case of the present project where the main agreement of the consortium regarding the status of the project, was recognizing that they do not know enough to properly handle innovation's implementation. Accordingly, this section aims to deliver a basis to improve the management perspective of uncertainty for the particular needs of the case. Understanding the types and sources of uncertainties contributes to structuring the needs and defining the efforts to be made in analysing and choosing appropriate method(s) to deal with it.

In an effort to better relate uncertainty types to their practical implications, Table 3.1 compares uncertainty as characterized by different authors in a decision-making perspective. As it can be seen there is general consensus on associating low uncertainty level with quantifiable conditions. While deep uncertainty level is associated either with limited knowledge or complete ignorance, which is related to the unpredictability of natural systems and particularly to the instability of social systems for which reactions can at best be described but not quantified.

Here, qualitative statements are the only available metric. Consequently, low uncertainty level can be referred as stochastic or epistemic nature for which the use of research, probabilities and quantification allows to better handle this type of uncertainty.

Table 3.1 Uncertainty: scales, associated nature and metrics comparison

Source: literature compilation

Level	Scale		Nature			Metrics
Deep uncertainty	Walker et al. (2003)	Ravetz (1990)	Walker et al. (2003)	MEA (2003)	Quade and Carter (1989)	MEA (2003)
	5. Total ignorance	Border with ignorance	Inherent variability (natural and social systems)	Unreliable human behaviour predictions	Real uncertainty (actors' behaviour)	Qualitative statements
	4. Irreducible ignorance					
	3. Recognized ignorance					
	2. Scenario uncertainty	Unreliability	Epistemic (knowledge flaws reduced by research)	Ambiguously defined data or terminology Quantifiable errors	Stochastic (frequency-based probabilities)	Quantitative metrics
Low uncertainty	1. Statistical uncertainty	Inexactness				

Notwithstanding the consensus in defining low and deep uncertainty, scales illustrate a blurry perspective for the type of uncertainty that is not totally quantifiable (low uncertainty) but that has either certain degree of predictability or possibilities to be clarified. This level is in the border of what Walker et al. (2003) call recognized ignorance-scenario uncertainty and that Ravetz (1990) generalizes as broader with ignorance-unreliability. At this middle uncertainty level, there is poor outcome understanding, which could be explained by the knowledge gaps on cause-consequence relation or by the impossibility to quantify such relations. Despite knowledge limitations, there is at least awareness of the unknown elements. Perhaps the major controversy relies on the nature of this middle uncertainty level. Here some authors suggest that its strong relation to social and natural systems makes quantification unfeasible (i.e. MEA, 2003; Quade, 1989). On the other hand, Walker et al. (2003) implied that research could possibly reduce this type of uncertainty, leaving an open window for quantification with an important warning about data ambiguity and reliability concerns associated to its nature.

Uncertainty is also related to other concepts found on its own definition. For instance, Goodwin and Wright (2014) explain decision-making under risk and uncertainty where the first can be related to low uncertainty while the second can be associated to deep uncertainty as found in Table 3.1. Similarly, the European Environment Agency (2001) distinguishes uncertainty from risk and ignorance. Here, ignorance is considered as disjoint from uncertainty, whereas a number of authors claim a relation between the two elements. To avoid terms confusion and following the advice of Walker et al. (2013), this research refers to risk as one type of uncertainty (low uncertainty level) and to ignorance as another type of uncertainty (deep uncertainty). This is based on the appreciation that both risk and

ignorance denote a barrier in the decision-making process. Therefore, both terms can be associated to uncertainty when referring to decision-making cases.

### **3.3. SENARIOS**

#### **3.3.1 Definition of scenario**

Scenarios are built from formal or mental models, representing descriptions of possible, but not necessary the most probable futures. This approach belongs to the field of futures or forward-looking studies and simulation research, which are considered very ambiguous multi-fields (Axelrod, 2003; Borjeson et al., 2006; Vennix 1990; Wollenberg et al., 2000). Authors such as Amer et al. (2003) and Zurek and Henrichs (2007) explain how increasing attention is being paid to the use of scenario techniques given its observed usefulness to study uncertainty and complexity. As for this case, Rhisiart et al. (2005) point out that forward-looking approaches have a key role when it comes to innovation uncertainty treatment. Here, scenarios can be useful outside the innovation process for strategy development, at the start of the innovation process to understand innovation's ground, and as a monitoring tool along the innovation process.

As it can be implied, there is an extensive list of scenario definitions addressing features, purposes and benefits of using scenarios according to the field of application. Perhaps a definition that encompasses the general elements found in typical scenario descriptions is the one provided by Schwartz (1991) who explains scenarios as “a tool for ordering one's perceptions about alternative future environments in which one's decisions might be played out” (Schwartz, 1991, p.4).

Such definition refers to one of the areas of debate on the way scenarios are described. According to the definition, scenarios are constructed upon perceptions. Depending on the interpretation of perception, this approach might conflict with the qualitative and quantitative characteristics of scenarios. If perceptions are taken as merely qualitative statements then it restricts the use of scenarios to narratives. However, when perceptions are interpreted as theories there is window for a quantitative construction and interpretation of scenarios (Borjeson et al. 2006; Sterman, 2000; Wright, 2005)

Intending to put together the different definitions of scenarios, Zurek and Henrichs (2007)'s and Wright (2005) provide an analysis out of their own definitions' compilation. Zurek and Henrichs (2007) explain that scenarios are a rational description of a set of logic assumptions and internally consistent relationships, for which the scenario construction process becomes more meaningful than the actual outcome. Meanwhile, Wright (2005)'s focused on analysing the practical implications of using scenarios. Correspondingly, the author's concluded that scenarios have the particular quality to stimulate dialogue, for which they can be described as useful for learning, controlling and communicating.

As suggested by the literature, scenarios are not about making predictions neither forecast; but are meant to improve understanding of the implications of known current options for which its proficiency level lays on the amount, quality and reliability of information used to construct them. Then, the difference with forecast and predictions comes to the point that those latter ones are based on trends and probability, mainly quantitative inputs. In this context, Schwartz (1991) artfully explains that the outcome is not the exact vision of the future, yet a formal recognition and evaluation of insights to potentially improve decision-making against potential occurrences.

- Scenarios and midlevel uncertainty

Following Walker et al. (2013)'s ideas, scenarios are especially useful to handle midlevel uncertainty or uncertainty level 3 according to their scale, because they allow visualizing the multiplicity of plausible futures by iterating among different structures.

Moreover, scenarios are suggested to be an efficient tool to draw assumptions and perceptions together with theories that explain a given situation. Hence, scenarios lead to decrease knowledge uncertainty by building up confidence in the assumptions described and perceptions hold (Zurek and Henrichs, 2007).

The fact that scenarios are considered to be useful to deal with uncertainty can also be related to their capacity of combining hypothetical descriptions of the future in qualitative terms using words or diagrams, together with quantitative terms using numerical assessment, (i.e. Sterman, 2000; Vennix, 1999; Zurek and Henrichs, 2007). To manage uncertainty at the identified midlevel, analysis is likely to require of quantitative metrics combined with qualitative statements to construct a comprehensive picture of available knowledge. If knowledge description gets restricted to either qualitative or quantitative terms, there is a potential risk to leave information behind.

These arguments support Rhisiart et. al (2005)'s proposition of using forward-looking approaches for innovation uncertainty cases. Then, it seems reasonable to say that scenarios are a suitable approach for the midlevel uncertainty on the innovation's perception case.

### **3.3.2 Types of scenarios**

Scenario typology is an important instrument to find the most suitable ways for choosing and developing the right method for a given case. To contribute structuring scenario categories, different authors have developed classifications based on the analysis of typologies found on the literature (i.e. Amer et al., 2003; Borjeson et al. 2006; Walker et al. 2013). For analysis purposes, Borjeson et al. (2006) proposed categorization is adopted given its detailed level of description. Such scenario types are explained next.

- Predictive scenario

Ambitions to know with close accuracy, how an event will develop in advance by studying the development of key variables and driving forces in a quantitative way where probability, historical data and trends play a significant role. Its use is associated with adaptive planning and threats identification (Borjeson et al., 2006 and Walker et al., 2013).

Types of scenarios as explained by Borjeson et al. (2006)

1. Forecasts: describe future conditions based on explaining the consequences of unfolding the most likely development. Mostly used to describe short term with a low uncertainty level.
2. What-if: describe future developments based on explaining a specific near-future critical event. Events are generally associated to externalities, decisions or a combination of both.

- Explorative scenario

This type of scenario helps to discovering and learning by studying plausible developments from a variety of perspectives within a long time-horizon. They are useful in cases where the structure or boundary is barely understood or unknown. In this regards, they are suitable to uncover the structure or part of it along the scenario strategy drawing. Its practical use is associated with decision-making, and learning (i.e. Amer et al. 2003; Borjeson et al., 2006; Walker et al., 2013; Wright, 2005).

Types of scenarios as explained by Borjeson et al. (2006)

1. External: focus on factors beyond the control of stakeholders and provide the background to assess policies and strategies. Its use increases organization's responsiveness level to weak signals of profound changes in the environment, being particularly convenient to build common understanding among stakeholders with different backgrounds and conflicting goals
2. Strategic: focus on internal factors and takes externalities into account, this type of scenarios integrates policy making and strategy design aiming to describe plausible consequences from a set of decision-making options. They explain how the outcome of a decision changes according to the future state of key indicators previously identified

- Normative scenarios

This type of scenario is goal directed and deals with finding the right paths to arrive to ideal futures. They are also considered to be useful to deal with stakeholder conflicting and uncertainty about future developments given a particular decision. Its main use is associated with strategy monitoring and implementation. (i.e. Amer et al. 2003; Borjeson et al., 2006; Walker et al., 2013).

Types of scenarios as explained by Borjeson et al. (2006)

1. Preserving: this type of scenario is used when it is possible to achieve a goal within the current

structure of the system, they are closely related to cost-efficiently and optimization modelling.

2. Transforming: this type of scenario is used when structural changes are needed to achieve the defined goal. They are closely related to backcasting to find alternatives fulfilling goals.

### **3.3.3 Scenarios' boundaries**

As it was explained, scenarios are built up over a set of theories, assumptions and perceptions that shape the context of analysis. This helps to define and construct the logic of the system behind the scenario and with this context, it aims to portray the plausible paths that problem of study might take. These two properties, constructing the logic behind a scenario and being able to analyse possible decision-making outcomes diminish uncertainty by reducing knowledge flaws and improving understanding of future situations respectively.

In general, scenario analysis literature acknowledges scenario-based approaches to be useful to handle uncertainty by studying the consequences of a range of different inputs given a defined context. Such context can be also understood as the boundary conditions that allow focusing attention on the area of study. This is a common area of concern and debate in the literature where a number of researchers look for a critical way to accurately define boundaries (i.e. Borjeson et al., 2006; Dewar, 2002; Rhisiart et al., 2005; Sterman, 2000; Vennix, 1999; Zurek and Henrichs, 2007). "Right boundary" can be interpreted as a figurative context limitation that represents the problematic area instead of the whole system. More arguments and reasoning about boundary topic are discussed in latter sections.

When it comes to uncertainty, boundaries are important because, by focusing the area of analysis better efforts can be made to understand the particularities of a given case. This allows for a detail study throughout the implications of decisions made as well as regarding occurrences outside the boundary, to define how such elements affect future conditions (i.e. Richardson, 2011; Sterman, 2000; Walker et al., 2003). Then, decision-making can be tested in isolation or together with hypothetical occurrences, while containing uncertainty about future developments and implications of changes in a wider decision context (Zurek and Henrichs, 2007).

## **3.4. MODELS**

In broad terms, it has been explained how scenarios help to diminish uncertainty in decision-making terms. Now it is necessary to relate scenarios to the construction that allows depicting them. For this, the key characteristics defined for scenario development of this case study are used to identify a suitable scenario building method. To recall, it was defined that an explorative scenario of strategic type is needed, taking into account that boundary and structure definition is critical for satisfactory development; it is also important to consider that the method must be able to properly handle

qualitative and quantitative data since the limited knowledge of this case study makes compulsory to use all information at hand.

Moreover, as it was described, scenarios exist in the form of narratives as a collection of qualitative statements, diagrams representing statements and lastly, quantified scenarios representing mathematical relations of quantitative and/or qualitative variables. Then, the possibility of using a narrative scenario is ruled out since it opposes the explorative scenario's demand to uncover the structure behind the scenario. Since structure is important, a diagrammatic scenario can be used to comply with structure representation requirement. Meanwhile a quantified scenario fulfils explorative scenario condition of representing plausible future developments.

Likewise, simulation indicates to be useful to reduce test structure adequacy and related scenario reliability. Such assessment can only be properly structured with the aid of scenario running tools (i.e. Amer et al. 2003; Dewar, 2002; Sterman, 2000; Walker et al., 2013; Zurek and Henrichs, 2007). With this, quantified models help users to drive conclusions that the limited information processing capacity of the human mind could not be able to take further from a merely assumption based assessment analysis (i.e. Meadows, 1976; Sterman, 2000; Vennix, 1999; Walker et al., 2013).

### **3.4.1 Definition of model**

Along the literature, models are generally described as an abstraction, a simplification or a close representation of reality (i.e. Sterman, 2000; Vennix, 1990). Since models aim to portray reality, it is evident that they should generate "true conditions". Somehow contrasting to this idea is the fact that models are expected to be only "close" to reality which recognizes that scenarios produced by models can merely be an approximation to real world behaviour. This argument raises awareness on the fact that models are imperfect efforts to describe real phenomena.

Models' limitation to reflect situations as they develop in real world can be associated with a few fundamental reasons. First barrier is the complexity to portray reality. Even when models aim to represent "simple" or very detailed phenomena, complexity lays on the fact that is particularly challenging to exactly replicate states that change over time. Second, is the fact that models are restricted to the boundaries around them; while real systems are composed by a combination of social, natural and artificial systems that rarely described strict boundaries. And finally, being a representation of reality, models are subject to interpretation and perception of what can actually be consider as reality. To better understand the limitations of models to accurately portray reality, it is necessary to briefly define what reality means for a modelling perspective and how it plays a role in model making.



### **3.4.2 Types of models**

In a very general way models can be classified as explicit or formal models and implicit or mental models (i.e. Sterman 200; Vennix, 1990). Explicit or formal models are the type of models that aim to translate observed reality into a formal and observable representation that allows them to be useful for research purposes. Some differences might be found in the literature when referring to formal models as mathematical representation, as defined by Vennix (1990). For classification purposes, this research refers to formal as a synonym of explicit models. The second category (implicit or mental models), refers to the knowledge available in people's minds which can be recognized as the interpretation that each individual has of the world based on processing ideas, opinions, assumptions and perceptions into their own creation of reality.

As explained along decision-making literature, mental models are limited by human processing information capacity which not only takes people to use heuristics as shortcuts to reduce mental effort, but it also creates bias in information selection by rejecting information that does not fit with the perceptions they hold at the moment (i.e. Goodwin and Wright, 2014; Meadows, 1976; Vennix, 1999). These developments on brains' information processing are known as selective perception and selective memory. Acknowledging the existence of selective perception and selective memory allow to see the subjectivity of mental models, so that reality as intercepted by individuals is more a social construction than an objective representation (Vennix, 1990).

Hence, people hold different ideas of what reality is and what it represents according to their mental models' construction. Understanding the dynamics behind mental models helps to recognize the existence of theoretical and unavoidable limitations of formal models. Consequently, formal models cannot claim to be representative of reality when reality has a different meaning for single individuals.

Although, it might seem contradictory to the explained brain's limited capabilities to process information, researchers acknowledge that there is a large amount of data stored in people's minds. This argument is key to understand the relevance of mental database information for formal model construction, particularly for the present case where the nature of the uncertainty is related to poor understanding and limited information available. In these circumstances, being able to elicit knowledge from people's understanding makes a difference between having variable information that might lead to close knowledge gaps and not having information at all (Vennix, 1990).

### **3.4.3 Explicit models**

A wide number of explicit model types are found in problem solving and policy making literature. For instance, Vennix (1990) classifies explicit models into physical models (employing a material analogy to represent the real system); conceptual models (describing ideas and physical components to

represent the real system); and mathematical models (using equations to portray relationships in the system's structure). Meadows (1976), describes models categories depending on their relationships (stochastic or deterministic, continuous or discrete, linear or non-linear, legged or simultaneous), their mathematical procedure (statistical estimation, optimization, randomized, differential equations either analytical or simultaneous for simulation) and their information bases (statistics, experiments, theory, observation). Homer (1996) points out two types of models impressionistic (build over judgment and generalizations, not a systemic explanation) and scientific (formally testable and validated). And Coyle (2000) makes a distinction between explicit models as qualitative (maps and diagrams) and quantitative (equations and numerical outputs).

One single model might belong to more than one of the different explicit model types described by the literature. Hence, before going into deep exploration of models' types and associated modelling methodologies, it is useful to narrow the available modelling approaches by characterizing the information and structure needs of explorative scenarios and with that, define a suitable methodology to treat the midlevel uncertainty of the current research.

In this regard, Borjeson et al. (2006) encourage practitioners to apply modelling methodologies that allow for the integration of qualitative and quantitative components within a model structure that facilitates the systematic collection of data. Accordingly, they urge to follow a mathematical modelling approach to cope with soft and hard data integration. From the mathematical models available, they distinguish the possibility to develop either explanatory modelling or optimizing modelling. Exploratory modelling methods are recommended when understanding structure and causal relationships are more relevant than defining a plausible range of future developments. If the modelling purpose is closer to the second priority, optimizing modelling turns to be a better tool. It should be noted that conceptual models also qualify as an explanatory modelling type. Nonetheless, the authors indicate that mathematical models describing system's structure turn to be particularly useful to make a distinction between the influence and impact of internal components and external factors to the system.

Moreover, Kwakkel and Pruyt (2013) propose two specific types of exploratory modelling methodologies to cope with complexity and uncertainty. The first is system dynamics and the second is agent-based modelling. These two methodologies have similar characteristics but also some differences that help to select the more convenient method for a given problem.

Agent-based models' main characteristic is to represent interaction among autonomous entities in a common environment where agents use the environment as a mean to communicate, react to changes, react to other agents' behaviour and share resources with each other. Hence, this modelling

methodology is able to represent behaviour with a rule-based, bottom-up directed approach. Accordingly, the key focus of this type of models is on the agents as to improve the understanding of key circumstances that influence individual responses (i.e. Axelrod, 2003; Kelly et al., 2013).

On the other hand, system dynamics models are built over a set of equations used to represent the structure and characterize relations and dependencies within the structure aiming to understand and replicate the behaviour of a system (i.e. Meadows, 1976; Sterman, 2000; Vennix, 1996). According to Richardson (2011), the foundations of the methodology lay over structural hierarchy. Consequently, boundary definition is key for system dynamics models. Boundaries contain feedback loops as basic structural elements, to describe accumulations' and identify suitable variables controlling rates as to represent activity within the feedback loops. Also, boundaries support the claim that systems naturally seek for equilibrium, so that any action based within system's boundary is directed to overcome discrepancies.

To help defining what approach is more suitable given the problem at hand, Kelly et al. (2013) developed a guide to differentiate methodologies' functional and operational characteristics. The authors suggest that both methodologies are suitable for system understanding and system learning purposes, which is coherent with the learning purposes of explorative models. Then, the main factor to define is if it is more important for the case study to focus on general systemic processes and behaviour or, in individual agents' behaviour.

### **3.5. SYSTEM DYNAMICS**

#### **3.5.1 A distinctive philosophy of science**

System Dynamics is primarily an analysis and impact assessment modelling approach applied to dynamic problems arising in complex social, economic and natural systems characterized by interdependence, feedback, time delays, nonlinearity and hence, circular causality (i.e. Galbraith, 2010; Kelly et al., 2013; Meadows, 1976; Sterman, 2000; Vennix, 1996).

In contrast to inductive or deductive methodologies, system dynamics belongs to a so called "third way to make science" in which discovering and learning from system's structure is believed to be effective to find unexpected consequences based on theory testing and simple assumptions identification that underline the causes of systemic reactions (i.e. Axelrod 2003; Videira et al., 2003). As explained by Axelrod (2003), p.5 "...like deduction, it starts with a set of explicit assumptions. But unlike deduction, it does not prove theorems. Instead, a simulation generates data that can be analysed inductively. Unlike typical induction ... simulated data comes from a rigorously specified set of rules rather than direct measurement of the real world".

The fact that the methodology stands in an intermediate, blurry point compared to typical problem framing and decision-making approaches allows system dynamics models to be useful to address ill-structured problems, confusing, messy and conflicting situations despite limited information and poor problem understanding. Nonetheless, this same feature might arise doubts on the formality and credibility of system dynamics models.

Introducing assumptions in system dynamics models is not seen as a weakness but as strength of the method (Barlas and Carpenter, 1990). By making assumptions explicit and integrating them in a logic structure, assumptions can be tested to define whether or not the ideas and perceptions they represent are appropriate to explain the problem at hand. Whenever they are not, they can be ruled out and a new hypothesis can be tested while improving systemic understanding in the process (Homer, 1996).

Consequently, a key aspect of developing dynamic theories is the level of consistency between the structure (graphic representation of the theory) and the behaviour produced (simulation results consistency). When a system dynamics model portraying a dynamic theory is capable to produce behaviour within a logic range and with a structure consistent with the causal relationships of the real system, then numerical imprecision of the output is not a major concern.

Acceptance of quantification inexactness comes from the relativist philosophy to which post-normal science belongs. From a fundamental philosophy perspective knowledge is objective; hence, formal accuracy is needed. Under this perspective, uncertainty, assumptions and perceptions are rarely addressed. In this case, purely data-driven, correlational models are considered as proper aids for decision-making purposes. On the contrary, post-normal science and the relativist philosophy recognized the utility of using assumptions, judgments and perceptions; particularly when these are the only available inputs. Here, causal models used for explanation are valid as long as the relationships they portray are accurate. Accordingly, under uncertainty cases, post-normal science is in an advantaged position to be employed. (i.e. Barlas and Carpenter, 1990; CEECEC, 2010; Meadows, 1976).

### **3.5.2 Strengths and limitations of a quantified approach in system dynamics**

The attention that the methodology pays to system's structure enables to find information gaps to improve understanding and uncover endogenous causes of the problematic situation at hand. As argued by practitioners, this endogenous perspective is system dynamic's most distinctive characteristic. It is commonly claimed that endogeneity enables to assist decision-makers based on finding leverage points that provide control over system's behaviour. Hence, problem owners and stakeholders can address feasible solutions by triggering change areas that they are able to influence. So that the endogenous point of view represents a change of perspective compared to typical

methodologies where exogenous disturbances are seen as problem triggers, while endogeneity explains how the causes are contained within the structure of the system itself (i.e. Galbraith, 2010; Meadows, 1976; Richardson, 2011; Sterman, 2000; Vennix, 1996).

Consequently, describing and understanding structure is key for system dynamics models. The purpose of the following discussion is to explain the different implications of endogeneity given the two ways used to represent structures in system dynamics; namely system dynamics models in qualitative and quantitative forms.

In qualitative terms, system dynamics models describe structure in the form of conceptual models or Causal Loop Diagrams (CLD). CLDs are useful to describe and communicate system components, interrelationships, causality and feedback loops in a graphical, schematic manner combining words with arrows and polarities that explain the dynamics of a given system (i.e. Sterman, 2000; Vennix, 1990). On the other hand, quantitative system dynamics models are described as a set of coupled, nonlinear, first-order differential or integral equations. Here, system dynamics software allows for a diagrammatic representation of the equations known as Stock and Flow Diagrams (SFD). Nevertheless, it is argued that the relevant structure is represented in mathematical terms by the equations themselves.

Deciding between qualitative and quantitative system dynamics modelling is a classic dilemma among practitioners and researchers. Researchers warn on the use of quantification arguing that the fact that concepts can be operationalized, does not necessarily mean that they can be measured. It implies that quantification could be superfluous and even misleading when pushed beyond a reasonable credibility of the parameters and numerical logic (i.e. Coyle, 2000). Other arguments refer to the fact that given the importance to communicate structure, qualitative models might be more useful for this purpose since quantification might compromise system's components description. In other words, qualitative models are believed to be less ambiguous compared to quantified ones for communication and knowledge sharing (i.e. Sterman, 2000; Vennix, 1996).

Hence, quantification faces clear challenges when translating concepts that might be easier to communicate as narratives than equations, especially when there is poor understanding of their numerical scale or limited numerical data available. Despite these limitations there is also a group of practitioner arguing that because simulation is at the core of the methodology, system dynamics models should always be able to be quantified. This idea is aligned with the arguments of forward-looking studies and simulation research described in the prior sections. Here researchers claim that simulation always adds to the insights even when facing uncertainties about soft variables and data. So that, when assumptions have been integrated in a logical way, they must be tested. Otherwise, there is

not a credible way to argue that insights arise from a credible source (i.e. Borjeson et al., 2006; Homer, 1996; Homer and Oliva, 2001).

These claims should be valid as long as users do not misperceive simulation as a mean to predict the unpredictable. As long as they keep in mind that simulation and corresponding scenarios are not a perfect picture of reality but a mean to experiment and explore causality as stated by the fundamental philosophy of post-normal science to which system dynamics belongs (Bankes, 1993).

Since adopting an endogenous perspective is key for the methodology, it can be argued that simulation is needed to test and observe the implications of endogenously generated behaviour. Without simulation, a CLD might include variables that are not relevant for the dynamics, which can only be verified by formal simulation. This suggests that quantified models provide confidence in the theories about the system that models aim to represent. Then, as long as resources allow it, quantification should be attempted along with an open discussion of limitations and possible drawbacks.

Hence, quantification seems to be a suitable approach when limited knowledge of the system indicates that qualitative modelling might fall short on improving understanding and testing assumptions. This is aligned with Wright (2005) proposed approaches of scenario mix for the quality of Europe, where he explains that to trigger learning, systems thinking and scenario assessment are needed. Moreover, Borjeson et al. (2006) argue that the way uncertainties are tackled has to be closely related to scenario development based on the possibility of combining the decision context and the decision-making process itself. Because of this close relation, a typical feature of scenarios is to identify feedbacks between both decision-making process and system structure, emphasizing interconnections, dependencies and dominance. So that simulation and quantification is necessary to better comply with scenarios' aim to improve understanding and reduce uncertainty.

### **3.6. INTEGRATED ASSESSMENT AND MODELLING**

Rotmans and Van Asselt (1996) refer to integrated assessment as an interdisciplinary and participatory process combining, transforming and communicating multidisciplinary knowledge to allow a better understanding of complex phenomena. The approach is commonly associated to environmental and organizational management topics; however, as argued by practitioners, its application is not restricted to these fields since it mainly attempts to address information needs (i.e. Jakeman and Letcher, 2001; Jones et al., 2009; Videira et al., 2003).

It can be understood as multidisciplinary process of problem framing, analysis, communication and intervention where incorporating interdisciplinary knowledge is key to broad research perspectives and value of results. In this scene Hisschemöller et al. (2011) stress the importance of explaining cause-effect relationships of the problem at hand to build-up a synoptic perspective. To comply with

its knowledge integration purpose, the approach must demonstrate an intention to be holistic in terms of knowledge production and assimilation by fulfilling the next criteria: (i.e. Hisschemöller et al., 2011; Jakeman and Letcher, 2001)

1. Have a genuine will to involve multi-stakeholder representation to inform decision-making
2. Boundary and problem definition are not dependent on the method or discipline of analysis, but on the concerns and interest of stakeholders
3. Bring together a wide set of areas, methods, perspectives, degrees and sources of knowledge

Accordingly, results are expected to differ from single method assessment in terms of added value by (i.e. Hisschemöller et al., 2011; Parker et al., 2002):

1. Delivering a broader perspective compared to single disciplinary assessment
2. Managing uncertainty by merging multidisciplinary knowledge
3. Enhancing action based in incomplete but sufficient knowledge

Integrated assessment often uses a modelling approach together with a participatory approach combining tools and scopes to improve knowledge and decision-making. Integrated assessment using modelling tools is considered a particular category where process is judge to be as important as the product itself. As explained by Jones et al. (2009), p.1183 “computer modelling plays an important role in achieving IA aims by simulating and examining complex and dynamic systems, while participatory procedures are used to enhance the usability and usefulness of the results produced”.

The main value of the approach lies on the creation of a shared pool of knowledge and understanding through a process where a model is used as a transparent and interactive framework for stakeholders learning (i.e. Jakeman and Letcher, 2001; Parker et al., 2002).

Parker et al. (2002) recognize five types of integration to integrated assessment and modelling:

1. Issues: one single situation represents different issues and concerns to stakeholders
2. Disciplines: to look at different perspectives and produce distinctive knowledge
3. Stakeholders: issues do not belong to a single group, decision-makers, policy makers, problem owners and target groups should get involve in decision-making processes
4. Models: different models types can be combined to capture discipline’s multiplicity
5. Scales: diversity of perspectives needs of different metrics to build up understanding

The fact that integration ranges throughout categories implies that tools and methods do not only co-exist, but are expected to be employed.

### **3.6.1 Participatory system dynamics modelling**

Participatory system dynamics modelling (PSDM) is a platform combining participatory procedures

translated into a diversity of tools that support stakeholder involvement in system dynamics modelling tasks for problem structuring and decision making purposes (Videira et al., 2003). This approach responds to integrated assessment needs of creating, analysing and communicating knowledge from diverse disciplines aiming to inform decision-making and is particularly acknowledged for its multidisciplinary character. The rationale behind it claims that by integrating a multiplicity of viewpoints, from layman to scientist, a collective vision is established to effectively work towards problem solving (i.e. Costanza and Ruth 1998; Bots and van Daalen, 2008; Jones et al., 2009; Videira et al., 2003).

By bringing relevant stakeholders' to the participatory modelling process, a neutral ground for communication and interaction is created. While effective communication enables decision-makers to acknowledge other perspectives and gain knowledge from different areas of expertise, direct interaction among actors contributes to develop commitment towards decisions and implementation (Rouwette et al., 2011; Videira et al., 2003).

As it can be expected participatory modelling often involves conflicting stakeholders perceptions, assumptions and understanding about reality. The variability of worldviews inevitably brings complexity to group interaction. Such conflict is managed through focusing attention on the collectively model building's aim (Vennix, 1996). Here the model is used as a boundary object where it becomes a mean for cross-disciplinary and multi-stakeholder communication, supporting collaboration among stakeholders while enabling knowledge merging by sharing ideas, perceptions and building consensus around the issue; by this exercise better, collaborative solutions are expected to arise (Jones et al., 2009; Parker et al., 2002).

In spite that the model is used as a boundary object, it does not mean that the model is the aim of a participatory modelling exercise. According the specific needs of a case, either the participatory process adjusts to cover the model needs, or the model serves to facilitate the participatory process (Bots and van Daalen, 2008).

Given the openness of the method, any type of participation in the modelling process can be considered as participatory modelling (i.e. van den Belt, 2004; Jones et al., 2009). Accordingly, each project combines a particular set of information gathering methods and techniques following its very own needs and resources. Concurring with the needs of the project it is defined whether participatory modelling will take part at some stage(s) of the research project or the whole project from problem identification, data gathering, information analysis, strategy/policy definition, communication of results and implementation (i.e. Hisschemöller et al., 2011; Jones et al., 2009; Parker et al., 2002).

Also, consistent with the principles of integrated assessment, participatory modelling integrates a



number of tools and techniques aiming to incorporate information from different sources to build-up understanding that enables expanding the scope of available information and analysis. As previously described, models depend on sources of information, which vary in terms of nature of data accessibility and problem context. Depending on the level of desired participation, as well as the type of information available participatory modelling might be either focus on knowledge elicitation from groups or individuals, or depend on information gather form the literature or empirical observation (Bots and van Daalen, 2008).

Different tactics are proposed to define a suitable set of tools and techniques to collect information. Some authors recommend starting by relating knowledge needs to the desired level of participation. For instance, if the purpose is knowledge transfer only, participatory modelling could be applied at the end of the project to validate results, communicate results or implement the project. When the aim is to co-produce knowledge it should be either integrated at early stages or along the whole process as pointed out by Jones et al. (2009). In an effort to relate project purposes and knowledge needs to desired level of participation, Arnstein (1969)'s proposed Ladder of citizen participation that has been used as a base for other authors to develop their own scale including Pretty (1995). Table 3.2 shows the similarities of both authors definition attempting to portray two common ways of participation categories as found in integrated assessment and modelling literature.

Table 3.2 Different levels of participation  
Sources: Adapted from Arnstein (1969) and Pretty (1995)

Arnstein (1969)			Pretty (1995)	
	<i>Level</i>	<i>Description</i>	<i>Level</i>	<i>Description</i>
Non participatory	Level 1 Manipulation	Informs participants on a specific process or decision already taken, expecting to gain public support.	Passive participation	Participants are informed of the decision taken in a one-way communication channel.
	Level 2 Therapy			
Degrees of tokenism	Level 3 Informing	One-way communication channel. Feedback aims to evaluate results.	Participation by consultation	Participants are information sources. Problem definition, information analysis and decision-making are tasks of the organizers.
	Level 4 Consultation	Triggers discussion to understand positions or access relevant information.		
	Level 5 Placation	Used when participants have enough information and capacity to propose solutions.		
Degrees of citizen power	Level 6 Partnership	Power is redistributed and negotiation among stakeholders is mediated. Participants share responsibility and action taken.	Interactive	Participants contribute to the analysis, decision-making and planning process where

<b>Arnstein (1969)</b>		<b>Pretty (1995)</b>	
Level 7 Delegated power	Participants represent a larger group, making decisions on their behalf.	participation	participation is recognized as a right aiming for a systemic perspective and a structured learning processes.
Level 8 Citizen Control	Citizens' groups trigger projects and participation where they act as decision-makers.		

Aligned to van den Belt (2004) and Jones et al. (2009) arguments, even a low level participation in model development can be consider as participation modelling. However it does not mean that passive participation is desirable since relating participatory modelling to low stakeholder involvement arises important concerns in terms of ethical considerations and hidden goals of the process. Related to this matter, Videira et al. (2009), encourage practitioners to involve stakeholders and general public as much as possible and throughout the whole participatory exercise to go further than information and consultation in the ladder of participation.

As it can be implied, a variable set of tools and techniques can be developed to respond to knowledge needs, desired level of participation and resources available. There is not a single, straightforward answer to define what tools are better to employ for a given case. This is a typical and crucial question when structuring participatory system dynamics modelling process for which the optimal choice of tools can be defined by responding to the research context at the various stages of the modelling task (Videira et al., 2003). Yet, guidelines provided by practitioners and researchers are helpful to define the particular set of tools that contribute to reach the aims of given participatory system dynamics modelling case.

In this regard, Videira et al. (2009) explain that throughout facilitated modelling workshops, stakeholders interact while contributing to development of a system dynamics model for which this practice is suggested to be a central element to participatory modelling process.

Given the relevance of workshop development to the participatory modelling process, the planning and settings of the workshops have to be carefully structured. Characteristics such as the length of each workshop and the number of participants involved, varies significantly from case to case and depends on different factors mainly associated to problem's complexity, time and available resources (Videira et al., 2009).

Hence workshop planning must account for such factors and to do so, the Scriptapedia as developed by Hovmand et al. (2015) becomes a handy tool to define the most appropriate scripts according to the purpose of the modelling session. This compilation of scripts, best and promising practices to facilitated system dynamics workshops, allows to structure workshop implementation in advance by

identifying the scripts that best suit the step of the modelling proses at which the workshop aims to contribute. Hovmand et al. (2015) advice on adapting the proposed scripts to each case application to better exploit the benefits of the exercise.

Further to facilitated workshops planning, participatory modelling recognises the significance of a number of tasks that complement workshop development and mediate between participation and model development goals. Such tasks contribute to model construction and are performed “behind the scenes”, meaning without direct participants’ interaction. As described by Videira et al. (2009), such paired actions to the participatory modelling process can be defined as preparatory activities and follow-up tasks.

Intending to set a perspective on the different possible tools available and relate them to the complementary workshop task proposition, a variety of tools have been listed as found in the literature (Tables 3.3 to 3.5). The lists do not attempt by any means to be a sample of available tools and do not claim to be comprehensive either. Nonetheless, it is useful to have an idea of the diversity of tools applicable to participatory system dynamics modelling and thus, appreciate the different paths that a participatory exercise can take.

Table 3.3 Tools for preparing a participatory modelling process

Tool	What it does	Use
<i>Preliminary interviews</i> (i.e. Vennix, 1996; Videira et al., 2009)	Introductory tool used as a point of departure to explain to the stakeholders the participatory process in detail and get feedback on initial planning	Used to build rapport with participants, collect relevant background and capture participants' mental models before holding the facilitated modeling sessions. It allows for workshop planning and workbooks development
<i>Informal interviews</i> (i.e. Denscombe, 2012; Vennix, 1996)	Script with topics to be addressed during the interview where questions are not defined	Explore a topic in a general level, particularly useful to build rapport with participant
<i>Semi-structured interviews</i> (i.e. Denscombe, 2012; Vennix et al., 1996; Vennix, 1996)	Standardized questions asked by the interviewer, leading to open responses (conversational style)	Explore a topic deeply and gather the detailed opinion of a group of interviewees, particularly useful to build a preliminary model
<i>Closed interviews</i> (i.e. Denscombe, 2012; Vennix, 1996)	Defined questions of fixed and quick response	Explore a topic in a general level, mainly useful to elicit information to identify causal relationships and to build cognitive maps
<i>Brainstorming</i> (i.e. Denscombe, 2012; Videira et al., 2003)	Organized group discussion for information sharing and ideas development	Useful for building rapport among participants, identify needs, resources and define objectives for project

Tool	What it does	Use
		breakthrough
<i>Define objective criteria</i> (Mostashari and Sussman, 2005)	Define some criteria to be able to evaluate the success or failure of the participatory modelling methodology on the issue to tackle	Definition of criteria as part of the modeling process is useful to be able to quantify objectively the level of success of such process
<i>Working Groups</i> (Mostashari and Sussman, 2005)	Differentiate the stakeholders by setting groups according to their respective influence on the process and organize several personalized working sessions	Used to organize work in an efficient manner taking into account the needs of each stakeholders group. Create synergies gathering the stakeholders with a similar level of participation
<i>Who Counts Matrix</i> (i.e. Colfer et al. 1999; Lynam et al., 2007)	Matrix with several dimensions, which provides a common scoring technique to determine which stakeholders are relevant in the resolution of a particular problem	Gives priority to most relevant stakeholders. Used to better structure the problem taking into account the links between participants
<i>Management pressure analysis</i> (Videira et al., 2003)	Accounts for key pressures at the management level and identifies potential stakeholders that influence or are related to such pressures	Useful to identify potential conflicts in terms of decision-making and stakeholders' power relation to estimate ways to contend them it during process implementation
<i>Modelling team role allocation</i> (Vennix, 1996)	Facilitator leads workshop and stimulates discussion along the model development stages; Gatekeeper intermediates between modelling team and participants to assists in process and model framing; Modeler is responsible for technical model development; Process coach observes group dynamics and provides advice to improve group process; Recorder takes notes in terms of the process and model progress	Useful to define the person(s) necessary to cover the five roles as they become relevant to the group model building process; this according to the specific characteristics of the modelling task and resource availability
<i>Choice of facilitator and neutral</i> (Mostashari and Sussman, 2005)	The neutral is the main person in charge of stakeholder selection whereas the facilitator is a discussion leader for the chosen group and an intermediary with the neutral	These actors are responsible to ensure the involvement of all the stakeholders and their active participation to all the sessions / steps of the participatory modelling
<i>Propositions</i> (Vennix et al., 1996)	Proposals to resolve the issue performed which are discussed afterwards between the participants	Understand if some disagreements exist in resolving the issue and if some natural proposals can be used in the issue resolution scheme
<i>4Rs framework</i> (i.e. Dubois 1998; Lynam et al., 2007)	Analyzes the balance/imbalance of the stakeholders' 4 "Rs": rights, responsibilities, returns and relationships	Can be used by outsiders to organize the information or in group settings for stakeholders to identify their roles and then analyze any imbalance between the 4 Rs

Tool	What it does	Use
<i>Venn diagram</i> (Lynam et al., 2007; Pretty et al. 1995)	Venn diagram are visual and easy to use tools representing social relationships and power differences between the stakeholders	Used to encourage participants to explore links between them and to detail the existing relations within the group
<i>Stakeholder value assessment interviews</i> (Mostashari and Sussman, 2005)	Interviews in which the stakeholders have to express their level of agreement or disagreement with an idea, a methodology, a solution, etc.	Used to quantify the qualitative aspects of an issue and to see their evolution over time. Objective manner to know the average or median opinion of a whole group on an issue

Table 3.4 Tools used during a participatory modelling process

Tool	What it does	Use
<i>Scriptapedia</i> (Hovmand et al., 2015)	Collects a number of scripts with documented references of its application, steps, effectively and utility as developed, tested and described by practitioners	Structure group model building sessions, serving as a reference point for participatory modelling activities. Additionally, it aims to improve research in terms of group model building effectiveness and to improve current practices. Documentation is very important to make progress in these regards
<i>Session workbooks</i> (i.e. Vennix et al., 1996; Vennix, 1996; Videira et al., 2009)	Reports summarizing the structure of the process, the objectives to pursue and the steps to go through in each session. Additionally, information and data can be request from participants as part of the report	Useful when sessions take place at different time periods to collect information from participants that allow to advance in the modelling tasks as well as to provide the participants with a summary of the session to come and get feedback to improve workshop planning
<i>Participatory systems mapping</i> (Lopes and Videira, 2015)	Develop a graphical representation of relationships capturing real system's structures	Used for the setting of individuals or group in the process of problem scoping and further causal loop diagram (CLD) development
<i>Participatory mapping</i> (i.e. Lynam et al., 2007; Sheil et al., 2002)	Develop a graphical representation of spatial relationships capturing real system's structures and objects	Used for the setting of individuals or group in the process of problem scoping and further geo-reference map development
<i>Mind mapping</i> (i.e. Vennix et al., 1996)	Diagram used to visually organize information around a central, single concept which is generally the issue to be tackled	Useful to have a first overview of the participants' ideas, view as and opinions with respect to an issue
<i>System scoping</i> (Mostashari and	Determine the scope of the problem to be studied, including determining where the	Useful to (i) frame the process, (ii) determine the participants which

Tool	What it does	Use
<i>Sussman, 2005)</i>	boundaries of the system are and the issues that need to be addressed	must be involved and (iii) clearly understand the objectives which are being sought during the process
<i>Hexagon brainstorming (i.e. Vennix et al, 1996)</i>	Using hexagons to create a web of ideas around an issue in order to do a general brainstorming on a specific issue or question.	Looking how ideas connect between themselves and distinguish the central ideas / solutions between those proposed by the participants
<i>Stakeholder Assisted Modelling Policy Design (Mostashari and Sussman, 2005)</i>	Complete approach that involves stakeholders to the modelling process. Synthesises insights from different aspects of the problem solving process into one coherent process	Allows stakeholders to take part to the elaboration of a complete model to be effectively part of the strategic decision making process
<i>Complex, Large-scale, Integrated, Open Systems (Sussman et al, 2000)</i>	Complex, large-scale, integrated, open systems process (CLIOS) analysis methodology can describe a wide variety of systems since it includes technological, social, political and scientific aspects	Used to describe systems with a high degree of complexity (interrelated units) and correlation (systems are coupled between them) from the representation of the issue to the implementation of a solution
<i>Data gathering and collection (i.e. Vennix, 1996; Videira et al., 2008)</i>	Data to be collected by the participants for the elaboration of the model.	Support the specification of the model. Generally the data to analyze is suggested by the participants.
<i>Vision/pathway scenario (i.e. Hovmand et al., 2015; Wollenberg et al., 2000)</i>	Participants are called to give their own view of an ideal future and the pathway to reach it as a basis for planning and decision making	Used to understand peoples' hopes and aspirations and to design strategies for change through the pathways
<i>Alternative scenario (i.e. Hovmand et al., 2015; Wollenberg et al., 2000)</i>	Participants must imagines and describe several possible alternatives (negative or positive) regarding a central scenario	Used to help to deal with uncertainty of a central scenario
<i>Pebble Distribution (i.e. Lynam et al., 2007; Sheil et al., 2002)</i>	Diagnostic scoring procedure, which aspects and criteria for scoring is decided with a target group among the participants	Used to clarify both the understandings and the priorities of the participants under the supervision of a facilitator who must introduce and guide the scoring process
<i>Variable rating (van den Belt et al., 2004)</i>	Participants together with modelling team, define the degree to which current information satisfies modeling goals by rating variables in the model	Contributes to acknowledge progress towards model quantification
<i>Spidergram (i.e. Lynam et al., 2007)</i>	Represents the different components, attributes of the answer to a particular problem or issue with their respective weights	Used by the group to define the main variables and the condensed weights associated with each variable

Table 3.5 Tools for following-up a participatory modelling process

Tool	What it does	Use
<i>Questionnaires</i> (i.e. Vennix et al, 1996; Rouwette, 2011)	"Pre and post questionnaires" analyze participants' opinion (and the evolution of this opinion) with regard to (i) the issue to resolve and (ii) the participatory modelling methodology	Used to evaluate the impact of the modelling sessions on the participants' perception of the issue
<i>Final questionnaire</i> (Videira et al., 2009)	It is structured with sentences for which the participants have to show their agreement or disagreement (with a numerical scale from 1 to 5 for example)	Used to have feedback about the important aspects of the participatory process
<i>Summary matrix</i> (Videira et al., 2009)	Matrix ranking the outcomes of the participatory process in terms of (i) process and information (ii) individual and group impact from low to high	Used to give a qualitative and organized summary of the main aspects of the participatory process
<i>Evaluation interviews</i> (i.e. Vennix et al, 1996; Rouwette, 2011)	Can be semi-structured or unstructured and can be performed with the participants at the end of a modelling session	Used to gather feedback about the workshop sessions and the efficiency of participatory modelling in a determined context
<i>Coding</i> (i.e. Denscombe, 2012)	Process to categorize and analyze relevant information as found in interviews or group discussion records, going from sentences to words and through attitude analysis to identify meanings based on the construction of the narrative	Used to structured information into categories for patterns identification and data integration into a systematic, theoretically embedded explanation
<i>Qualitative content analysis</i> (i.e. Denscombe, 2012)	Process to elicit relevant information as found in interviews or group discussion separating and identifying similar ideas exposed by different persons without considering the form or position of the statements in the discourse	Used to structured information into categories for patterns identification and data integration into a systematic, theoretically embedded explanation
<i>Observation</i> (i.e. Denscombe, 2012; Vennix, 1990)	Consists of direct observation of group interaction taking into account changes in the group dynamics according to settings in the exercises or group composition	Used to explore the causes of behavior related to group dynamics settings and group discussion settings
<i>Observation</i> (i.e. Denscombe, 2012; Rouwette et al., 2002)	Evaluation is recorded as a description of the modelling process focusing on project's settings and lessons learned	Used to describe evidence on exercise implementation, especially when facing varied structural relations gaps that are sensitive to context

As advised by Videira et al. (2003), planning and structuring a participatory modelling process requires cautious preparation from the beginning of the project. Given the unpredictability of participants' reactions to the planned exercises, possible barriers to participation and contingences to the process, several factors have to be anticipated as to account for process adaptation to enhance a successful development of the exercise.

## 4. RESEARCH STRATEGY AND METHODS

### 4.1 RESEARCH STRATEGY OVERVIEW

As previously stated, the purpose of this research is to create a framework for participatory system dynamics modelling to contribute to value co-creation deployment, and with that, support the successful implementation of sustainable innovations.

Therefore, the research process answers the research questions explained in Chapter 1, by adopting a mixed methods strategy combining (i) case study for problem framing and data collection; (ii) system dynamics, for problem structuring and analysis; and (iii) participatory system dynamics modelling to structure the modelling task and allow for stakeholders interaction. The general research process and its relation to the methods and tools employed are summarized in Table 4.1.

Table 4.1 Research process

Stage	Operationalization
S1. Problem formulation	<i>Preliminary activities to PSDM</i> Case study: background and structuring
S2. Dynamic problem conceptualization	
S3. System dynamics model development	<i>PSDM process</i>
S.4 System dynamics model validation	Modelling workshops and supporting activities behind the scenes
S.5 Scenario and policy analysis	
S.6 Analysis of results	<i>Follow-up activities to PSDM</i> Case study to assess the PSDM

As a research approach, case study refers to data collection, description and analysis of a particular person/group, or problematic situation (Denscombe, 2012). The current research tests the implications of using a participatory system dynamics approach, to improve communication and reduce uncertainty in the development of a sustainable innovation. Accordingly, the framework is applied to an energy efficiency case study where the innovation is at an early maturity phase.

System dynamics methodology intends tackling complex, uncertain and dynamic issues characterized by feedback, time delays and non-linearity (i.e. Sterman, 2000). Considering the relevance of discovering the dynamic properties of the issue at hand, namely revealing the relationships behind perceived value and handling uncertainty related to innovation development, a quantitative system dynamics approach was applied to the case.

This is related to Borjeson et al. (2006) arguments to quantification. The author explains that the way



uncertainties are tackled has to be closely related to scenario development based on the possibility of combining the decision context and the decision-making process itself. So that simulation is necessary to comply with the learning aims of sustainable innovations. Identifying plausible developments (scenario drawing) within an endogenous perspective is also useful to describe leverage points to influence perceived value during product's implementation. And with this, system dynamics contributes to define actions that improve innovation's development.

Finally, participatory modelling aims to include all interested parties in a decision-making process, being particularly acknowledged for its multi-organizational and multidisciplinary character (Costanza and Ruth, 1998). Given the match of participatory modelling with the needs of the case, multi-stakeholder integration to prompt value co-creation, it was selected to structure the modelling task. This exercise allows participants to share concerns and views while bringing knowledge together to construct common and improved understanding which suggest that the methodology is a good match to value co-creation's aims.

The first research question refers to evaluate the appropriateness of adopting perceived value as a concept of interest to open dialog and construct a bridge for interaction between both sides of innovation development (developers and end-users). For that, an outline of the case study related to sustainable innovations was developed. Working closely to problem owners, helped to identify potential knowledge gaps to the sustainable innovation case and introduce perceived value assessment as a concept of awareness to innovation implementation. Likewise, the active participation of problem owners regarding case structuring and defining the aim for the participatory system dynamics exercise was relevant to appraise the meaningfulness of using perceived value as a neutral concept to raise discussion and support the inclusion of end-users to the process.

The second question is related to the application of system dynamics methodology and development of a quantified model to introduce dynamic thinking and improve the understanding of sustainable innovations. A system dynamics perspective challenges the linear and static approach of current perceived value models. Introducing causality and endogeneity to perceived value assessment, helped to uncover the causes that make a difference between developing a positive or a poor value perception. This creates a dynamic perspective to the topic, contrary to linear models where the implications of changes (i.e. benefit-risk relation), or the contingencies of externalities to the system are not taken into account.

Moreover, system dynamics allows for an analysis that is closer to reality, compared to linear models where perceived value appears to be inert concept. Then a quantified system dynamics model enabled to envision the consequences of present actions through the development of explorative scenarios to

make better-informed decisions for sustainable innovation development and uncertainty management.

Lastly, the third research question related to evaluating the convenience of employing a participatory system dynamics methodology to improve the design of sustainable innovations, is answered by assessing the participatory modelling exercise in terms of (i) model outcomes as being relevant to understand innovation's standpoint and (ii) process outcomes as to test its suitability to create a value co-creation platform from which, communication and learning regarding innovation's development are achieved.

Bots and van Daalen (2008) address the importance of carefully defining the set tools to carry on the modelling process to the explicitly comply with the purpose of the modelling exercise, the desired level of participation and the group context in which it is applied. This implies an analytic process on its own including a series of decisions about the process to underpin the tools needed to address the problem. Bearing Bots and van Daalen (2008) arguments in mind and according to Videira et al. (2009) suggestions, the participatory modelling exercise for the innovation case has been based on facilitated modelling workshops.

Since workshops allow for stakeholders interaction the purpose of value co-creation can be accomplished while contributing to develop the system dynamics model enables to comply with uncertainty management and knowledge gain needs. Given the relevance of workshop structuring to the proposed framework, a detailed explanation of the plan to deploy the participatory system dynamics modelling exercise is provided in the following section.

Aiming to test the efficacy of the exercise, it is recommended to get direct feedback from participants in terms of knowledge acquisition and possibly, the change on attitude towards the topic. Here, interviews and questionnaires are common tools to support evaluation (Rouwette et al., 2002). In this matter, Rouwette (2011) suggests that there is no reason to believe that interviews lead to a more correct evaluation compared to questionnaires in terms of facilitated modelling assessment. Moreover, practitioners recognize that not all assessment can be done under a formal framework. Thus, evidence based on session observation is recognized as a valid practice to participatory modelling assessment (Rouwette, 2011; Vennix, 1996). Therefore, a final questioner and observation were used to complement the overall assessment and evaluate the adequacy of the participatory modelling exercise to the sustainability case.

## **4.2 PARTICIPATORY SYTEM DYNAMICS MODELLING IMPLEMENTATION**

Explained in Table 4.1, the planned participatory system dynamics modelling exercise encompasses a significant number of the research steps. Giving its relevance to structure the research, a detailed view to the application of participatory system dynamics modelling is required. Consequently, Table 4.2

describes the tasks and activities structured under the participatory system dynamics modelling approach as well as its relation to the general research stages described in Table 4.1.

As referred in Table 4.2, participatory modelling may cover a sequence of model-building stages, from problem-model conceptualization, model development, model validation to policy analysis (i.e. Videira et al., 2003; van den Belt, 2004; Vennix, 1996). Aiming to address all modelling stages and taking into account (i) the context of the case study where participants were geographically displaced and (ii) the limited time and limited budget available to develop the participatory modelling exercise, a set of tools were selected to be implemented throughout two workshops and behind the scenes activities.

Table 4.2 Tasks and activities to developed the Participatory System Dynamic Modelling Process

<b>Relation to general research process</b>	<b>Task</b>	<b>Activities</b>	<b>PSDM process</b>
<i>S1. Problem Formulation</i>	Preliminary stakeholder meetings	Define the PSDM aim; Role identification to the PSDM; Desirable stakeholder participation to the PSDM	Behind the scenes to
<i>S2. Dynamic Problem</i>	1 <sup>st</sup> workbook development	Introduce participants to PSDM; Present first workshop agenda	1 <sup>st</sup> workshop
<i>Conceptualization</i>	Facilitated modelling	Define model's structure; Elicit model's parameters for quantification	1 <sup>st</sup> workshop implementation
<i>S3. System Dynamics Model Development</i>	Model quantification and data gathering 2 <sup>nd</sup> workbook development	Technical modelling Data gathering from expert consultation Data gathering from literature Data gathering from participants; Feedback of data gathering and modelling behind the scenes	Behind the scenes to
<i>S4. System Dynamics Model Validation</i>	Model validation	Validity test to identify assumptions, limitations and potential flaws	2 <sup>nd</sup> workshop
<i>S.5 Scenario and policy analysis</i>	3 <sup>rd</sup> workbook development Facilitated modelling	Present second workshop agenda Running scenario and analysing structure-behaviour relation	2 <sup>nd</sup> workshop implementation

The first workshop aims to define model's structure and elicit model's parameters to have a running model ready for the second workshop. Accordingly the second workshop is devoted to scenario and policy analysis.

The next sections describe the workshops, workbook, as well as behind the scene activities planned to support the modelling process. Following practitioners' advice, the information described as part of the workbook and agenda was validated before implementation, by sending it to the gatekeeper who shared it with the rest of the participants prior to the meetings. In this regard, the gatekeeper has the role to provide feedback on group related activities as well as advice on the ways activities are implemented, to maximize the impact and success possibilities (i.e. Vennix, 1996; Videira et al., 2003).

#### **4.2.1 First workshop: behind the scenes activities and planning**

- Preliminary meetings with stakeholders

Throughout preliminary meetings, the specific aim of the participatory modelling process was defined along with other relevant decisions regarding process implementation as suggested by Mostashari et al., (2005). Such decisions include: role definition of the stakeholders, gatekeeper designation and identification of relevant stakeholders outside the group.

This information is relevant to workshop planning, mainly to define how other stakeholder may be invited to the process and to schedule the workshops accordingly to time and agenda availability. Moreover, preliminary meetings and discussion are as useful for further activities development as they contribute to familiarize participants with the project and to build-up rapport with the team (Vennix et al., 1996).

- 1st workbook

As recommended by Vennix (1996), it is important to familiarize participants to the project and the methodology before holding the first session.

To support this goal, a workbook was prepared previous to the first workshop aiming to set a common ground and ease discussion by:

1. Creating homogeneity in terms of project's understanding; for that, a description of the project was added as a short narrative;
2. Offering participants an initial approach to system dynamics to ease overture to the participatory modelling exercise; for that, a short explanation of the methodology's principles was given together with an illustration of stock and flow diagram symbols and meaning;
3. Setting positive expectations about the workshop and motivate participants by pointing out the contribution of innovation to tackle societal challenges; for that, an overview of the workshop's agenda was sent together with a description of the purposes, expectations and needs to develop the participatory modelling exercise.

The agenda was planned under the understanding that the first workshop should contribute to have a running model for the second workshop. Hence, the first workshop's agenda was developed as follows.

#### Step 1: Problem framing

The purpose of the introductory stage is to position participants into the context of problem and to familiarize them with the computer simulation environment. It included the following phases:

1. Project's description recap, based on workbook
2. Participatory modelling exercise's goal discussion, based on workbook
3. Linking the purpose of the project to participatory modelling exercise (Vennix, 1996)
4. Introducing system dynamics, based on *concept model script* (Hovmand et al., 2015; Richardson, 2013)
5. Dynamic problem definition, based on *nominal group technique* and *graphs over time* scripts (Hovmand et al., 2015; Lopes and Videira, 2015; Otto and Struben, 2003)

The expected outcome of these activities was to prompt active participation during the workshop, as well as to enhance systems thinking capabilities, which are needed to work on later exercises.

#### Step 2: Problem structuring exercise

The intention of this stage was to frame the problem into system dynamics terms as to identify loops that portray relevant components identified by participants in the previous step. For that, an exercise to accelerate model building is developed based on *structure elicitation* and *ratio exercise* scripts (Hovmand et al., 2015).

The expected outcome of the activity was to build-up a structure around participants' identified areas of interest and concerns and to close loops that explain system's behaviour.

#### Step 3: Parameters exercise

This stage aims to define perceived value in quantitative terms by studying its components and interrelations as follows:

1. Eliciting graph functions, based on *parameterized relationship between two variables* script (Hovmand et al., 2015)
2. Eliciting the utility function, based on swing weight technique (Goodwin, and Wright, 2014).

The expected outcome of the exercises was to calibrate the model, which at the same time contributes to review the system's boundary and assumptions made about the structure as to validate or define if changes are needed.

#### Step 4: Closure

To finish the participatory modelling exercise a brief wrap-up was used to connect the results achieved with the expectations, as well as to emphasize the importance of answering the workbook to give continuity to the modelling process.

#### **4.2.2 Second workshop: behind the scenes activities and planning**

- Model quantification and data gathering

After involving end-users to characterize perceived value, information and insights elicited during the sessions were gathered and analysed to integrate them to the quantified model developed behind the scene.

Considering the limited time and data available to quantification, additional information was obtained separately of workshop sessions. Here, data gathering from the literature and experts was used to contribute to model's quantification purpose.

Then, expert consultation using an open interview was implemented. The identified expert for the interview is the CEO of Cleopa GmbH Detlef Olschewski. Cleopa GmbH is one of the organizations involved in the case study, however the interviewee is not part of the workshop participants. Considering his expertise in energy efficiency projects and his professional experience in innovation research and development, the expert was consulted in subjects related to variable quantification and relationship validation.

- 2nd workbook

A workbook between sessions serves to keep focus on discussion by reviewing and validating perceptions, assumptions and data used in the model. This enables participants to either approve or reject model's development as to keep ownership (Vennix, 1996; Videira et al., 2003). Hence, a second workbook was prepared based on the next areas of attention.

1. Review work, ideas and information elicited during the first session.

Participants were asked to review the current state of the model as well as to clarify ambiguous or conflicting concepts.

2. Review and validate new evidence obtained behind the scene

A graphical representation of the quantified model was shared explaining changes and inclusion of new evidence and ideas as obtained from the literature and expert consultation.

### 3. Eliciting additional information for quantification

Participants were asked to either provide data or provide their best educated guess as to contribute to model quantification purposes.

- Model validation

Before holding the second workshop, sets of model validity tests as recommended by Barlas (1996) were applied. It led to model, theory and data review as well as further changes as part of a process to build-up confidence in the model.

- 3rd workbook

Based on model progress behind the scene and information gathered through the second workbook, the second workshop agenda was developed to focus on scenario analysis and model validation as explain next.

#### Step 1: Model review

*Model review* script as developed by Hovmand et al. (2015) was used first to formally acknowledge model's assumptions and limitations. In this manner, validation principles suggested by Barlas (1990, 1996) and Lane (1995) were used to configure the *model review* script regarding structure and scenario analysis to facilitate the learning of stakeholders, gain insights and define policy making by implementing the two following activities:

##### 1. Structure and quantification overview

By implementing Hovmand et al. (2015)'s proposed script, the first part of the session was planned to go through the model structure, parameters and graphical functions to validate them and define changes if needed. This is, according to Barlas (1990, 1996) and Lane (1995) useful to perform direct structure validation test together with participants.

##### 2. Scenario analysis

Then the second part was devoted to challenge participants' views in terms of model's structure-behaviour relation, particularly concerning loop dominance. Here, participants were questioned about scenario expectations after modifying key parameters to validate the model and elicit policy insights. Meanwhile, scenarios' comparison to graphs over time drew in the first workshop aimed to validate initial assumptions and identify structure-behaviour relationship. This is, according to Barlas (1990, 1996) useful to perform structure-oriented behaviour and behaviour pattern validation test together with participants.

## Step 2: Closure

As suggested by Vennix (1996), the session ended by making a quick review of the progress made in terms of knowledge and understanding gained and explaining how the model contributes to enhance the development of the sustainable innovation.





## 5. RESULTS

### 5.1 CASE STUDY OUTLINE

#### 5.1.1 Case study background

A technology developer from Nitra's University of Agriculture in Slovakia found out that people with low technical skills commonly expose themselves to harmful situations driven by energy failure. Intending to keep users safe, technical research was carried out finding potential improvements related to the way electrical phases and energy backup systems interact when energy failure occurs. As a result, a device aimed to regulate the energy supply for small/medium appliances was patented by Nitra's University of Agriculture.

The invention is a smart switch that can be integrated to individual appliances requiring of one-energy-phase to operate. The innovative connection designed makes it impossible to short out two electricity phases and allows to separately operate inverter, charger and accumulator with a lower power consumption by integrating the smart switch allowing automatic operation of multiple-interconnected energy sources as shown in Figure 5.1.

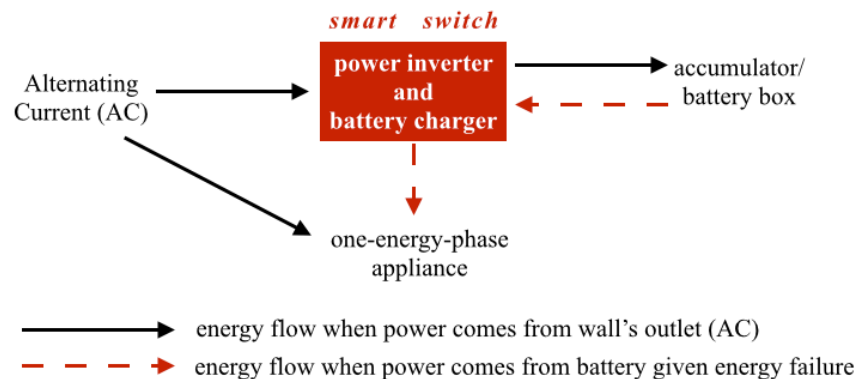


Figure 5.1 Smart switch set up

Source: Based on developers' explanations

Although similar products exist, the characteristics of this new switch allow it to be used in a broader variety of devices compared to current options in the market. Also, given that present switches uninterruptedly supply energy to batteries, they spend additional energy than needed, reduce battery's life and potentially increase lethal voltages risk within power inverter and battery charger. A picture representing similar solutions can be observed in Figure 5.2, the physical aspect of the current innovation is equivalent to the switch shown in Figure 5.2.



Figure 5.2 Representation of a similar product (Texas instrument's battery management switch)

Source: Mouser Electronics (2016)

The benefits that such technical transformation brings to end-users, as described by its inventors are:

1. Reducing battery's replacement since using the device increases battery life from 200 to 400%. With this, battery disposal is also reduced;
2. Increasing personal safety in energy risk situations where the device alerts of failures and prevents users to directly handle electric or gas equipment;
3. Reliance on continuous energy supply by automatically switching between electricity phases and, eventually, energy backup devices.

After patenting the device, inventors envisioned the opportunity to build-up an international and cross-organizational alliance to form a consortium in which each individual partner contributes to integrate a multidisciplinary platform, with the objective to take the invention to a market level. Consequently, a consortium including a university, a private research institute and two industry partners in Europe was established to develop a pilot test that would determine the invention's readiness level in terms of technology and market uptake.

As it was mentioned, this is an invention and initiative of University of Nitra and for that reason it was decided that the university would be the leading partner of the consortium. The rest of the partners also play a key role. Cleopa is an energy innovation SME. In this project, the organization collaborates instructing the consortium on the technology readiness of the innovation as well as defining market uptake goals; the company is based in Germany. Marpos, as an industrial partner is in charge of the manufacture of the device; the company is based in Check Republic. GKD is an industrial design firm responsible for product design and packaging; the company is based in UK.

This multidisciplinary team seeks for a knowledge ground that contributes to better understand the standing of the device when it comes to product performance (technology readiness) and end-user valuation (market readiness). Measures will aim at (i) breaking down communication and understanding barriers between inventor and end-users (ii), enhancing research and innovation, (iii) contributing to tackle European Union's societal challenges and, (iv) contributing to achieve European Union's sustainability goals as set by the European Commission (2016).

### 5.1.2 Case study structuring

As observed bellow, Table 5.1 aims to identify the elements in the described sustainable innovation case. Thereby, the current case study's characterization allows grasping the low level of understanding of the issue at hand. Initial analysis suggests that the main complexity of this case lays on the lack of structure in terms of stakeholders' cooperation (incommensurable and/or potential conflicting interests) and the lack of understanding on innovation's potential performance (key uncertainties).

Table 5.1 Structuring the innovation case

Source: Based on preliminary stakeholder meetings, adapted from Rosenhead and Mingers (2001)

<b>Multiple actors</b>	<b>Multiple perspectives</b>	<b>Incommensurable and/or potential conflicting interests</b>	<b>Important intangibles</b>	<b>Key uncertainties</b>
Public institutions	Environmental challenges	Participation opportunities	Multidisciplinary integration benefits	Innovation's perception
Developers	Social wellbeing	Multi-stakeholder cooperative relations	International cooperation gains	Technology effectiveness
Manufacturers	Technology progress	Consortium's reaction capacity	Citizens involvement in solution making	Innovation's adoption
End-users	Europe's competitiveness	Financial sustainability	Social and environmental benefits of implementation	Social and environmental impact
				Financial development

In terms of stakeholder's cooperation, lack of structure comes from the fact that the consortium was built in a relative short time given pressure to react on time to a funding application for further innovation development. In addition of being geographically apart, the members of the consortium formed this group only to cooperate in this project, with no previous work experience together, which limits their response capacity and creates inequality in the level of commitment. Also, a key

stakeholder group was not integrated to the initial structure. That is the end-users group. Their involvement is critical to improve innovation's understanding throughout value co-creation (i.e. Martinez-Canas, 2016), and it also represents an opportunity to create solutions beyond top-down policymaking (i.e. Kempt et al., 2007; Mitchell et al., 2007).

On the other hand, the lack of understanding on the potential performance of the innovation is related to the multiple uncertainties that bound this initiative. Given the number of uncertainties identified, it is desirable to formally analyse them to recognize interrelations, which as recommended by Schwartz (1991) and Walker et al. (2013), helps to define priorities to the problem solution process.

Some of the key uncertainties identified in Table 5.1 have a technical solution, such as technology effectiveness that is solved by testing the product under laboratory and real usage conditions. A similar principle applies to the uncertainty related to the financial development of the project. Such uncertainty can be reduced by constructing a financial plan, as well as by developing commercial studies. Nevertheless, before being able to work on market indicators, the consortium has to be sure that the device has an added value representative enough as to be accountable and valued by end-users.

Taking this into account, it comes clear to mind that uncertainty solving is a gradual progress based on constructing understanding of innovation implementation. Figure 5.3 represents the hypothesized and uncertainty solving chain. The figure was constructed based on partners' concerns, understanding and agreements from early discussions over partnership assessment triggered by the leading partner.

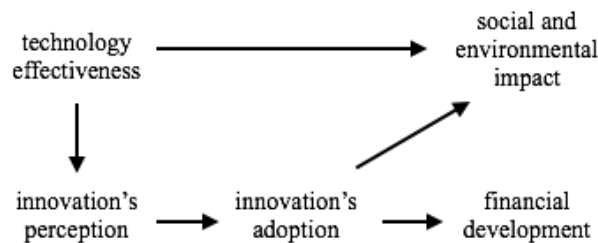


Figure 5.3 Uncertainty chain

Source: Based on preliminary stakeholder meetings

As suggested by Figure 5.3 the rationale, and apparently the most useful steps to implementation, are addressing technology effectiveness and innovation's perception uncertainties first. This idea is supported by diverse literature where research refers to the relevance of understanding end-users perception of a product, attitudes and standing towards its employment to decide whether or not the product is ready for commercialization (de Jong et al., 2015; Gourville, 2005; Kotler et al., 2005).

Since the level of technology proficiency influences the perception of the product, it can be stated that the two concepts are not only dependent (innovation's perception being the dependent one) but they are also co-evolving. Given this close relation between the two uncertainties, technology effectiveness and innovation's perception assessment can take place at the same time.

Figure 5.3 also indicates how innovation's perception gives ground to define whether or not the innovation is likely to be adopted. Once adoption scenario is clear, the consortium will count with bases for financial development assessment. Similarly, technology efficiency achieved together with willingness to adopt innovation, will lead to identify the potential social and environmental impact. The more efficient the innovation and the more people adopting it, then the larger the impact.

To summarize, innovation's implementation was defined as the consortium's explicit aim. To achieve such aim, partners have to work on key aspects as a team. Despite the short time working with each other, the consortium must be capable to overcome potential conflicting interest as identified in Table 5.1, for which they need to adopt a perspective that allows to structure cooperation as well as to include other relevant stakeholders to the process (i.e. end-users). At the same time, the consortium needs to tackle the diverse uncertainties surrounding the future development of the device. Assessing technology effectiveness and consequently, identifying innovation's perception becomes stakeholders' priority.

## **5.2 BEHIND THE SCENES TO FIRST WORKSHOP**

### **5.2.1 PSDM aim identification**

During the case study structuring process and as a result of discussion during stakeholder preliminary meetings, the purpose of the modelling exercise was defined by the consortium as: explaining perceived value of the energy efficiency device to better understand end-users' perception, concerns, needs and expectations and with this, reducing the probability of implementation failure.

Vennix (1999) suggests defining the goals and desirable outcomes of the modelling process to keep focus on concepts that matter. For that, stakeholders defined the next questions as a guide to the modelling process: (i) what are the components that define the perceived value of the energy efficiency innovation? and (ii) how can such components be influenced to improve the standing of the device?

### **5.2.2 Role identification to the PSDM**

As part of the process, the stakeholder group defined the gatekeeper to the modelling process. The team leader of Nitra's University of Agriculture was identified to be the most appropriate person to cover this role given that is the person that has been involved in the development of the innovation

since the idea emerged. She was also the person that had the initiative to bring stakeholders together to form the consortium and thus, she is the closest person to all members of the group.

### **5.2.3 Desirable stakeholder participation to the PSDM**

Intending to construct a bridge to enhance interaction among inventors and end-users to overcome typical causes of innovation failure including: lack of understanding of end-users' perspective (needs and concerns) and miscommunication of product's attributes (overrating or addressing wrong attributes) as pointed out throughout the literature (i.e. Gourville, 2005; Repenning, 2012; Sterman, 2013), it is the aim of the consortium to promptly involve end-users in the innovation process.

Accordingly, it was agreed that at least one representative of the end-users' groups identified would be invited to participate of the modelling exercise. Given that Nitra's University already contacted potential end-users to be part of the pilot test in the region, the consortium decided that end-users' representatives would be invited out of the university's current network to ease the planning process.

### **5.2.4 First workbook**

A preliminary workbook was sent for revision to the gatekeeper containing an introduction to the project and the methodology, plus the first workshop's agenda which content was detailed in the previous chapter. After sending the agenda to the gatekeeper a few suggestions were made. The first was a warning over the time planed and order set for each exercise. The gatekeeper explained that some of the participants from the end-users' side could not commit to stay for the whole session due to other obligations. Therefore, the session should be planned for three hours instead of the five hours initially considered for the whole workshop.

Also related to this concern, the gatekeeper suggested reorganizing the order of the activities to make sure that the end-users would participate in the exercises for which their contribution was critical. Finally, the gatekeeper asked for a detailed description of the exercises related to quantification so that she could take a look beforehand and prepare translation in case technical vocabulary could complicate understanding for the participants with limited knowledge of English language.

In response to these recommendations, the timeslots for each exercise were reallocated, a detailed description of the exercises was sent to the gatekeeper along with a "plan B" agenda where exercises involving end-users' knowledge or perceptions were decisive for the workshop's goals. It is important to highlight that this second agenda was developed only for facilitation purposes so that it was not shared with participants. Yet, participants were warned at the beginning of the workshop about possible changes on the agenda during the session responding to the evolution of the modelling exercise.

Then the workbook was sent to a total of 12 confirmed participants were 50% represented the consortium and the other 50% represented end-users. The material was sent a week before the workshop and participants were encourage to approach with questions, requests or suggestions to the workshop.

Since no questions were asked, it was assumed that the information contained in the workbook already contributed to bring participants into the project's settings and the workshop activities.

### 5.3 FIRST WORKSHOP

A total of 10 participants attended the session (out of 12 invited). Four participants were end-users representatives so that 4 out of 5 identified groups were represented in the session. The other 6 participants were part of the consortium representing device developers.

A detailed list of stakeholders that attended the workshop is provided in Table 5.2. In Figure 5.4 some pictures of the first workshop participants are displayed.

Table 5.2 First workshop participants overview

<b>Category</b>	<i>Developer</i>	<i>Developer</i>	<i>Developer</i>	<i>End-user</i>	<i>End-user</i>	<i>End-user</i>	<i>End-user</i>
<b>Organization/ group</b>	Nita's University	Marpos	Cleopa GmbH	Municipality	Smart buildings	Retailer	House hold
<b>Knowledge contribution</b>	Technical	Technical	Market	Public institutions settings	Building management settings	Food sector settings	Private housing settings
<b>Country</b>	Slovakia	Check Republic	Germany	Slovakia	Slovakia	Slovakia	Slovakia
<b>Total</b>	3	2	1	1	1	1	1

The following section explains how the first workshop was developed following the agenda explained in the research method's section, along with corresponding participants' reactions and changes made during the process. Facilitation was aid by a PowerPoint presentation, iThink as system dynamics software for simulation and model structure drawing and a blackboard to make notes and additional remarks.





Figure 5.4 First workshop participants

*Note: images are blurred for confidentiality purposes*

### 5.3.1 Problem framing (Step 1)

Problem framing activities helped to build-up project and methodology's understanding based on the workbook previously sent. It consisted of a brief presentation to recall the information already shared, which allowed elaborating on the methodology explanation.

- Project description

Transition management perspective was used to explain project's contribution and workshop relevance of the project to comply with higher goals and societal challenges at a macro level. Additionally, the characteristics of the device were explained to the participants. During the technical and functional description it was clarified that listed features correspond to developers' understanding but that end-users perspective was needed to validate that such features are relevant and potentially, to identified other features out of the ones described by developers.

- Participatory modelling exercise's goal

Characterize the dynamics behind product's perceived value was defined as the overall goal of the workshop. It was explained that determining the perceived value of an innovation is a particularly challenging task, warning participants that frustration might arise simply because it is hard to

understand and explain things that are different of what we know. It was also explained that it was normal to be confused during the exercises given that participants are not familiar with the methodology. It was commented that confusion was not necessarily bad, since it leads to make more questions that can potentially improve understanding of both the device and the perceived value of the device. The idea that confusion leads to improve knowledge and that frustration can be transformed into understanding as explained by Vennix (1996), was underlined aiming to calm possible group's anxiety.

Later, it was underpinned how understanding the dynamics behind perceived value contributes to recognize end-users position regarding the product, helping the consortium to better focus on end-user's priorities.

- Linking the purpose of the project to participatory modelling exercise

In this section, an overview to system dynamics and participatory modelling was provided to familiarize participants with the exercises and create expectations about the outcomes. Participants stated that they understood the project's goals and its relation to the workshop.

- Introducing system dynamics, based on *concept model* script

This exercise aimed to make participants acquainted with accumulation process and symbols used in stock and flow diagrams, based on Hovmand et al. (2015) and Richardson (2013) tub with faucet and drain example was used as a metaphor to explain accumulation of informational and noninformational entities and the meaning of stock, flow and variable icons in system dynamics software were related to the tub example.

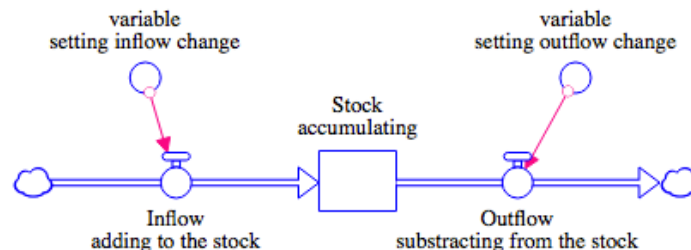


Figure 5.5 Accumulation related to the tub-faucet-drain example

A tub with faucet and drain was drawn on the blackboard and a stock and flow diagram representing accumulation related the tub example was shown on iThink software, expecting to simulate and trace behaviour to better explain the logic used in the model (Figure 5.5). Due to technical issues the model was not ran. Afterwards, the exercise ended with a verbal explanation on the implications of adopting an endogenous point of view as to help finding causes contained within the structure of the system and

analysing strategies' possible consequences by means of scenario running.

- Dynamic problem definition, based on *nominal group technique* and *graphs over time scripts*

After having a better understanding of both the problem and the methodology, this exercise helped to make a transition to the modelling part. As a prelude to *graphs over time* exercises it was needed to guide participants into characterizing perceived value. For that, a perceived value linear model was explained as adapted from Goodwin and Wright (2014), Fleith de Madeiros et al. (2016), Heetae et al. (2016) and Zeithaml (1988) as referred in Figure 2.2, Chapter 2.

After explaining perceived value components, *nominal group technique* (i.e. Hovmand et al., 2015; Vennix, 1996) was used to elicit variables that explain sacrifices and benefits as described by the group. Here participants were asked to individually list non-monetary risks, extrinsic and intrinsic attributes, to later take turns and share them one by one with the group as to write them down in the blackboard by the facilitator.

Some participants proposed to start by analysing the device's description showed at the beginning of the workshop, participants agreed and they started to list components accordingly.

*Nominal group technique* started by listing intrinsic attributes. Discussion was generated around the *battery duration* concept, wherein some participants said it was repetitive considering that because of longer *battery duration*, both *environmental impact* and *battery cost* are reduced. Discussion allowed describing the relations among these concepts and took to the decision of deleting battery duration (Table 5.3).

Table 5.3 Intrinsic attributes identified

Source: First workshop

Initial list	After discussion
Energy reliance and continuity	Continuous supply
Safety	Safety
Environmental impact reduction	Environmental impact
Battery cost savings	Battery cost
Battery duration	---

Moving to extrinsic attributes, a number of new features were identified by the group. While some attributes were mentioned developers questioned their addition to the list arguing that they do not contribute to differentiate the device from current solutions in the market, so that is not relevant to focus attention to attributes that are not relevant. This perspective triggered questions from the end-users side about device potential, which helped to envision possible customization opportunities of the

device. After questions and answers were made, participants representing potential end-users showed more enthusiasm about newly defined attributes.

*Small size* was eliminated after participants decided that it was not a relevant enough concept. Then it was considered that a number of attributes referred to similar issues and they were clustered accordingly. Clustering helped to identify relations among attributes and took participants to agree on transforming clusters to attributes, aiming to ease comparison to other features. Table 5.4 shows attributes as listed and final list after discussion.

Table 5.4 Extrinsic attributes identified

Source: First workshop

Initial list	After discussion
GSM notification	
Energy online monitoring	
Battery online monitoring	Status monitoring
Output data charts	
Automatic mode	
Easy to use	User friendly
Simple operation	
Small size	---
Charger, inverter, breakdown alarm	
Energy breakdown alarm	Alarm

Non-monetary sacrifices were harder to identify. Only few participants had some examples to share with the group, then few more came up with ideas as listed in Table 5.5.

Table 5.5 Non-monetary sacrifices identified

Source: First workshop

Initial list	After discussion
Large router needed	
Internal components replacement	---
Complicated installation	
Maintenance service	

When going through the initial list, it was pointed out that sacrifices related to acquiring or replacing components were connected to monetary sacrifice since it involves equipment expenses. Given that discussion about extrinsic attributes already drove to the idea of developing different versions of the device, developers argued that such sacrifices were non-existent when end-users decided to acquire a

version of the device including all components. Similarly, it was argued that maintenance service is also part of the price given that payment for an extended guarantee should include such services.

This vision seemed to be supported by developers. However, participants representing end-users seemed less participative so they were invited to share their opinions reminding them that the purpose of the model is to represent situations as they happen in reality and that they should think carefully whether they considered that the discussed sacrifices are associated to price or not. Then one of the end-users representatives said that he agreed on the reasoning of “the more it costs the more you get” and discussion evolved around this comment. It was also argued by end-users that complicated installation does not represent a risk for all users. Depending on country’s legislation, users can handle such equipment themselves while in other countries; it is required to be installed by a qualified technician.

End-users consider that receiving extra services such as maintenance or getting a technician to install the product is not really expected for the particular case of Slovakia, however it would be handy to provide such services as long as they are not overpriced. Then an end-user suggested that developing a device that is adaptable and easy to install would reduce such sacrifices so that the issue was not about price but product improvement. No agreement seemed to be achieved given the divergent opinions mentioned above.

Participants were subsequently invited to think about other sacrifices that were hard to relate to price. After a few minutes of individual thinking participants did not come up with new ideas and in the end they agreed that the elements on the list could be part of price and that it made sense to pay extra for it as long as the price increase was reasonable. Therefore, the whole list was deleted, assuming that price will vary depending on the version of the device and the service level that better matches individual users’ needs.

For the next part of the exercise, participants were asked to take all identified perceived benefits (intrinsic and extrinsic) and perceived sacrifices (price) to do the *graphs over time exercise* (Hovmand et al., 2015; Lopes and Videira, 2015; Otto and Struben, 2003). Probably because the exercise was not clearly explained upfront, some participants questioned for clarification of its purpose. Then, they were told that it was helpful to uncover possible perceived value development by sharing expectations and building a base to study future behaviour as to define a reference mode. It was emphasized that the exercise was particularly important given the lack of a reference mode, which is at the core of quantified system dynamics modelling. Thus, their educated guess is the best approximation to identify plausible innovation development scenarios.

A total number of 10 components to perceived value were identified covering sacrifice and benefits. Considering drawing graphs over time for 10 variables might turn difficult given the available time, it was decided to select the variables that participants considered more relevant, namely: *continuous energy supply*, *safety*, *environmental impact*, *price* were chosen to be drawn, plus perceived benefits and perceived value. Time scale was set to 40 months corresponding to the device's pilot test period.

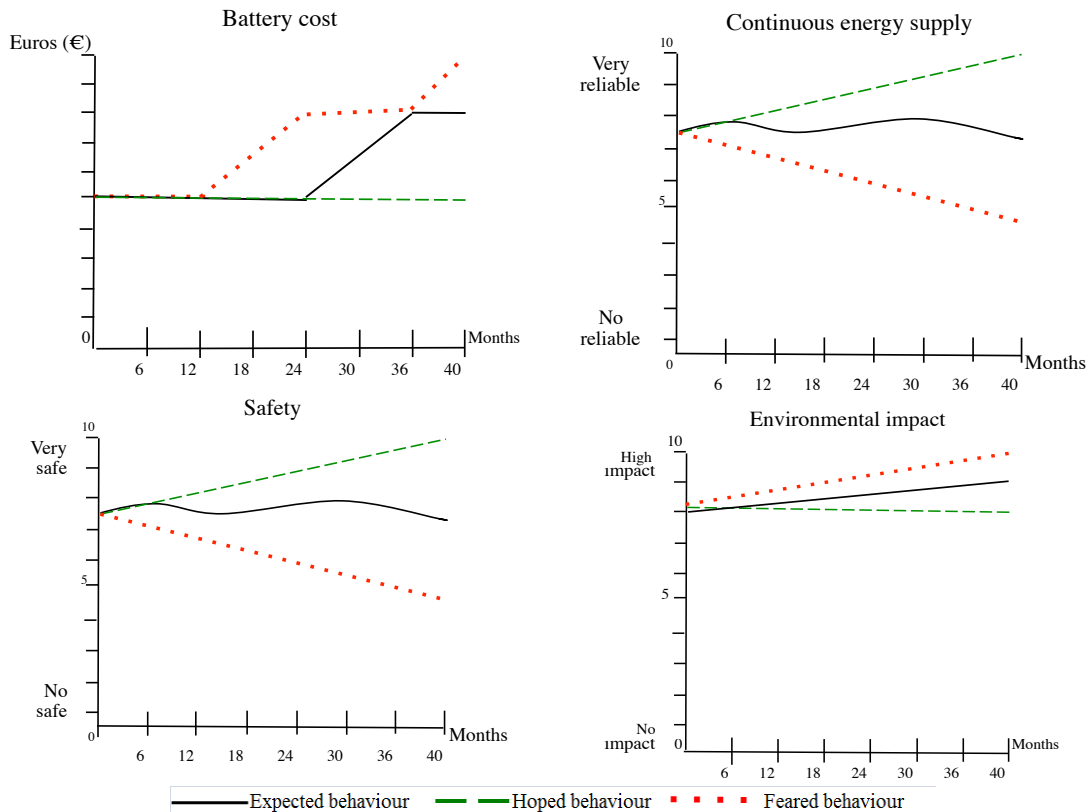


Figure 5.6 Benefits graphs over time, fears and hopes representation

Source: First workshop

Then, the facilitator provided an example of a graph over time drawing battery cost in the blackboard as seen in figure 5.6. It was argued that expected behaviour (black line) is to spend more money on batteries as a consequence of not having the device; hoped behaviour (green dashed line) is not to spend extra money since batteries will last longer; and feared behaviour (red pointed line) is to spend extra money in case that acquiring the device increases battery replacement given product malfunction.

Aiming to clearly explain to the group the logic behind drawing, *continuous energy supply*, *safety* and *environmental impact* were sketched in a collective exercise by the facilitator guided by participants' comments resulting in the graphs observed in figure 5.6.

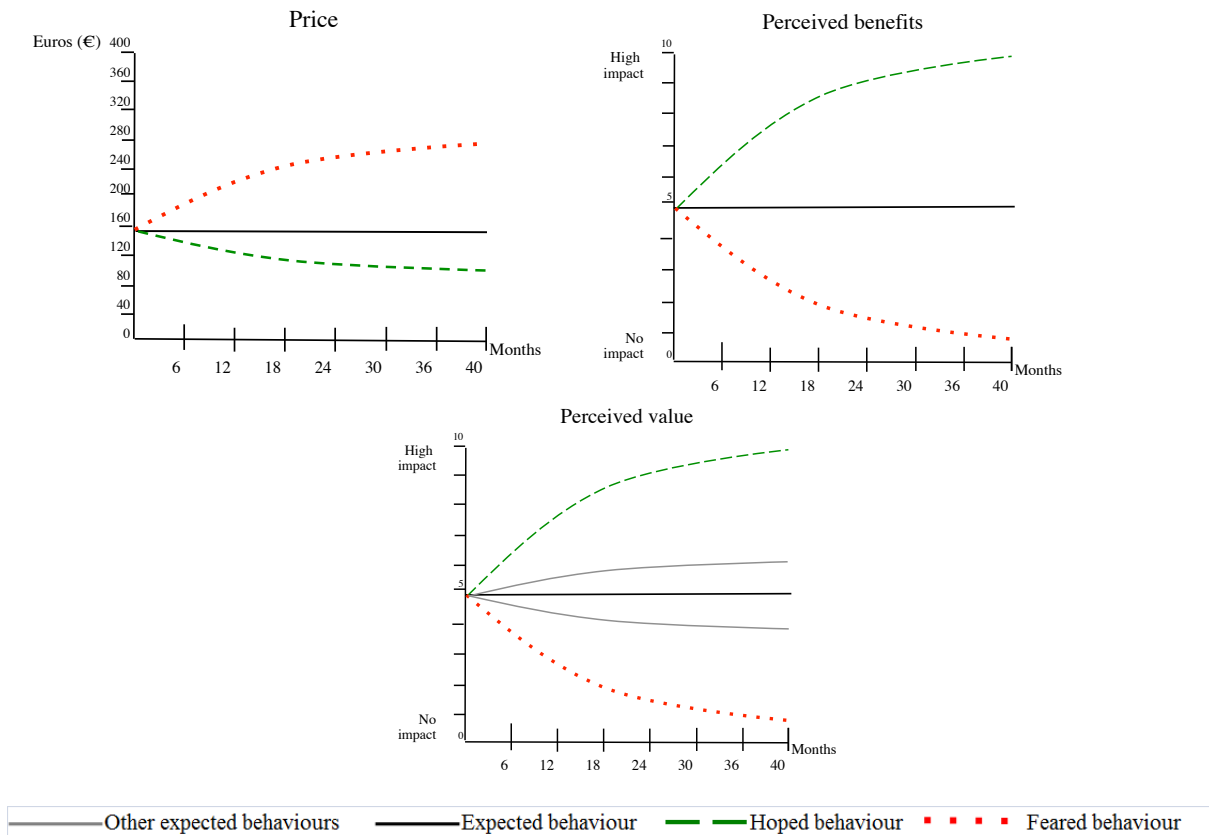


Figure 5.7 Price, perceived benefits and perceives value graphs over time, fears and hopes representation

Source: First workshop

Accordingly, participants considered that continuous energy supply is expected to be somewhat unstable since errors occur from time to time in the Slovak energy supply system. Good device performance would lead to a very reliable energy supply while a poor performance (defection) might cause more energy failure than those usually happening without the device. Similarly, safety is expected to be a little unstable due to potential energy failure. Again, a good performance would lead to increase safety level at work or household level while a poor performance might cause more incidences than those usually happening, which might turn into a less safe environment. Finally, environmental impact related to battery disposal is expected to increase, stagnate in the hoped scenario as a consequence of battery optimization and increase in case that poor performance increases battery replacement.

Since the beginning of the exercise, participants were asked to work in pairs and then share graphs with the group. Given that first graphs were built collectively instead, it was expected that the last three variables to graphs could be done in pairs but participants said that they prefer to do it individually to allow representation of individual views. Subsequently, price, perceived benefits and

perceived value were drawn individually. The logic behind eliciting price is to represent the main variable of perceived sacrifice; drawing perceived benefits intended to put together individual benefits while perceived value aimed to represent the overall perception of benefits and sacrifice in one inclusive indicator. Agreed graphs' representations after the group discussion are shown in Figure 5.7.

To draw the price graph, *price* was considered to represent a device in a complete version. Namely, including all features described along with components needed to for installation. Participants agreed on using the same starting point for graph drawing purposes. The facilitator encouraged them to start graph drawing at any point (price level) that they would judge plausible as a device launching price. However, all participants ended up using the same price reference according to what they considered a standard price for this type of technology. Highest and lowest prices in the graph are the average of the prices given by participants. Prices fluctuated in the same range, 170-350 Euros for the highest possible prices and 100-125 Euros for the lowest ones. This shows that participants consider that a decrease in price is likely to happen with limited variability compared to initial price, while price increase might vary in a broader range. Such conclusions link up to the earlier discussion about price increase for more complete versions of the device (e.g. including maintenance and installation). Expected behaviour was to keep the same price, hoped to reduce it to 150 Euros and feared to get to 275 Euros.

Regarding perceived benefits, participants assumed that initial perception could be 50% of total benefits, showing that they are uncertain on whether or not the device complies with all described characteristics. Perceived benefits were expected to remain the same. Hoped behaviour is to perceive all listed benefits. Feared behaviour is not to perceive any benefit at all assuming continuous product quality erosion.

Perceived value was the variable with the lowest level of consensus among participant's expectations. Participants draw hoped and feared behaviour following the same pattern and logic of perceived benefits. However, expected behaviour showed different insights (grey lines in figure 5.7).

Here, some participants representing end-users considered that there is a 50% chance of good performance, and they expect it to remain the same. Others considered that expected behaviour would be to increase perceived value given that once they get used to new technology, product dependence increases. They refer to it as it happened with Internet and cell phones but not everybody considered that the level of dependence on this particular device would be that high. These arguments are aligned with Porter (1998) and Kotler et al. (2005) theories of product dependence in high impact products so that the argument made by participants makes sense only under the assumption that the device outperforms. On the other hand, a participant representing end-users expected perceived value to



decrease over time assuming an inevitable price raise because of developer's ambitions to increase price, implying that a higher price for the same product would mean a lower perceived value.

### 5.3.2 Problem structuring (Step 2)

For this exercise, a concept model structure was built to develop the *structure elicitation* exercise as suggested by Hovmand et al. (2015) and Richardson (2013) aiming to introduce system dynamics iconography, prompt understanding of dynamic behaviour and initiate discussion about the issue at hand. The concept model intended first to validate the proposed perceived value definition as a ratio variable as it is suggested by the literature review and perceived sacrifices and benefits as stocks, building on the idea that perceptions are the result of accumulated experience. For that Figure 5.8 was showed to participants using iThink software.

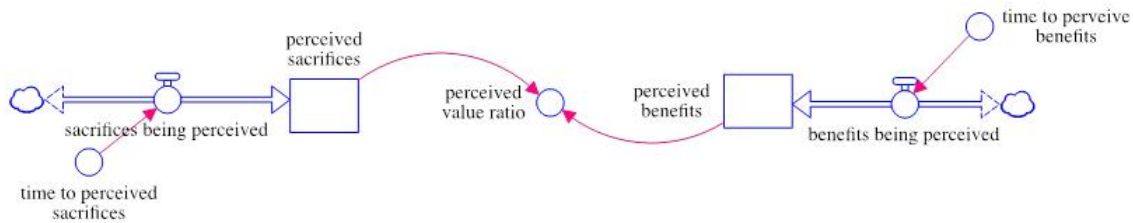


Figure 5.8 Perceived value concept model

Participants agreed with the proposed structure and this was used to start discussion to elicit dynamics behind the perceived value concept. Then, they were asked about possible consequences about perceived value ratio changes (exceptionally small or large) expecting to get feedback stories about systemic reaction as suggested by *ratio exercise* (Hovmand et al., 2015). In case that the exercise would turned out to be complicated, the plan was to encourage participants to add relationships and variables to the structure starting from a stock as suggested in the *structure elicitation* exercise.

Participants agreed on the proposed exercise, and the concept model was drawn in the blackboard adding the perceived value components as identified in the *nominal group technique* previous exercise. The resulting stock-and-flow structure is depicted in Figure 5.9.

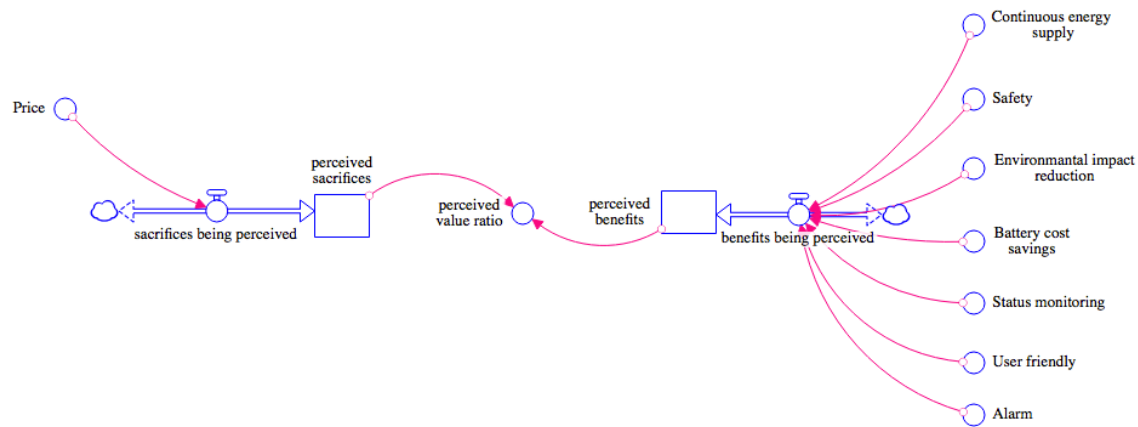


Figure 5.9 Perceived value concept model with added components

Source: First workshop

Giving that some participants were available to stay only for one more hour, the facilitator initiated discussion to prompt dynamic thinking using the *ratio exercise*. Accordingly, participants were asked to think on balance in terms of *perceived value*. Then it was suggested that when perceived benefits equal perceived sacrifices, perceived value gets to an equilibrium (balance); suggesting that balance represents somehow a fair exchange since it implies coherence between benefits obtained compared to sacrifices made.

Having consensus around this idea, the next question made was: how can we intervene when perceived value is not in balance? It was visible that participants were confused and no suggestion was made. Therefore, the facilitator pointed out that perceived sacrifice may be influenced by adjusting price as it was pointed out by one of the participants when drawing perceived value expected behaviour, which in consequence influences perceived value (Figure 5.10). Participants agreed with the proposed idea and a variable called price pressure was explained as a representation of the effect that perceived value has on price adjustment decisions.

Linking perceived value to price, and price to perceived sacrifice, implied some changes in the structure. Since price was the only variable influencing perceived sacrifice stock, participants guided by the facilitator agreed representing price as a stock and using the flow to represent price adjustment decisions as seen in Figure 5.10.

Structure allowed observing how sacrifice was a single attribute component while benefits were multiple. It enabled to go back to discussion on whether it would make sense to include non-monetary risks into the model. This time, discussion did unfold around whether or not price can overcome such sacrifices but one of the developers argued that defining sacrifices is even harder to generalize compared to benefits. For instance, participants pointed out that the culture in countries such as

Slovakia is more oriented to “do-it yourself” so that users might not perceive installation as a sacrifice, which might not be the case in other countries.

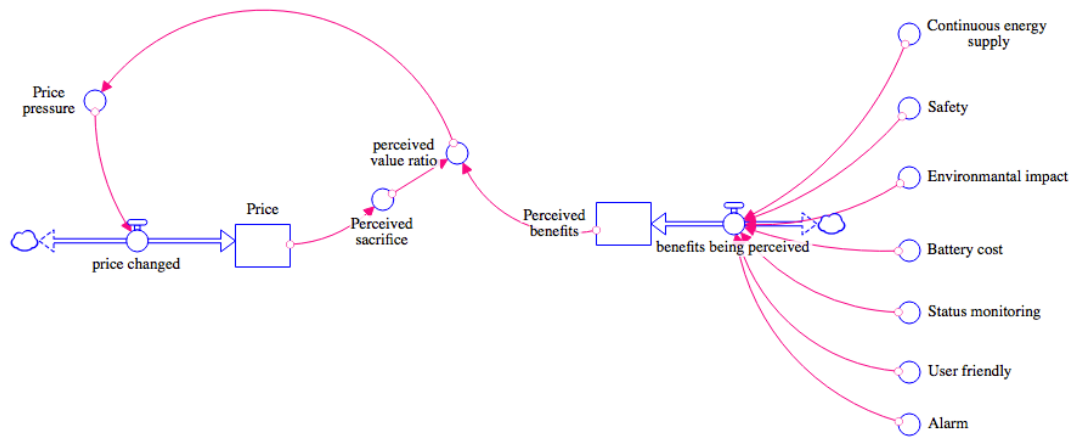


Figure 5.10 First loop construction to perceived value model

Sources: First workshop

Then the facilitator asked to analyse the relevance of such argument considering that the benefits identified so far might not be that generalizable either. Then some discussion occurred trying to differentiate the idea of attribute identification and attribute relevance. It was concluded that some attributes might be less or more relevant depending on the end-users’ context but as long as they can be recognized by end-users in all contexts they should be kept in the model. Since it was considered that identified sacrifices are hard to recognize in a different cultural context, it was decided not to include them in the structure.

### 5.3.3 Parameters exercise (Step 3)

Having agreement on the first loop, there was a transition to step 3, Parameters exercise, before looking for more loops. This switch among exercises was made as part of the “plan B” agenda as elaborated in the preparatory activities of this workshop given that some end-users had about 40 extra minutes left for the session.

The purpose of the exercise was to integrate stakeholders’ individual insights to produce a group norm-representing quantified relations (Goodwin and Wright, 2014; Hovmand et al., 2015). The activity started by explaining participants the need to quantify the two variables identified in the loop for which graph axes were drawn on the blackboard representing perceived sacrifice and price pressure effects. This time, participants preferred to work individually.

In the case of perceived sacrifice, Goodwin and Wright (2014) method to elicit attitude to risk was followed. It consisted on taking the average price values represented by participants in the individual

plots at the reference sacrifice level points 0, 0.25, 0.5, 0.75 and 1, where 1 represents maximum sacrifice and 0 represents no sacrifice. Given the limited time available, participants were informed that results of this exercise would be shared on a workbook for their subsequent analysis and validation.

Then, it was needed to come back to structure analysis using the *structure elicitation* exercise. Understanding dynamics behind sacrifice change, participants were questioned on possible ways to change benefits perception. Right after the question was made, a participant came up with the idea that investing resources on innovation would help to comply with end-users requirements to improve features and consequently, influence perception. A variable called innovation pressure was added, building up the second loop of the system as seen in Figure 5.11.

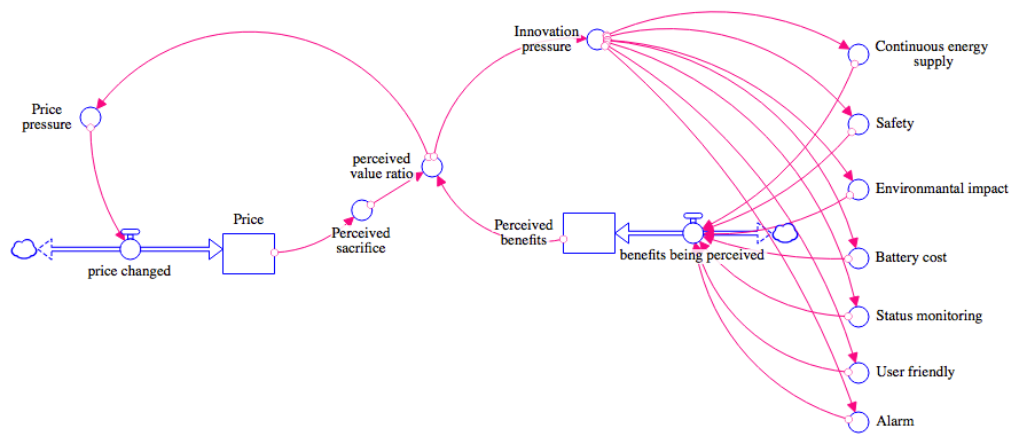


Figure 5.11 Second loop construction to perceived value model

Source: First workshop

Then a quick revision of current components was made to proceed according to the *parameterized relationship between two variables* script. The group discussed about their interpretation of price pressure and innovation pressure. Regarding price pressure it was argued that certain flexible range had to be defined in order to increase or decrease price according to product's perceived value. Based on previous discussion about perceived sacrifice as well as hoped and feared price behaviour graph over time, it was decided that setting a base price of 300Euros allowing an adjustment of +/-200Euros, would reflect stakeholders expectations. Then it was discussed how aggressive the price policy should be. Considering that innovations cope with multiple risks from product malfunctioning to end-users misunderstanding of the product, it was decided to follow a non-aggressive price policy, decreasing price fast when performance is low and increasing price slowly when performance improves.

Giving that some representatives from the end-users needed to leave soon, participants agreed on

sketching the price policy later so that end-users would have time to contribute defining the relative importance of the identified benefits for which their contribution was critical to model's quantification.

For this exercise, Swing weight technique as explained by Goodwin and Wright (2014) was employed. Here, participants were asked to individually rank attributes from preferred to last and then share their ranking one by one, allowing for discussion. After hearing other participants' points of view, they were asked to review their arguments and change their ranking if they desire to do so. However individual ranking had little variability among participants so no changes were made. Next, participants were provided with an example of weight allocation where first attribute is given a weight of 100 and the rest are compared from most to less relevant, according to the relative importance of a swing from worst to best possible performance of the next attribute. Results were shared among participants to allow for revision and discussion. After that, final scores provided by participants were written in the blackboard as showed in Table 5.6.

Table 5.6 Benefits comparative assessment

Sources: First workshop	
<b>Benefit</b>	<b>Weighted average</b>
Continuous supply	100
Safety	98
Alarm	64
Environmental impact	61
Status monitoring	55
Battery cost	51
User friendly	21

After finishing this exercise, participants representing end-users left the session and the *parameterized relationship between two variables* activity to sketch price policy was finished with consortium representatives only. Despite that end-users did not stay to contribute to the price policy representation, they were present when the arguments were made about applying a non aggressive policy as to minimize perceived sacrifice as much as possible to end-users.

#### 5.3.4 Closure (Step 4)

After the last exercise end-users left and six participants remained (consortium representatives). A few extra minutes were devoted to review progress made, explain the need to collaborate with workbook

activities, creating expectations for the next workshop and reminding how the model will serve as a tool to have a better vision of innovation performance to develop an innovation according to end-users needs and expectations and thus, minimizing failure likelihood.

## **5.4 BEHIND THE SCENES TO THE SECOND WORKSHOP**

### **5.4.1 Technical modelling**

In order to comply with the quantification purposes of the model, a few layout modifications were made to the stock-and-flow structure as developed during the first workshop (see Figure 5.11 for reference). This is because the structure drawn during the session represented perceived benefits as a single stock and individual benefits as variables. Nonetheless, it was needed to characterize individual benefits as stocks since the relative importance and perception of each benefit changes from one to another. Although individual attributes accumulate to define overall perceived benefits, they evolve with different dynamic each according to the particular perception of single attributes. After such change, parameters and data gathered from the workshop were added to the resulted stock-and-flow diagram for model quantification (see Figure 5.12 for reference).

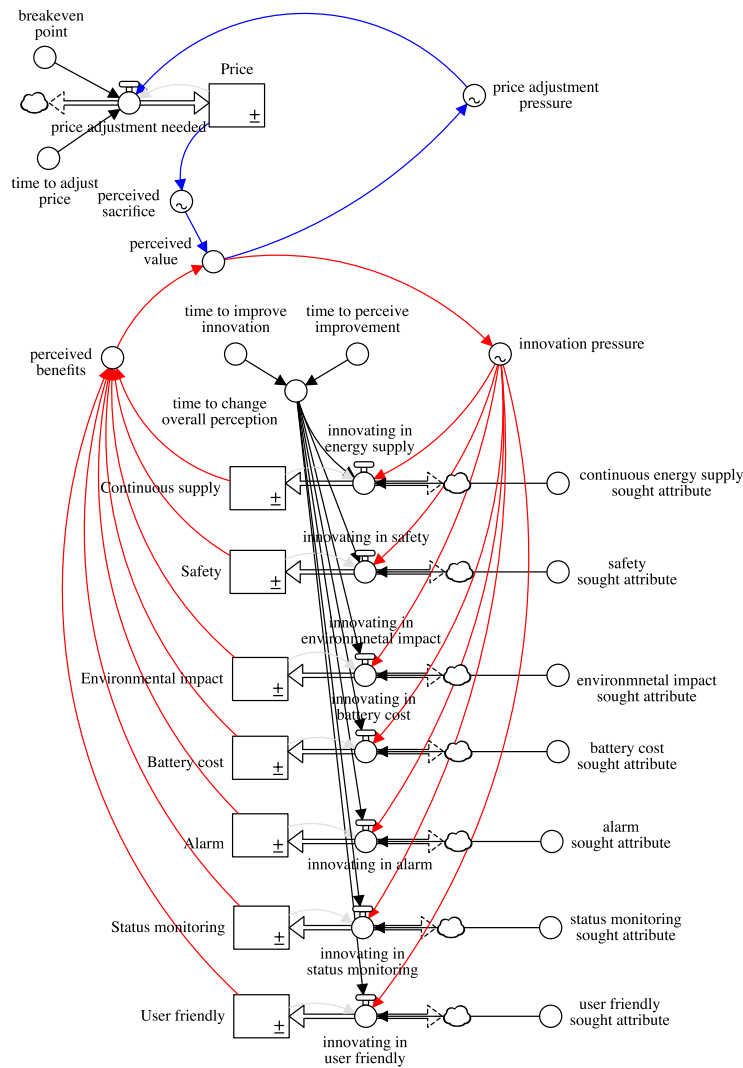


Figure 5.12 Stock and Flow Diagram representation

Sources: Adjustments behind the scene based on first workshop

*Note: two major loops identified, innovation loop in red and price loop in blue*

#### 5.4.2 Data gathering from expert consultation and literature

Aligned to the new structure and quantification needs, time related parameters were identified. As part of the data gathering and collection planned, expert consultation was implemented by means of an open interview. Accordingly, the CEO of Cleopa, Detlef Olschewski was consulted aiming to elicit such parameters from his expertise and professional experience. As the interview developed, the interviewee also provided his opinion on the theories and assumptions portrayed by the model. Having a wide experience in energy innovation field, his contribution was particularly relevant given the short time available for quantification. Eliciting such information from participants using a workbook would have comparatively delayed the modelling progress.

Accordingly, he suggested values to time to improve innovation and time to perceive improvement parameters. Then model was reviewed and it was suggested to differentiate the innovation pressure variable defined by participants as to create two different pressures one corresponding to intrinsic and another to extrinsic attributes based on the fact that extrinsic attributes are easier to improve than those related to product's internal operation. Model' structure after changes required for quantification, and suggestions made by the expert is shown in Figure 5.13.

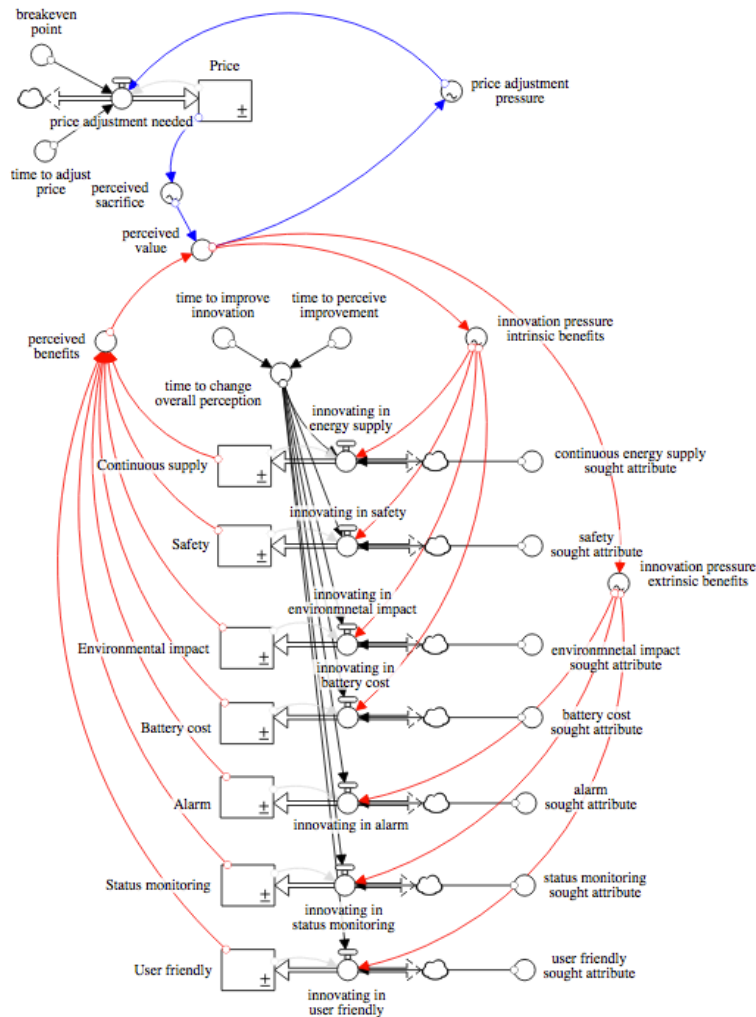


Figure 5.13 Stock and Flow Diagram changed representation

Sources: Adjustments behind the scene based on first workshop and expert interview

*Note: two major loops identified, innovation loop in red and price loop in blue*



### 5.4.3 Second workbook

Giving limitations of using English language in the first workshop, two versions of the workbook were prepared, one in English and a summarized version in Slovak. Both were reviewed by the gatekeeper and later, emailed to participants.

Overall, this workbook aimed to (i) assemble the data elicited from workshop, expert's consultation and literature as to validate or reject evidence and finally (ii) to obtain additional information from participants for quantification purposes. The second workbook structure is described next.

- Model's theoretical base and variables elicitation

The concepts found in the literature regarding perceived value linear models were described as a reminder of the theory behind the dynamic model next to the list of the benefits the participants listed during the session. Here, they were asked to review the list and make changes in terms of wording and content as previously showed in Tables 5.3, 5.4 and 5.5. Attention was set back to ambiguous concepts and particular interest was put to take discussion back to identified sacrifices as to validate their relation to price.

Participants agreed with the current list and only one additional comment was provided by developers explaining that they are unable to provide end-users with a clear description of how non-monetary risks (e.g. installation, maintenance or guarantee) will be addressed since they are not at a product readiness level as to account for it. They recognized that the exercise contributed to create awareness of non-monetary risks; however, they also considered that describing them at this point will hardly bring significant insights because it depends on market and regulation topics they are not ready to explore yet.

- Model's structure and quantification

The graphical representation of the quantified model was shared as seen in Figure 5.13. The model was explained as well as a set of equations that aim to quantify perceived value theory. Additionally, participants were given a list of single links with arrows and polarities corresponding to equations and relations portrayed in the model. Then they were asked to comment, validate or reject such representation. Next to it, the parameters and graphical relationships used in the model were explained to give participants the opportunity to review their views, suggest changes, ask for further explanation or validate them.

The workbook was also used to explain to participants the discrepancy that became evident when structuring the quantified model: the model only represents benefits perception improvement unlike in

the *graphs over time* exercise, where participants described a scenario in which benefits decrease due to product malfunctioning.

To overcome such limitation, it was suggested to introduce improvement failure or error as a separate component to the model. Then participants were asked to comment on the proposed idea and the issue in general.

- Returned workbooks

Workbooks helped to add missing information in terms of parameter quantification were participants indicated price, breakeven point and time to adjust price to the model. However no changes were required to the current parameters or model structure. Probably because of the complexity to grasp the implications of adopting different assumptions to the model or the lack of clarity to communicate the possibility of introducing defection in the model, no comments were made and the issue was left for workshop discussion.

Given the amount of workbooks returned (4 out of 10) concerns were raised in terms of participants' motivation. Nevertheless, two of the workbooks were filled out by two participants possibly because they considered that information and questions were hard to understand on their own. Perhaps the technical topics addressed in the workbook might have discouraged some participants from responding.

#### **5.4.4 Model validation overview**

Given that validation for system dynamics models is often charged with non-technical, qualitative test, defining the framework for model validation is a common topic of discussion among practitioners (i.e. Axelrod, 2003; Barlas, 1990, 1996; Lane, 1995). On this matter, authors claim that the validity of a model is in direct relation to its purpose; hence, validations frequently becomes an informal process oriented to build confidence in the model as it is carried out in every stage of model development (i.e. Sterman, 2000; Vennix, 1996). Nevertheless, treating validation as a formal and separate step from model building process is expected to improve clarity and support credibility of the model at hand (i.e. Barlas, 1990; Lane, 1995).

Barlas (1990) suggests that in the case of facilitated modelling, apart from formal validation test, validity should be thought in terms of model ownership by stakeholders. Since the model serves as a synthesis of stakeholder's worldviews, the validity of the model relies on participants' judgment of model usefulness and learning gained through the process, beyond model's technical correctness.

Following the recommendations regarding model building by means of facilitated modelling, it seems reasonable to formally perform validity tests together with participants for which workshops and

workbooks appear to be useful tools to (i) challenge participants to explain the logic behind the model, (ii) disclose their views and (iii) test their understanding and knowledge gained of the problematic situation, throughout model analysis (Hovmand et al., 2015).

Aiming to comply with formal system dynamics validity, this section submits a sequence of basic validity test as suggested by Barlas (1996) as to cover the core validation needs for the case at hand (Table 5.7). The table represents the total number of tests performed to the model, differentiating between empirical and theoretical validation.

Table 5.7 Validity test list as applied to the perceived value model

Source: based on Barlas (1996)

Type	Test	Validation
Direct structure tests	Structure confirmation	Empirical and Theoretical
	Parameter confirmation	Empirical and Theoretical
	Direct extreme-condition	Theoretical
	Dimensional consistency	
Structure-oriented behaviour tests	Extreme-condition	Empirical
	Behaviour sensitivity	Empirical and Theoretical
	Boundary adequacy	Empirical
	Phase relationship	Empirical and Theoretical
Behaviour validity test	Behaviour pattern	Empirical

Before describing tests implementation, it is important to mention that Modified behaviour prediction and Turning tests suggested by Barlas (1996) as Structure-oriented behaviour tests were not performed since they require “real system's” data, which is not possible given lack of real systems' reference mode for the case at hand.

#### 5.4.5 Direct structure validity tests

These types of tests assess validity of the structure as to the real system by individually examining the similarities and differences of the relationship represented in the model, either by means of equations or a stated relationship. No simulation is needed to perform such tests (Barlas, 1990).

- Structure confirmation test

As explained by Barlas (1990), the empirical application of this test is hard to formalize since it attempts to directly compare the form of the equations of the model with the form of the relationships that exist in the real system. Aiming to validate such test in a systematized way, a table was

constructed and shared with participants in the second workbook to validate the structure built before simulation.

Table 5.8, summarises information describing the relations that single differential equations aim to portray as validated by participants through the first workbook. Arrows and polarities correspond to the equations and relations in the model while interpretation is given in terms of linear causality.

Table 5.8 Results of the inspection list

Source: based on Barlas (1996)

Variables' relation			Interpretation
<i>Innovation pressure intrinsic benefits</i>	→ +	<i>Intrinsic attributes</i>	The higher the innovation pressure, the more improvement achieved in both extrinsic and intrinsic attributes
<i>Innovation pressure extrinsic benefits</i>	→ +	<i>Extrinsic attributes</i>	
<i>Intrinsic and extrinsic attributes combined</i>	→ +	<i>Perceived benefits</i>	The more extrinsic and intrinsic attributes improve, the higher overall perceived benefits
<i>Perceived benefits</i>	→ +	<i>Perceived value</i>	The more perceived benefits, the higher the perceived value
<i>Perceived value</i>	→ -	<i>Innovation pressure intrinsic attributes</i>	The higher the perceived value, the less pressure to innovate intrinsic attributes
<i>Perceived value</i>	→ -	<i>Innovation pressure extrinsic attributes</i>	The higher the perceived value, the less pressure to innovate extrinsic attributes
<i>Price adjustment pressure</i>	→ +/-	<i>Price</i>	The larger the price adjustment pressure, the higher the price adjustment. Adjustments require either raising or lowering price level. Accordingly, price adjustment needed takes price towards two different directions (+ or -)
<i>Price</i>	→ +	<i>Perceived sacrifice</i>	The higher the price, the higher the perceived sacrifice
<i>Perceived sacrifice</i>	→ -	<i>Perceived value</i>	The higher perceived sacrifice, the lower the perceived value
<i>Perceived value</i>	→ +	<i>Price adjustment pressure</i>	The higher the perceived value, the higher the price

On the other hand, the theoretical application of this test corresponds to a direct comparison of perceived value models found in the literature, to the relations depicted in the model by the equations. A standard perceived value model was directly translated to the model and used as a base for the

concept model in the first workshop (See Figure 5.8 for more references). On perceived benefits side, equations sum the accumulated perceived benefits and on perceived sacrifice side, price is translated directly to sacrifice. Accordingly the system dynamics model corresponds to the perceived value models theories in which perceived value is described as the ratio of total benefits divided by total sacrifices (i.e. Fleith de Madeiros et al., 2016; Zeithaml, 1988).

- Parameter confirmation test

The purpose of this test is to compare the value assigned to parameters in the model, against measurements from the real system. If no numerical information is available or it cannot be recorded, an estimation based on systems' understanding is considered to be useful as well (Barlas, 1990). Table 5.9 collects the results of this exercise in which parameters sources are identified explaining whether data corresponds to a theoretical estimation of the real system, if it represents participants perceptions translated into a quantified description or if it is a combination of both.

Table 5.9 Results of numerical and graphical parameter confirmation

Source: based on Barlas (1996)

Type of parameter	Name used in the model	Sources
<i>Variable</i>	Continuous supply sought	Empirical: elicited using swing weight technique (Goodwin and Wright, 2014) during the workshop and reviewed by participants throughout workbook
	Safety sought	
	Environmental impact sought	
	Battery cost sought	
	Alarm sought	
<i>Variable</i>	Status monitoring sought	Theoretical: using Schneiderman (1988)'s half-time standard calculation of the time and manufacturing cycles required for a product improvement over time. Empirical: reviewed by expert and validated in the workshop
	User friendly sought	
<i>Variable</i>	Time to improve innovation	Empirical: reviewed by expert and validated in the workshop
<i>Variable</i>	Time to perceive improvement	Empirical: reviewed by expert and validated in the workshop
<i>Variable</i>	Breakeven point	Empirical: calculated by developers throughout workbook and reviewed by participants during workshop
<i>Variable</i>	Time to adjust price	Empirical: defined by participants during the workshop and reviewed throughout workbook
<i>Initial stock</i>	Price	Empirical: calculated by developers throughout workbook and reviewed by participants during workshop

Type of parameter	Name used in the model	Sources
<i>Graph function</i>	Innovation pressure intrinsic attributes	Theoretical: the concave shape of the graph follows the representation of improvement in operations literature (Repenning 2012, Schneiderman 1988 and Sterman 2013).
<i>Graph function</i>	Innovation pressure extrinsic attributes	Empirical: reviewed by expert and validated in the workshop
<i>Graph function</i>	Price adjustment pressure	Empirical: elicited from participants using <i>parameterized relationships between two variables</i> (Hovmand et al., 2015)
<i>Graph function</i>	Perceived sacrifice	Empirical: elicited from participants using risk function as explained by Goodwin and Wright (2014) respectively

- Direct extreme condition test

This is exclusively a theoretical test based on numerical analysis. It consists in taking a single equation in isolation and using extreme values as inputs to validate the plausibility of the output against the anticipation of what would happen in the real system under the same extreme condition Barlas (1996). To ease the understanding of this test, equations are first described and then tested when feasible. Before going to the equations description, it is important to highlight that although equations were defined behind the scene, the logic to build up the equations is based in group discussion.

Fist equation, innovating attributes is used to keep track of perception changes in each benefit in the model. Accordingly, this equation is used 7 times in the model (refer to Figure 5.13 for more details). The equation is composed of two parts, each of them with an If...Then...Else rule (Table 5.10).

Table 5.10 Representation of the If...Then...Else equation in the innovation loop

Equation	
If(innovation pressure =0) Then(0) Else(If(((perceived benefit *innovation pressure)+ benefit)<benefit sought) Then((perceived benefit *innovation pressure)/time to change overall perception) Else((benefit sought-perceived benefit)/time to change overall perception))	
First part	Second part
If(innovation pressure =0) Then(0) Else <i>second equation part</i>	If(((benefit*innovation pressure)+ benefit)<benefit sought) Then((perceived benefit *innovation pressure)/time to change overall perception) Else((benefit sought-perceived benefit)/time to change overall perception))

The second equation, price adjustment is used to adjust price and, as in innovating in attributes equation, it is composed by an If...Then...Else rule (Table 5.11) that reacts to price pressure.

Table 5.11 Representation of the If...Then...Else equation in the price loop

Equation
If(price adjustment pressure+price<breakeven point) Then((breakeven point-Price)/time to adjust price) Else((price adjustment pressure)/time to adjust price)

*If, Then, Else* equations are useful to portray real decisions as made by decision makers in real life. The downside is that this type of calculation is that it limits the possibility of making a straightforward interpretation of the equation. Given the nature of both equations, it would not be relevant to test them under direct extreme condition test. Additionally, the concepts represented by these formulas, particularly in the case of benefits, exemplify ideas that are difficult to quantify to develop an appropriate analysis for the proposed exercise.

Table 5.12 Representation of the ratio equation

Equation
$\frac{\text{perceived benefits}}{\text{perceived sacrifice}}$

A different case is observed in perceived value equation (Table 5.12). This equation represents the ratio linking the two loops in the model where perceived benefits are the sum of all benefits (stocks) and perceived sacrifice is a price (stock) representation. The ratio has been mathematically and conceptually explained by a number of authors including Fleith de Madeiros et al. (2016) and Zeithaml (1988). It simply indicates the relation between perceived benefits and perceived sacrifice as to define end-users' general impression of a product. Here are some basic examples of the mathematical interpretation of the ratio:

1. Perceived value  $> 1$ , benefits are higher than sacrifice, it is interpreted as “product is judged to be (very) good” i.e.  $0.7/0.5 = 1.4$
2. Perceived value  $< 1$ , sacrifice is higher than benefits, it is interpreted as “product is judged to be (very) bad” i.e.  $0.5/0.7 = 0.7$

Performing direct extreme condition to the equation helped to uncover important assumptions and limitations of the model, for which results and analysis are explained next.

First, it is necessary to define what the extreme values of the inputs mean. In this regard, maximum perceived sacrifice (1), implies that the device will still be used but under high-risk conditions for the end-user. The minimum perceived sacrifice (0), implies that the end-user perceives no sacrifice. Maximum perceived benefits (1), implies that the product complies with all promised benefits at its best. And, minimum perceived benefits (0), implies that the product failed to deliver every promised benefits.

Under the understanding of what each extreme value implies, a possible extreme values' combination was defined and tested in the model. When results drove to confusing outcomes, model was reviewed and changes were made until results were coherent to expectations as described next:

Perceived value= 1/1. Sacrifice and benefit are coherent so that there is technically no need to change neither price, nor current innovation performance. The model behaves accordingly to the statement.

Perceived value= 1/0. Having no sacrifice means market impossibility since it implies that the device is given for free. The model does not allow for sacrifice to ever be 0.

Perceived value= 0/1. Having no benefits is virtually impossible since users cannot claim that there is not even a minor benefit perceived. The model does not allow running scenarios when benefits are 0.

Perceived value= 0/0. There is neither sacrifice, no benefits which is virtually impossible. The model does not allow running scenarios when benefits or sacrifice value is 0.

- Dimensional consistency test

As suggested by Barlas (1996) this test should be only performed once the model has passed the parameter-confirmation test. The test aims to verify unit consistency of the model by verifying that the right- hand side and left-hand side of each equation have the same units. This is probably one of the most common tests to be performed by practitioners first because it helps to verify that parameters are coherent to equations as to avoid “being fooled by the numbers” and secondly, because system dynamics software include automatic unit consistency test. Accordingly, the automatic test was performed using iThink software where unit consistency was verified.

#### **5.4.6 Structure oriented behaviour validity tests**

- Extreme condition test

Extreme condition test or indirect extreme condition test involves defining extreme values to identified parameters in the model to compare the outputs to observed or expected behaviour in the real system



(Barlas, 1996). For this, perceived risk and perceived benefits were identified as outputs to the test based on its significance to perceived value definition. Accordingly a number of model runs were performed under different extreme value experiments to innovation and time pressure. Whenever scenario results seemed unrealistic (i.e. perceived risk does not stabilize despite that price pressure equals 0, or perceived benefits remain low despite innovation pressure increase), equations and structure were reviewed until outputs turn to be coherent to expectations.

- Behaviour sensitivity test

This test is entailed to define those parameters to which the model is highly sensitive, as to perform reality check by consulting experts, stakeholders or reviewing in the literature if the real system displays the same sensitivity (Barlas, 1996).

As parameters were set, first model runs behind the scenes allowed identifying model's sensitivity to graph functions, particularly perceived sacrifice. This reaction in the model is due to the fact that time to make and perceive changes in price is almost five times faster compared to effective changes and changes perception to innovation improvement. Additionally, graphs function to price draw a slope that signifies are faster reaction than those to innovation (see ANNEX 3 for references). This behaviour is considered valid given that both graph functions and parameters correspond to data and information elicited from participants. As additional evidence, according to the literature, changes in price turn to be more significant for end-user perception compared to changes in product quality (i.e. Goodwin and Wright, 2014; Kotler et al., 2005; Trout and Rivkin, 2000).

- Boundary adequacy test

As explained by Lane (1995), boundary adequacy can only be understood as a process that starts in the problem definition phase and is developed throughout the entire modelling exercise. It consists first in defining model's desired scope that must be large enough to enable problem representation and small enough to ease system's understanding. Accordingly, boundary adequacy test involves judgment of modeller, experts or stakeholders to determine the level of detail to be used, so that an adequate model's boundary is one that suits the purpose of the model.

Hence, boundary adequacy was mostly validated as a result of a iterative exercise developed together with participants during the firsts workshop and confirmed throughout expert consultation and workbook where stakeholders defined which information, relations and parameters were believed to be relevant to explain perceived value given the specific circumstances and information available for the case at hand.

- Phase-relationship test

The purpose of this test is to analyse the relationships between pairs of variables in the model to define if the output is coherent to either expected or observed relationships in the real system (Barlas, 1996). Similarly to extreme condition test, a number of model runs were performed under different parameters as to make comparisons to available knowledge. For instance, based on generalized knowledge about perceived value theories (i.e. Fleith de Madeiros et al., 2016; Zeithaml, 1988) if price increases perceived value is expected to decrease. Also according to managerial theory, (i.e. Kotler et al., 2005), if perceived benefits increase, price is expected to increase as well. Whenever scenarios seemed to contradict such expectations, equations and structure were reviewed as to make sure that scenarios portray relations according to anticipated paired variable behaviour for a given set of parameters.

#### **5.4.7 Behaviour pattern validity test**

This last test aims at measuring model's outputs accuracy compared to the real system. As it was previously discussed, system dynamics models do not claim precision so that the emphasis of the test relies on pattern prediction including periods, frequencies, trends, phase lags and amplitudes. A simple test consists in graphical visual comparison, a more formal one requires measuring behaviour features as maxima, media, inflection points and distances (Barlas, 1996).

Either by performing graphical observation or formal measurements, the main goal of behaviour pattern test is to assess how close the model represents the structure of the real system. Given the nature of this case, outputs cannot be compared to real system information. The closest system to compare outputs to real system information is using graphs over time diagrams drawn by participants.

Consequently, no formal measuring seems appropriate since graphs drawn were showing a lack of accuracy to represent real system values, mainly because they were depicted from participants' understanding of assumed future perceptions, which is too artificial for formal comparison. Hence, this test is based on trend prediction and phase lag only, assisted by graphical/visual representations as done in other cases where lack of a real system's reference mode was overcome by comparison to graph over time representation (i.e. Otto and Struben, 2003; Vennix, 1996).

For this reason, the reference modes drawn by stakeholders are used to evaluate the correctness of trend prediction and phase lag only, seeing as virtually unfeasible to evaluate periods, frequencies and amplitudes as recommended by this test. After performing this test, it was confirmed that model scenarios match graphs over time behaviour drew by participants in expected, hoped and feared scenario of perceived sacrifice and perceived value. However, when it comes to perceived benefits, behaviour is only coherent to expected and hoped behaviour.

Since feared behaviour associated with the perceived benefits scenario cannot be represented this is explained by the fact that the model does not account for the possibility of device's defection or quality deterioration overtime. As previously explained, such issue was pointed out in the second workbook developed previously to performing this test. However participants did not elaborate on the topic and the discrepancy of the model structure to model outputs is only addressed during the second workshop as to review assumptions and define the desirable relation that the output should portray according to participants expectations.

#### **5.4.8 Third workbook**

The last workbook was prepared after formal model validation and was used concomitantly to send to participants the agenda of the second workshop. Previously, the gatekeeper had informed that a second in-person workshop was not possible to schedule since it implied a lot of time and expenses for partners to go back to Slovakia. Instead, the gatekeeper proposed to hold a virtual session after the teleconference partners usually have to discuss matters related to pilot project planning. Accordingly, end-users representatives were invited to the go back to Nitra's University to hold the session along with inventors while the rest of the consortium representatives confirmed to attend the virtual session throughout GotoMeeting platform.

Due to time constraints, the workbook containing the agenda was only sent in English. As with the previous agenda, it was first reviewed by the gatekeeper and with no changes requested, the agenda was sent to participants one week before the virtual workshop.

### **5.5 SECOND WORKSHOP**

A total of 7 participants attended the virtual session (out of 10 invited). Two participants were end-users representatives and the rest were part of the consortium, representing developers as detailed in Table 5.13.

The last workshop dedicated to model review and scenario analysis followed a simpler and different agenda from the first workshop, and no changes were made to the intended schedule. The following section explains how the first workshop developed along with participants' reactions to activities. Facilitation was aid by a GotoMeeting, an electronic platform for virtual meetings and iThink as system dynamics software for model simulation.

Table 5.13 Second workshop participants overview

<b>Category</b>	<i>Developer</i>	<i>Developer</i>	<i>Developer</i>	<i>End-user</i>	<i>End-user</i>
<b>Organization / group</b>	Nita's University	Marpos	Cleopa GmbH	Retailer	House hold
<b>Knowledge contribution</b>	Technical	Technical	Market	Food sector environment	Private housing environment
<b>Country</b>	Slovakia	Check Republic	Germany	Slovakia	Slovakia
<b>Total</b>	2	2	1	1	1

### 5.5.1 Model review (Step 1)

*The model review* script as described by Hovmand et al. (2015) was used to analyse model's structure and data used to quantification as well as to challenge participants' views in terms of model's structure-behaviour relation to gain better understanding of the model and with that, gain knowledge about the current standing of the device.

For that, the facilitator started by briefly describing model's structure, parameters and equations referring to the changes made behind the scenes. Participants agreed with current structure and parameters and asked for access to literature used for parameter definition. They also asked to review the difference between the two innovation's graph functions with some explanatory questions that did not lead to further changes.

As for the topic of concern regarding the lack of structure representing product defection, participants judged that it was acceptable to model only innovation improvement without making product defects explicit. As argued by participants, the idea behind this decision it is that the purpose of the model is to have a better understanding of the possible perceived value achieved by the end of the pilot phase. On this matter, characterizing innovation improvements helps to envision how much effort and resources the consortium needs to put to the device according to initial value perception. Thereby, it was suggested that it is reasonable to use the model as a tool for goal setting as for its direct application in the pilot project to which quality degradation in a 40 months period seems unlikely.

After agreement was reached in terms of structure, a number of model runs were performed to analyse dynamic scenarios, clarify ideas and elicit feedback from participants to validate the model as recommended by Barlas (1990, 1996) to formalize validity test and increase confidence in the model and ownership of participants.

This stage of the session contributed to generate agreements on perceived value expectations. In general, participants were able to recognize dynamics and relate outcomes to parameter changes in scenarios. A detail scenario analysis and insights obtained from this exercise is given in the scenario and policy analysis section of this chapter.

### 5.5.2 Closure (Step 2)

To finish the session, a quick wrap-up of the activities developed along the workshops and workbook was made. With that, it was easier to participants to follow how progress was made in terms of modelling and how the parallel activities to support technical modelling contributed to gain understanding of the innovation process.

Accordingly, initial modelling objectives were compared to results and after discussion, it was suggested that the model contributed to improve their understanding of perceived value development as well as to recognize that end-users involvement brought a new perception to identify hidden needs that have to be address before attempting market uptake.

Finally, participants request a written report about scenario analysis and insights gained as to properly integrate it to their pilot plan.

## 5.6 MODEL'S OVERVIEW

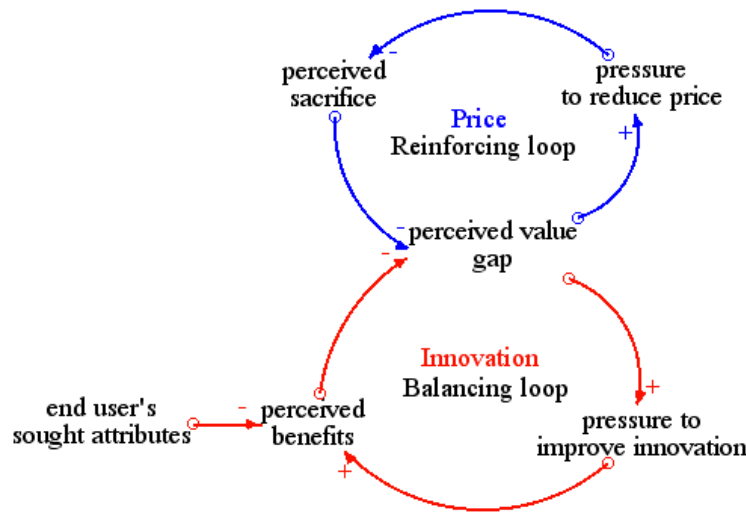


Figure 5.14 Casual Loop Diagram representing the quantified model

To recall, Causal Loop Diagrams (CLDs) are conceptual models used to describe structure and portray interrelationships among system's elements as to describe feedback implications in a graphical way (i.e. Sterman, 2000; Vennix, 1990). In this sense, a CLD is used to provide a synthetic view of the quantified system dynamics model as a framework to describe perceived value components, causality

and feedback loops that explain and trigger perceived value's behaviour.

Aligned with the results of the participatory modelling exercise, the model suggests that the plausible paths that perceived value might follow are given due to two components mainly, innovation degree and price evolution, as observed in Figure 5.14.

Perceived value is identified as a gap in the middle of the structure representing the interaction between developers and end-users. In this context end-users define what the perceived value is according to the inputs provided by developers, namely price and innovation quality. Here, innovation quality is defined as the degree at which the device complies with the attributes sought by end-users. According to system dynamics theory, systems seek for equilibrium, which is achieved by closing gaps. Therefore, perceived value not only represents end-users' reactions to developers' offer, but it also represents a measure of understanding and harmony of the interaction among the two of them.

Here, it is in the interest of the consortium to close the gap by delivering a product that complies with attributes sought by end-users and in exchange, make a profit that allows for financial sustainability and further innovation investment. On the other hand, it is in the interest of end-users to acquire a product that fulfils their needs, closing the perceived value gap by paying a fair price for what they receive.

#### **5.6.1 Price reinforcing loop**

Price dynamics are represented in Figure 5.14 using blue arrows and describing a reinforcing loop. Reinforcing loops capture circular causality in which the combined actions produce an effect that influences more of the same action resulting on growing or decline over time (Sterman, 2000). In this case price represents a tool to get the system back to balance by diminishing perceived sacrifice. As read from the loop in Figure 5.14, the larger the perceived value gap, the larger the pressure to reduce price. The more price is reduced, the smaller the gap. In this sense, it is important to remark that price decrease is a "quick" and "easy" solution to gap closing, however price can also increase as long as end-users consider that price increase stay within a "fair range". In this case, price is seen as an opportunity for developers to increase profits under the understanding that end-users' satisfaction is not in risk.

#### **5.6.2 Innovation balancing loop**

Innovation dynamics are represented in Figure 5.14 using red arrows and describing a balancing loop. A balancing loop represents circular causality creating resistance to change that aims to take the system to equilibrium (Sterman, 2000). Accordingly, the innovation loop can be explained as the efforts made by developers to comply with end-users' sought attributes. The larger the gap is, the more

pressure to innovate. For the purpose of this model, it is assumed that pressure translates into effective product improvements. So that the more improvements, the more benefits perceived by end-users. Such perception is compared to end-users' sought attributes. Hence, perceived benefits is taken as an indicator of device performance, while end-users' definition of sought attributes serves as an innovation goal.

As observed, the conceptual model is relatively simple. However, changes compared to linear perceived value assessment as analysed in Chapter 2 are evident. This dynamic perspective contributes to identify not only the nature of the assessment as previous models do (i.e. Fleith de Madeiros et al., 2016; Goodwin and Wright, 2014; Heetae et al., 2016; Zeithaml, 1988), but the nature of the interactions among actors. Namely the way that developers and end-users individual actions transform the value perceived of a given solution.

## **5.7 SCENARIO AND POLICY ANALYSIS**

As explained in the second workshop implementation, the following description of scenario runs and policy analysis is based on workshop activities where participants aid by the facilitator, went through key model parameters to run scenarios and analyse outcomes that helped them to better understand model's structure and dynamics.

The approach taken to scenario and policy analysis responds to Hovmand et al. (2015), Barlas (1990,1996) and Vennix (1996) suggestions to perform scenario and policy analysis as part of a group learning process to enhance group's understanding of the problem, create confidence in the model, identified and agree on the development of strategic solutions.

In view of this assumption, the next section gathers the results and insights gained from the *model review* script (Hovmand et al., 2015) for which Barlas (1990,1996) and Lane (1995)'s proposed validity test were used as a base to structure analysis. Likewise, the following paragraphs summarize the results of discussion, analysis and agreements where running scenarios are used to learn more about innovation and the way value co-creation supports the innovation process.

### **5.7.1 Base run scenarios**

In view of the fact that no real system data exist for the current model, the base runs of the model shows the scenarios where participants' expectations, concerns and aspirations are portrayed as elicited during the first workshop. In consequence, scenario analysis uses the reference modes drawn by stakeholders throughout the graphs over time exercise to describe and study scenario development for perceived benefits, perceived sacrifice and perceived value as key indicators to the perceived value model.

- Perceived benefits base scenario run

According to participants assumptions, initial perceived benefits equal half of total benefits promised, since there is some uncertainty on whether or not the device complies with all described characteristics. This might be related to the limited exposure they had to the device which was only a description made by developers and a device inspection under working conditions.

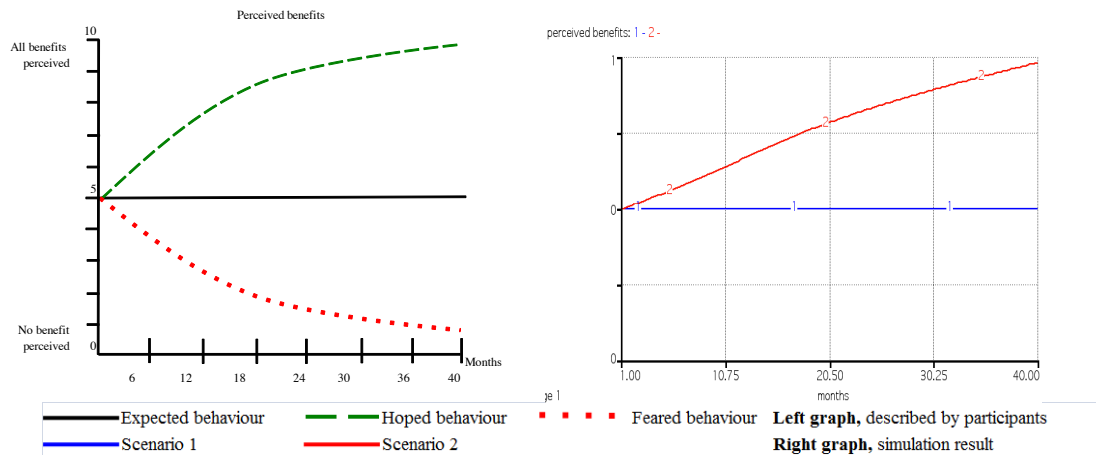


Figure 5.15 Perceived benefits base run comparison to participant's assumptions

With this background, perceived benefits are expected to remain the same (see expected behaviour on left graph, Figure 5.15). Referring to desired benefit perception, more benefits are expected to be recognized over time (see hoped behaviour on left graph, Figure 5.15). A third possibility to perceived benefits is to decrease over time because of product malfunction (see feared behaviour on left graph, Figure 5.15).

As observed when comparing the graph drawn by participants with model's simulated behaviour (Figure 5.15), outputs are coherent with expected and hoped behaviour. In model's scenario 1, perceived benefits start at half benefit perception scale (see scenario 1 on left graph, Figure 5.15) and then remain the same as long as there is no pressure to improve and no desired to change price either. This implies that when pricing the device at a level of sacrifice that matches the level of perceived benefits, there is not explicit need to improve the innovation or make price adjustments, because the system reached the desired equilibrium as described in the previous CLD (see Figure 5.14).

A similar situation is observed in scenario 2 (see left graph, Figure 5.15), which imitates hoped behaviour described by participants. In scenario 2 perceived benefits also start at half benefit perception scale but this time, they increase over time when pressure to improve is at its highest level. To be possible to run such scenario, it is assumed that developers desired to implement an ambitious



policy and keep working on innovation improvement despite that end-users are satisfied with the device.

On the contrary, the model may not simulate the feared behaviour scenario. This is due to the fact that the model only allows for benefit improvement. Based on discussions with participants, the fact that perceived benefits drop over time was considered unrealistic given a revision of initial assumptions. In this term, based on laboratory test results, participants judged that it is very unlikely that the device proficiency is as bad as to constantly erode the potential benefits of the device, so that there is no point to develop such scenario. Although product defection is recognized as a possibility, developers pointed out that based on their experience, most defects are related to manufacturing, installation or operational error, which is not directly related to product's functionality as aimed to be portrayed by the model. Therefore, the fact that benefits can only be improved over time seemed reasonable to participants, suggesting that feared behaviour as initially characterized is unrealistic.

- Perceived sacrifice base scenario run

According to participants assumptions, initially perceived sacrifice will be half of total sacrifice. In this case, sacrifice is associated to price only. As in perceived benefits analysis, the halfway initial level might be indicative of the uncertainty associated to the case study. With this, perceived sacrifice was expected to remain the same considering that price does not change (see expected behaviour on left graph, Figure 5.16). Consequently, hoped behaviour is associated to decreasing perceived sacrifice over time and feared behaviour is in nature associated to perceived sacrifice increase (see hoped and feared behaviour on left hand side graph, Figure 5.16).

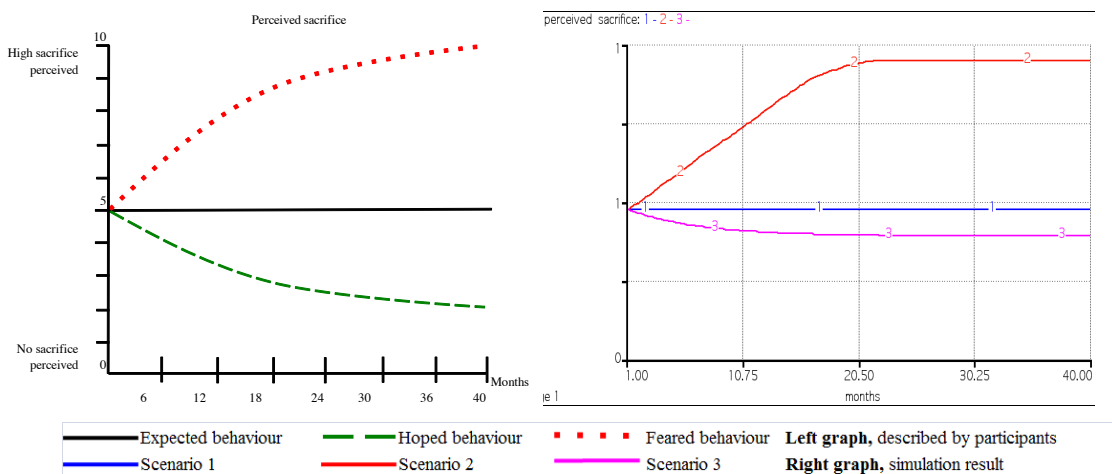


Figure 5.16 Perceived sacrifice base run comparison to participant's assumptions

An interesting point made by stakeholders is the expectation of sacrifice increase to be higher than sacrifice decrease. Namely, stakeholders consider that sacrifices can increase more of what they can

diminish which implies that participants are risk averse when it comes to evaluate the device. Again, this could be explained by the uncertainty around the device, in highly uncertain situations risk is likely to strain pessimistic views (i.e. Goodwin and Wright, 2014; Holmes et al., 2011). In this case, the model is capable to reproduce the three scenarios as envisioned by participants, including the discrepancy on the higher increase of sacrifice perception compared to its lower decrease as described by stakeholders (Figure 5.16).

In scenario 1, expected perceived sacrifice starts at half sacrifice perception scale and then remains the same given systemic equilibrium where there is no pressure to adjust price (see expected behaviour on right graph, Figure 5.16).

In scenario 2, hoped perceived sacrifice starts at half sacrifice perception scale and then decreases over time. To be possible to run such scenario, a policy of price reduction has to be assumed by setting price adjustment pressure to constantly decrease price.

In scenario 3, the opposite effect is observed. Here, to be possible to run such scenario, a policy of price increase has to be assumed by setting price adjustment pressure to constantly augment price.

- Perceived value base scenario run

Perceived value describes hoped and feared behaviour following the same pattern and logic of perceived benefits. It increases either because of benefit improvement, price drop or the combination of both and decreases because of price rise along with no innovation improvement.

Model's behaviour is coherent to expected behaviour's trend prediction and phase lag. In scenario 1 perceived value starts at 1 in the perception value scale, which means that there is a balance between benefits and sacrifice. At this point the whole system is in equilibrium (Figure 5.17).

Model's behaviour is coherent to hoped behaviour's trend prediction and phase lag. In scenario 2 perceived value also starts at 1 in perception value scale, and then increases over time when price adjustment pressure is set to constantly decrease price by 10Euros while keeping a constant innovation pressure that continues to increase perceived benefits (Figure 5.17).

Model's behaviour is coherent to feared behaviour. In scenario 3 perceived value also starts at 1 in perception value scale, and then decreases over time when price adjustment pressure is set to constantly increase price by 10Euros while innovation pressure equals 0, so no improvements are made to the device (Figure 5.17).

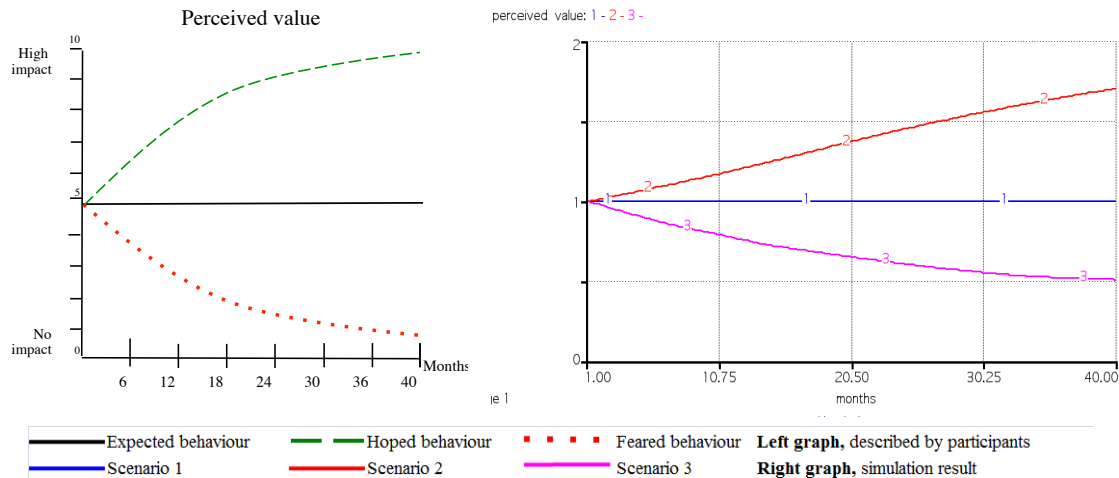


Figure 5.17 Perceived value base run comparison to participant's assumptions

Parameters set emulate circumstances to cause perceived value to either increase or decrease as described by stakeholders. To be possible to develop such scenario, two possibilities were identified: (i) either sacrifice level decreases by constantly reducing price or (ii) developers assume an ambitious policy and keep working on innovation improvement despite that end-users are satisfied with the device.

### 5.7.2 High vs. low sacrifice-benefits scenarios

The following set of scenario runs were developed to identify those parameters that influence systems behaviour and draw expectations on desirable outputs. Scenarios are based on story telling exercise where participants defined meaningful and plausible circumstances of innovation development and then parameters were set to match stories as to define means for desirable scenario development in the perceived value case.

It is important to recall, that the consortium aims to develop a product pilot test in different locations across Europe to address identified end-users' groups (i.e. household group, retail industry group, health service group, hotels and restaurants). During the pilot test, representatives of each group will provide feedback on product performance, satisfaction and perceived value. Based on such information, the consortium will define which potential end-users' groups value the product enough as to become real end-users. This is key to understand in order to achieve financial sustainability. Also, developers will have a knowledge base to define product improvement, which needs to comply with end-users' requirements and expectations as well as to set a price that finds a balance between end-users' satisfaction and developers financial needs. Hereby, the model helps participants to identify the areas that demand end-users' attention as to better plan for the pilot test and product proficiency goals.

Having that in mind, participants told hypothetical stories of what they might encounter during the pilot phase and how their intervention in price decisions and innovation improvement might change the course of the scenario.

- Perceived benefits scenario analysis

For the analysis of perceived benefits scenarios, the story telling was described as follows: “Let’s assume that we have two end-user groups, A and B. We applied a satisfaction survey to evaluate the device performance in each of the identified attributes. Results per group will be averaged and introduce to the model to decide whether is feasible to focus market efforts in such groups”.

*High perceived benefits scenario (Group A)*

Initial price: 200 Euros

Group A overall perceived benefits: 0.75 out of 1

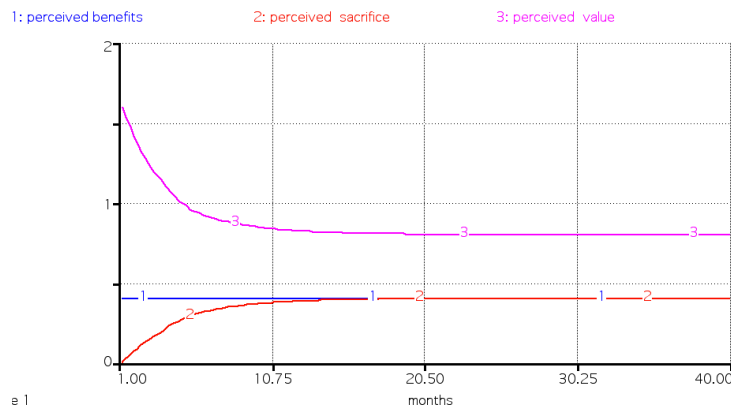


Figure 5.18 High perceived benefits scenario

Under this hypothetical scenario, developers still have some features to improve. If improvement is achieved at best only 50% of the attributes can be effectively improve according to Schneiderman (1988)’s half-life rule. Hence, target A will be willing to pay around 360 Euros by the end of the pilot phase. This is because end-users have an initial high perceived value that outstripped sacrifice from the beginning. Hence, developers can still improve the product at the same time that end-users assent to pay a higher price, which is possible as long as there is a perceived value gap, as well as a difference between attributes sought and perceived benefits.

The previous graph (Figure 5.18) shows simulation results explaining feasible price increase (represented as perceived sacrifice raise) where perceived benefits are initially higher than perceived sacrifice. In this case, perceived value drop does not necessarily have a negative connotation since it reaches equilibrium at a considerably high level (0.75).

### *Low perceived benefits scenario (Group B)*

Initial price: 200 Euros

Group B overall perceived benefits: 0.25 out of 1

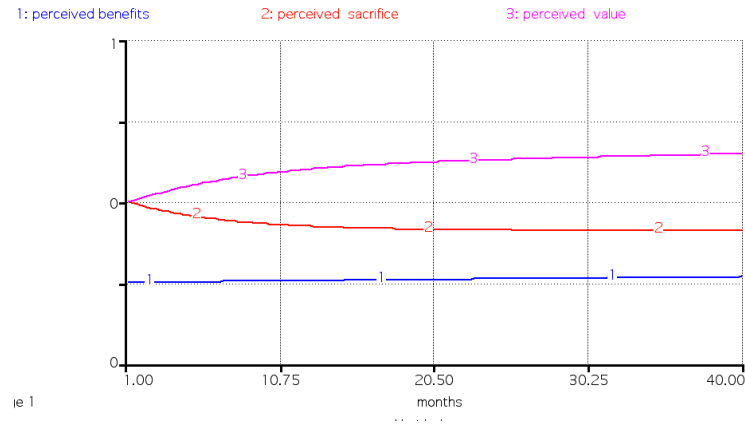


Figure 5.19 Low perceived benefits scenario

Under this scenario, developers have plenty features to improve. Assuming that the half-life rule applies (Schneiderman, 1988), even when improvement is achieved at best the most attractive price that can be offered to target B is 170 Euros by the end of the pilot phase. The previous graph (Figure 5.19) shows simulation results explaining price drop.

Perceived benefits are initially lower than perceived sacrifice. Given that innovation pressure is higher, benefits increase in a higher rate than for group A. Perceived value gets to 0.6 but too many efforts seem to be needed to achieve such level. Despite innovation improvement and perceived sacrifice drop, product performance is not likely to satisfy this group. This is a risky group if the consortium decides to make efforts to improve value perception.

Based on this analysis only group A could be considered for market uptake over group B. Probably the main insight drove out from this scenario is to understand the relevance of initial conditions to define the development of perceived value.

- Perceived sacrifice scenario analysis

### *High perceived sacrifice scenario (Group C)*

For this scenario analysis, a story was described as follows: “Let’s assume that group C has an overall perceived benefits of 0.5 out of 1. Under such initial perception the next scenarios can be analysed”.

Initial price: 700 Euros

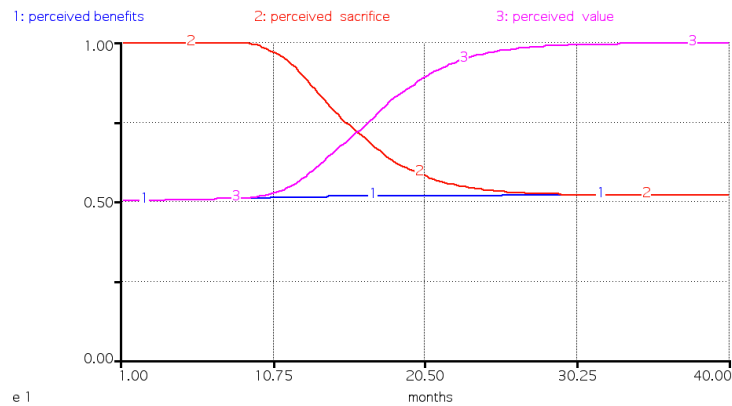


Figure 5.20 High perceived sacrifice scenario

There is a discrepancy between sacrifice and benefits where sacrifice is higher than benefits, which makes price to go down until reaching 207 Euros by the end of the scenario run. Only when sacrifice drops significantly (because of price reduction), then perceived value starts to stabilize to 1 (Figure 5.20). Innovation improvement is low given that participants decided to set an aggressive price policy to quickly reduce price when facing large perceived value discrepancies. Accordingly, the fast solution (price drop) outstrips the long-term solution (innovation improvement).

#### *Low perceived sacrifice scenario (Group C)*

Initial price: 100 Euros

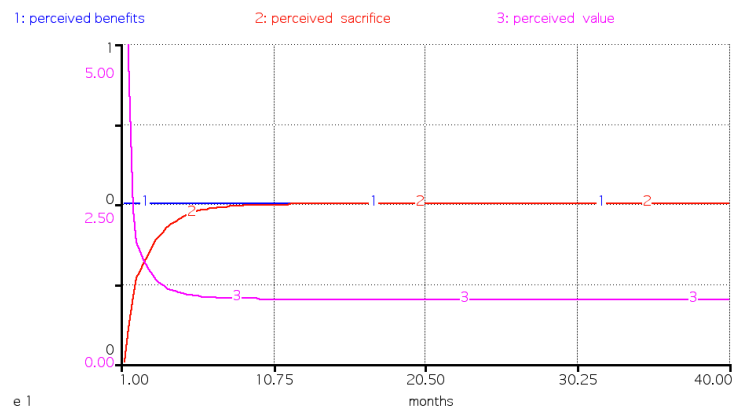


Figure 5.21 Low perceived sacrifice scenario

In this case there is a large discrepancy between sacrifice and benefits where benefits are considerably higher than sacrifice. This scenario takes price up until reaching 200 Euros which drives perceived sacrifice to a stable level relatively fast. This is plausible because given a high perceived value, developers can increase price level as long as perceived sacrifice is lower than perceived benefits.

The large discrepancy generates a quick systemic reaction given perceived value price sensitivity. In this case equilibrium is reached when perceived sacrifice equals perceived benefits. Different from the previous case perceived value decreased over time, which suggests that although price increase is feasible it does not mean that is desirable if it is at the expense of perceived value reduction (Figure 5.21).

### 5.7.3 Loop dominance analysis scenarios

The purpose of these scenario runs is to analyse the relationships between pairs of key variables to better understand loop dynamics and identified leverage points for policy making. Here the same story telling dynamic was followed as to connect the meaningfulness of studying feedback to real life decision-making.

- Innovation effect scenario analysis

For the analysis of the innovation loop the story was told as follows: “Let’s assume that equilibrium has been achieved so that perceived value in the model equals one, but as it has been discussed the fact that the system is in balanced does not mean that the device is fully performing. At best it can be assumed that end-users are satisfied with the sacrifice-benefits so that they observe coherence and thus, the device is well accepted the way it is”.

#### *Constant innovation improvement scenario*

Initial benefits: 0.5

Initial sacrifice: 0.5

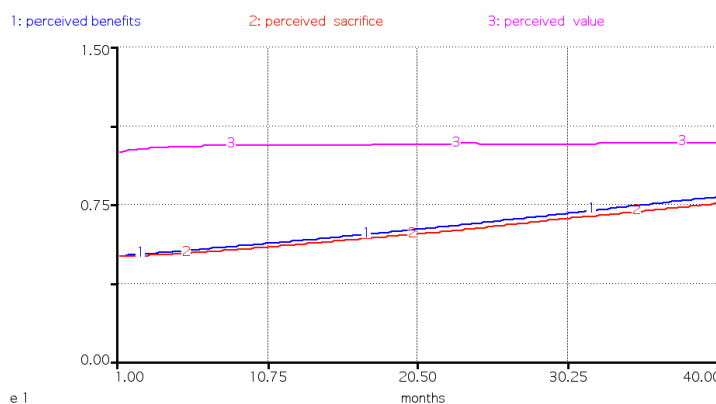


Figure 5.22 Innovation effect, benefits exceed sacrifice scenario

This scenario was run under the assumption that end-users are initially satisfied with the trade-off benefit-sacrifice but that the device is not performing at its best so that the consortium decides to set improvements goals. Accordingly, the model recreates a scenario where the system is taken out of

balance by inducing innovation pressure as a constant. Then constant pressure represents the ambition of developers to deliver a better product, being aware that there is room for improvement. It allows perceived value to increase continuously while the gap between benefit and sacrifices gets larger. Such phenomenon is plausible since benefits increase together with sacrifices and benefits are always higher than sacrifice, which allows perceived value to rise gradually, together with price. The system will only get back to equilibrium when the device achieves all attributes as sought by end-users (Figure 5.22).

Given that innovation pressure represents the efforts that developers make in order to improve the current state of the innovation, a hypothetical scenario in which sacrifice exceeds benefits is not possible to develop for the innovation loop. Doing so would imply that innovation has the effect to decrease benefits, which is not realistic according to the developed model.

- Price effect scenario analysis

To make a comparative analysis of the effect of price loop to innovation loop, price effect scenarios are run under the same initial conditions used for the innovation effect analysis. Accordingly, the same story as the one described for the innovation loop is used to analyse the two following scenarios.

*Constant price increase scenario*

Initial benefits: 0.5

Initial sacrifice: 0.5

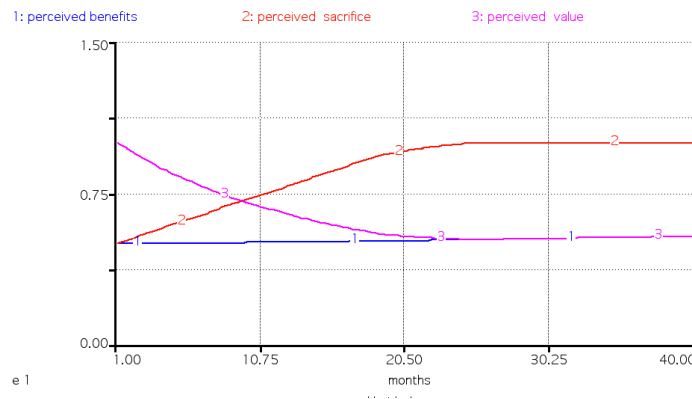


Figure 5.23 Price effect, sacrifice exceed benefits scenario

Under the same equilibrium conditions, developers decided to set a price policy in which price increases 150 Euros per year. A constant price increase will take perceived sacrifice up and perceived value down with a very slow increase on perceived benefits. Since price never stops to increase, the



effect of innovation pressure on benefits is very low compared to price effect on sacrifice raise. Moreover, benefits improvement impact on perceived value is barely noticeable (Figure 5.23).

#### *Constant price decrease scenario*

Initial benefits: 0.5

Initial sacrifice: 0.5

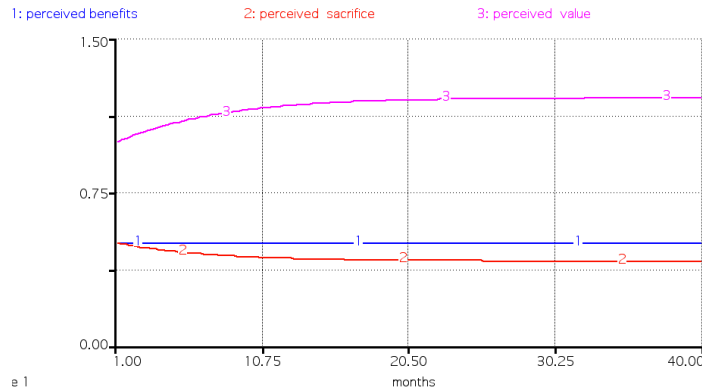


Figure 5.24 Price effect, benefits exceed sacrifice scenario

On an opposite situation to the one previously described, this scenario explains a policy to decrease price on 150 Euros per year. It would increase perceived value since price stagnates at 170 Euros (breakeven point). A slow but constant price drop will take perceived sacrifice down. Thus, allowing perceived value to rise with a very slow increase on perceived benefits, which is characteristic of innovation pressure when pressure is close to 1 (Figure 5.24).

The former scenario analysis made evident that price reinforcing loop is the dominant one to the system. This can be explained for a number of factors as defined along the participatory model building process and as described in the scenario analysis. Therefore, the main cause for price loop dominance are (i) end-users sensitivity to recognize and react to price changes compare to innovation improvement, (ii) faster systemic reaction to price adjustment compared to innovation improvement according to time delays in the model and (iii) easiness to modify price than to modify innovation.

#### **5.7.4 Policy lessons**

After performing scenario analysis, takeaway policy lessons to improve perceived value are described based on price and innovation, identifying the leverage points of the system. Accordingly, policy lessons from the previous section are listed and summarized as follows:

## 1. Manage sacrifice

In order to allow for perceived value to either stabilize at a high level or increase over time, sacrifice has to be kept, as much as possible, to a low level. For that, it is important to make sure that paying the price set represents a sacrifice which is lower than the level of benefits obtained. This implies that innovation has still space to improve and gives also space to price to increase according to innovation improvement achievements. In other words; when innovations continue to improve; end-users consider that price increase is acceptable as long as each new improvement comes with a price increase relative to the improvement accomplished. Then the price increase is recognized as fair to end-users.

This idea also drives an evident but significant policy, which is to never set the initial price at a high level since this will only creates a negative value perception that is hard to overcome despite future innovation improvement or price reduction.

Finally, an initial low price is neither recommended. As it was observed through the scenario analysis, the possibility to rapidly adjust price will take price to drop too quickly. Therefore, the system equilibrium is found at a point at which innovation improvement is feasible, but will probably not take place given that developers observed that end-users are satisfied with the benefits the innovation offers, considering the price they pay.

## 2. Improve benefits

In order to allow for perceived value to either stabilize at a high level or increase over time, improvements have to be constant. This is clearly related to developers' decision of whether it is necessary or not to improve the innovation. Such decision can be based on its own desired of making a product as best as possible, even beyond end-users expectations. Yet, the model suggested that such decision is strongly related to the pressure to improve innovation and such pressure drives from end-users valuation of the device. Hence, if developers get signs and feedback from end-users indicating that they are satisfied with the way the innovation is, they might not make extra efforts to improve it which signifies missing opportunities of delivering better solutions.

This is way a correct interpretation of end-users' value perception becomes critical to developers. In this regards, understanding the dynamics of perceived value helps them to make better decisions are not get fool by the idea that correct pricing is all what they should seek for. Their most important role is to work on improvements as to trigger long lasting effects in value perception.

### 3. Different policies are required to different end-users

As it was learned from developing scenarios and defining parameters to tell plausible innovation development stories, it becomes clear that the principles mentioned before about sacrifice management and benefits improvement have to be analysed and customized as for each end-user group, particularly because perceptions indicate to vary among end-users.

### 4. Starting point matters

Finally, the different scenario runs enable to realize how perceived value develops differently according to the started level of sacrifice and benefits perception. This stresses importance of getting close to end-users and allow for value co-creation opportunities. Hence, before aiming for innovation implementation, is critical to clearly understand end-users as to provide a solution that is relevant for them, complies with the attributes they seek for, and at a price that signifies a sacrifice level they can deal with.

Ignoring such perceptions might drive to an initial implementation point that does not correctly manage sacrifice or that addressed the wrong benefits. Both are weaknesses that, as explained by Gourville (2005), Sterman (2003) and Repenning 2012, become potential causes of innovation failure. Hence, trying to improve innovation's perceived value on the run will prove hard to accomplish, as suggested by Sterman (2003) and supported by scenario analysis conclusions.

## 5.8 ASSESSMENT OF THE PARTICIPATORY MODELLING APPROACH

As stated in the research methodology section, the assessment of the participatory system dynamics modelling exercise aims to identify relevant outcomes to the method by final questionnaire evaluation that is complemented by observations of the exercise implementation. Also, sessions' observation is used to explore the utility of the approach to enhance value co-creation. With this, the participatory modelling assessment aims to contribute to explore new applications to value co-creation practices, at the same time that brings evidence to the efficiency of facilitated modelling to problem structuring as well as to improve decision making in a group process (Rouwette, 2011; Vennix, 1996).

### 5.8.1 Lessons learned regarding the PSDM methodology

- Observed workshop dynamics

Probably one of the main challenges faced for method implementation was the fact that language became a barrier to communication between the facilitator and participants. Before the session, the gatekeeper judged that participants' English understanding was good enough to hold the workshop in English. Nevertheless, during workshop implementation most of them appeared confused and after

some minutes the gatekeeper stepped up suggesting making direct translation to avoid misunderstandings and optimizing time.

A possible consequence of having a translator could be related to the change in the group's atmosphere. When participants were requested to speak English they seemed introvert. However, when the gatekeeper intervened they were more participative which could be associated to reducing the pressure of losing face in front of a facilitator, a person not all of them are familiar with, enquiring information that is not simple to depict that besides addresses them in a language they do not feel comfortable with. As explained by Vennix (1996), a positive group atmosphere contributes to good group performance particularly in terms of team building, and conflict handling. To do so, the facilitator is expected to contribute creating such environment by keeping a helping, neutral, authentic attitude and enquire mode, which in this case was performed and probably better accomplished throughout the intervention of a third person (gatekeeper as a translator).

Having language as a critical communication barrier, forced the process to be more open in terms of activities' adaptability. As the session progressed, it seemed that both the translator (gatekeeper) and the facilitator were leading the session since they would talk to each other before addressing the whole group. Although it might be assumed that having two persons leading activities creates confusion, this was not the case.

The translator was familiar with the activities, the group and had a genuine intention to integrate end-users to the innovation process. In this respect, her attitude suggests to hold the desired characteristics of a facilitator. She seemed to be neutral when enabling to encourage the whole group's participation following facilitator's directions, and helpful when she contributed to consult with both facilitator and the group to make changes that would ease exercises' implementation.

As it can be implied, a familiar and open atmosphere characterized the group's environment. For instance, participants felt comfortable to suggest slightly modifying the *graphs over time* exercise where handling too many variables turned out to be overwhelming. Additionally they believed that drawing was not enough to explain their fears and hopes, so they proposed to write down a short explanation on the reasons to hold such beliefs. It seemed that being flexible and allowing participants to suggest changes prompted engagement and an active participation.

According to Schein (1990), these kinds of interventions have potential positive effect on results based on the idea that only the group knows what is best for them. Hence, it can be said that the facilitator was effectively seen as a guide to the process throughout the translator, and not a judge to the group.

Motivation among participants was also evident. The first workshop finished after five hours and end-users representatives stayed for four hours and a half instead of three hours they originally planned.

Additionally, no break was taken. When participants were asked, they preferred to keep on working on the exercises.

After experiencing language barriers in the first workshop, concerns increase about the implementation of a virtual workshop for the second session, particularly because this practice inevitably makes communication impersonal which is to be avoided in participatory practices. Additionally, the virtual workshop came at the end of one-hour of teleconference. Indeed, conditions of the virtual workshop were not as optimal as the face-to-face event.

Since the gatekeeper was also the organizer of the teleconference, her leading role appeared to be somehow influential during the virtual session. She made most of the interventions and it seemed that participants waited for her to interfere before making their own contributions. This could be because they might be less confident when using electronic means or because the workshop did not manage to detached participants from the dynamic of the teleconference held before.

According to the observed level of participation in the second workshop, it could be said that virtual environments are less motivating or less appropriate to address participants, which could explain the fewer interventions of participants compared to the first workshop. The second explanation could be related to the level of consensus reached in terms of system's boundary and parameters along the process, since both topics were addressed during the previous session and through the workbook. This remains as an open question to analysis since Vennix (1996), warns on the negative implications of reaching agreement too fast. In this regard, reaching agreement is not as important as the learning process behind it. With few ideas to be shared, there were limited possibilities to discuss model changes and the session was more focused on scenario analysis.

While the lack of model changes might be questionable, this workshop turned to be positive in terms of model validation where participants elaborated in the way scenarios are understood and how outputs are interpreted. Participants were more attentive on following the stories told by the model and although the consortium side of the participants was more active in terms of scenario analysis, end-users seemed to be interested in getting to hear explanations as well.

Another relevant lesson was related to the model review developed in this second workshop. Since it was anticipated that the virtual workshop may face additional challenges to keep active group interaction, model review was planned in a more structured and instructive way, using story telling of plausible and meaningful circumstances that stakeholders might encounter during product implementation.

In this respect, validity tests served as inspiration to set relevant scenario analysis and consequently, policy setting for the model review activity. A set of validity test described by Barlas (1996) and Lane

(1995) were used as a base to define the story telling framework to which participants agreed to and to which they contributed by setting the parameters' values they wanted to test. The purpose of such exercise was to gain relevant insights that are often obtained by the modeller when performing model validation tests. This was also inspired on Barlas and Carpenter (1990) suggestions to involve participants in model validation test to build up reliability on the model when modelling with a group of stakeholders.

Accordingly, structure-oriented behaviour test and behaviour validity test were used as a base for setting story telling. The result was quite positive and practical to apply. By telling stories participants identified those parameters that influence behaviour and drew expectations on model's outputs, which helped them to review assumptions, identify leverage points and define policy settings. Results suggest that using story telling based on relevant validity tests, positively helps participants to drive their own conclusions based on a clear line of scenario analysis which, being prepared before the session, eases model review task.

- Final questionnaire

As it is suggested by the previous analysis, the outcomes of the exercise were positive in terms of the group and modelling process, particularly considering time, language and logistic constraints. Such conclusion is supported by the results of the final questionnaire application. In this matter, Rouwette (2011) suggests that questionnaires are a useful tool compare evaluation across facilitated modelling cases. Promoting the use of a standard framework is important to identify best practices to improve the standing of the method and deliver better results to problem owners and decision-makers.

Despite case variability, combining analysis of multiple cases enables for statistical testing of relations. Therefore, the Communication quality, Insight, Consensus and Commitment to Conclusion questionnaire (CICC) was applied to participants of the participatory modelling exercise hoping to contribute to a metadata construction of facilitated modelling as proposed by Rouwette (2011). Beyond the desire to contribute to a larger cross-case analysis, the CICC questionnaire is relevant to the case giving its focus on areas that are aligned to the purpose of the current participatory modelling exercise.

In this matter, communication assessment is key to the case since one of the main aims is to improve communication among developers and end-users as to contribute to value co-creation aims. As it has been highlighted, allowing the exchange of ideas, perceptions and information is significant to deploy product co-creation opportunities. Despite that direct communication between facilitator and participants was not possible (translator intervention); it seems not to have negative implications in

participants' perception of the way that communication was developed among the group. Here, questionnaire valuation reports a mean of 3,49 in a scale 1 to 5 (Table 5.14).

As for the case of insights, the result of insights evaluations is important because it reflects the knowledge and understanding gained through the modelling process. In the case of innovations, knowledge gain is suggested to contribute to reduce uncertainties regarding innovation development, which becomes essential to improve planning and create better opportunities for innovation development. Here, questionnaire results report a mean of 3,72 in a scale 1 to 5 which is also quite positive (Table 5.14).

In the case of consensus, this can be understood as a process mental model alignment achieved when group's beliefs and opinions are in harmony. Consensus can be related to one or several phases of the participatory process; for instance, agreement to problem definition, agreement to problem conceptualization, agreement to the solution, agreement to the task and resources allocated for problem solution etc. (Rouwette et al., 2002). In the innovation case, consensus mainly refers to the possibility to joint and synchronize perspectives around the innovation so that both end-users and developers acquire a sole vision of what the device is capable to do and how it contributes to create value. Here, questionnaire results are also positive where valuation reported a mean of 3,55 in a scale 1 to 5 (Table 5.14).

Finally, commitment refers to the degree to which agreements transcend the participatory modelling exercise to the implementation arena. In this case commitment mainly impacts the willingness of developers to take into account the inputs (needs, requirements, knowledge, etc.) of end-users as well as to make decisions regarding innovation's development according to participant's contributions. Here, questionnaire valuation reports a mean of 3,55 in a scale 1 to 5 (Table 5.14), for which it can be assumed that developers are committing to implicit compromises created with end-users as to develop the product according to the inputs provided along the participatory process.

As a side remark to the current assessment, knowing from the beginning that participants' availability and budget limitations could potentially limit the development a second workshop, the results of the CICC questionnaire refer to a evaluation of the process developed up to the first workshop only. Hence, questions related to scenario run and model quantification were not consider for questionnaire assessment. After the virtual workshop was hold, participants were asked to review their answer to the questionnaires as well as to answer the questions related to scenario development. However participants stated that their general perceptions did not changed and only two of them returned the questionnaire answering the missing questions. With such a low response rate, answers to model

quantification were left out of analysis as to maintain a homogenous assessment on the final questionnaire analysis.

Table 5.14 CICC questionnaire results

Source: based on Rouwette (2011)

Variable	n	Minimum	Maximum	Mean	SD
<i>Communication</i>	7	2.57	4.00	3.49	0.56
<i>Consensus</i>	7	3.25	4.00	3.55	0.27
<i>Commitment</i>	7	2.67	4.00	3.40	0.49
<i>Insights</i>	7	3.20	4.20	3.72	0.46
<i>Efficiency</i>	7	3.15	3.92	3.66	0.30

*Note: Scale 0 to 5, where 0 refers to very poor and 5 to very good rated*

### 5.8.2 Lessons learned regarding the usefulness of the process for value co-creation

Based on observed workshop dynamics and questionnaire results, participatory system dynamics modelling appears to be a suitable approach to value co-creation. This is due to the opportunities to improve innovation standing by opening dialogue among an heterogeneous group of stakeholders where conflicting interest are likely to create misperceptions regarding innovations performance. Supporting this theory, some concrete evidence can be driven from the occurrences observed in workshop interaction.

For instance, one of the main outcomes of the workshop to support cooperation among stakeholders, was having agreement on defining perceived value as the reference mode of the model. Despite being a qualitative concept only existing in the imaginary of the group, perceived value was considered to be useful since it helps to represent sacrifice and benefits together as to set a ground to mediate among developers and end-users interests.

Another clear moment of cooperation benefits was observed when participants listed more benefits of those first identified by developers. Here end-users actively intervened in the characterization of the attributes. Such behaviour is aligned to the theories of Alves et al. (2016) and Sterman (2013) suggesting that when giving the opportunity, end-users can positively contribute to improve innovations since it is in their interest to achieve higher and common goals beyond product's commercialization.

Since developers already spent a considerable amount of time and effort developing the product, they were not willing to invest extra money on product improvements. Sharing ideas with end-users helped



them to broad their vision in terms of users' needs and product readiness. This led to the idea of developing different versions of the device right after realizing that improvements and customization are needed to comply with end-users needs. While during preparatory meetings developers seemed reluctant to the option of making improvements to the device.

However, a few doubts in terms of the effectiveness of the method to problem framing remained. This is given the difficulty of identify and validate other sacrifices than price. It seemed that participants were not really open to formally acknowledge other sacrifices that might not be fully associated to price. Although participants stated that it was useful to recognize such components, in the end discussion led to not considering them relevant enough as to be part of the simulation model.

For this particular issue, there is not enough evidence to define if it responds to a drawback of the methodology or the process followed. It could be related to the methodology in the sense that aiming for quantification could have created a barrier to include concepts that were too uncertain given the little familiarity with no monetary-risk concept. Other option is related to the way the exercise developed, perhaps starting by defining sacrifices instead of benefits would have led to a different problem framing and the inclusion of such sacrifices to the model. This is a relevant concern given that underestimating costs is considered a reason for innovation failure in the market place (e.g. Gourville, 2005; Repenning, 2012; Sterman, 2013).

The overall experience reveals that using participatory system dynamics modelling to prompt value co-creation is useful to enable direct interaction, improve dialogue and create more and potentially, better ideas to improve sustainable innovations. To effectively accomplish such goals, some considerations must be taken into account for methodology implementation.

First, it implies that stakeholder groups participating in the exercise have to represent two basic kinds of knowledge, the one of product developers and the one of end-users. Such groups have to represent a good mix in terms of number of participants.

This indicates that some additional difficulties are faced when setting up the workshops. On one side, developers often represent a group of scientific or technical people that might have very busy agendas to compromise to workshops. Also, the number and profile of end-users invited has to be carefully defined to represent as much views as possible.

The proposed settings for the participatory modelling framework differ from other value co-creation methods where direct developers are not involved but a large number of end-users are invited, consulted or observed to elicit ideas that improve innovation. Instead of integrating real product developers, representatives of the organization(s) involved in product development are invited to such sessions. However, this approach might not be enough for participatory modelling where the

knowledge of original developers seems more critical given that the debate is likely to require a deep understanding of technical development possibilities.

Second, some compromises have to be made in terms of model ownership. Although the model is useful for communication, developers might be more interested in the implications that modelling has in terms of uncertainty management and innovation planning.

This indicates that in spite of end-users interest to contribute to value creation, they may not necessarily take part to all modelling activities. For instance, discussion between both groups is useful to understand and identify innovation's sources of value. Nonetheless, model quantification of components related to product manufacturing does not require of end-users involvement to be done. On the contrary, it might be too much of a technical debate for end-users, which might decrease their motivation for the project in general.

Accordingly, workshops must be planned with this perspective in mind. In this case, involving both groups in tasks that are relevant for both of them is needed to optimize time and resources available.



## 6. CONCLUSIONS AND FURTHER RESEARCH

Policy makers, scientists and citizens have acknowledged that by enhancing technology development, sustainable innovations contribute to tackle social concerns and improve welfare (Stermann, 2003; Yang and Sung, 2016). Giving the great aspirations of sustainable innovations to contribute to societal change, a major effort has to be made in order to overcome challenges and improve the discouraging failure likelihood that sustainable innovations face (de Jong et al., 2015; Gaurav, 2010; Gourvielle, 2005; Repenning, 2012).

Aiming to contribute to the ultimate sustainability goals, tools and techniques have been developed departing from existing methodologies as to adapt their objectives towards value co-creation, hoping that direct interaction among end-users and developers becomes the trigger of change in the way sustainable solutions are thought and developed (Alves et al., 2016; Grönroos and Voima, 2013; Janeschek et al., 2013; Yang and Sung, 2016). The interaction of stakeholders at multiple levels, merging top-down and bottom-up approaches, is believed to allow for major transformation and deep innovation to occur (Kemp et al., 2007). In this way, transition management can operate and prompt social ecological system co-evolution by convening end-users and developers to learn together and combine their capacities to adapt social systems towards a desirable environmental change to achieve positive, long-term transformation (Carey and Harris, 2016; Loorbach, 2004).

Hence, the current thesis adopts the perspective of system dynamics and participatory modelling approaches, aiming to build up a platform for developers and end-users dialogue in joint decision-making regarding sustainable innovation development, enabling value co-creation opportunities to generate bottom-up solutions that tackle societal challenges. With this, we explore the role of participatory modelling as a platform for stakeholders' interaction, as well as system dynamics as a methodology to improve innovations development. Hereby, this contributes to better design sustainable innovations and reduce implementation failure possibilities. Accordingly, three research questions were addressed:

1. What are the implications of eliciting and integrating end-users and developers' standpoints concerning sustainable innovations perceived value?
2. What are the effects of adopting a dynamic view of perceived value to potentially improve the understanding of sustainable innovation development?
3. What are the potential contributions of system dynamics methodology to improve the design of sustainable innovations when using a participatory modelling approach?

To accomplish these objectives a participatory system dynamics modelling framework was developed throughout facilitated modelling workshops, data gathering, parameters quantification and technical

modelling behind the scenes to ease end-users and developers engagement into model building activities, prompting dynamic thinking and sharing knowledge, ideas and interests regarding perceived value concept. The framework was tested and applied to an illustrative case study throughout five research steps explained and discussed in chapters 4 and 5.

In the first step, problem formulation set the ground for the case to which the participatory system dynamics methodology was applied. The case study was structured throughout preliminary meetings with stakeholders to define the problem, identify the gatekeeper to the case, as well as desirable stakeholder involvement, invite participants and schedule the workshops accordingly.

Preliminary meetings effectively contributed to structure the case and plan for workshop implementation. Given that most of the identified stakeholders for the case attended the meetings, active interaction between the facilitator and participants contributed to build rapport, and thus no additional tools as interviews were needed to planning as suggested by practitioners (Vennix, 1996, 1999; Videira, 2009). Due to logistics' constraints, participants that were not part of the preliminary meetings were not previously interviewed either. Nonetheless, a workbook with relevant information to the project and the process was sent to familiarize them with the aims of the case. The fact that no previous contact was established seemed not to have negative consequences regarding group dynamics.

The second step refers to dynamic problem conceptualization, which was mainly achieved during the first workshop and supported by the first workbook. Here a linear perceived value model was translated into a dynamic one. With this, end-users and developers found a concept of mutual interest to define goals and raise concerns regarding innovation development. The concept of perceived value assessment demonstrated to be useful in two ways mainly: (i) serves as an opening and mediating dialogue concept, given the significance that developing a high value solution has for end-users and the fact that perceived value is seen by developers as an indicator of potential innovation success (Hair and Ortinau, 2003; Kotler et al., 2005) and (ii) shows to be useful to analyse scenario development to reduce uncertainty about innovation development (Walker et al., 2000; Walker et al., 2003; Wright, 2005).

In the third step a quantified system dynamics model was developed. Then, technical development of the model (equations and concepts' quantification) was carried out according to the theories and assumptions elicited in the dynamic problem conceptualization step. The quantified model was mainly developed behind the scenes, supported by general knowledge found in the literature, the contribution from an innovation expert and participants' interventions through the second workbook activities.

Regarding the model, a shortcoming of the structure calls for attention. The current model left non-

monetary sacrifices out of quantified analysis, which bounds the possibilities of developing a comprehensive perceived value model for sustainable innovations. In this matter, Sterman (2003) states that ignoring cost is also a cause of innovation failure. According to discussions with participants it seems that the implications of not including non-monetary sacrifices might not have a negative effect. This is because in the tested case, the device is at an early maturation state, which makes it hard to account for such factors. Nevertheless, it might also be that a different approach to the methodology, such as devoting an entire workshop to the matter or choosing a different script, might have driven to different results.

Consequently, future research in terms of perceived value models should expand the model boundaries as to include other relevant dynamics that allow for additional policy making analysis. Other factors to be explored in further research include the use of managerial or psychological theories to expand on certain parts of model's structure. For instance, modelling price as a variable that depends not only of perceived value but that also reacts to the financial situation of the organization could be useful to study the dynamics of perceived value. This would allow testing how perception can influence sales and production decisions as suggested by Kotler et al. (2005) and Porter (1998). Another idea is introducing desired attributes as a dynamic concept and uncovering how end-user's needs and priorities evolve over time. This responds to the fact that in reality people adjust beliefs and perceptions according to changes in the system (i.e. Sterman, 2000; Vennix, 1990).

The fourth step consisted of the validation of the system dynamics model. For that a number of validity tests were performed, both behind the scenes and together with participants throughout workbook activities (Barlas and Carpenter, 1990; Barlas, 1996; Lane 1995). Given the close association between validity and usefulness of the model that characterizes participatory modelling, model's validation is strongly related to ownership and relies on participants' judgment (Vennix, 1996). On this matter, it can be argued that in an informal way the second workshop also contributed to model's validation.

The fifth step consisted of scenario analysis, to define policy alternatives based on model runs. These were discussed throughout the second workshop and supported by the third workbook. A relevant lesson was learned regarding perceived value assessment. It was found that dynamic models offer richer conclusions compared to linear ones. Accordingly, the dynamic model helped to identify loop dominance along with leverage points to innovation improvement and price. Linear models do not offer such possibility since they can only assess perceived value for a given set of assumptions in a single moment in time for which perceived value's understanding is limited when it comes to policy making purposes (Fleith de Madeiros et al., 2016; Heetae et al., 2016; Zeithaml, 1988).

Also, the dynamic model showed how linear perceived value models might lead to misinterpretations of the concept. Here, scenario analysis helped to uncover important sacrifice and benefit relations behind perceived value, which shows that looking at perceived value only might create confusion if other indicators are left behind. For instance, according to linear models, the ratio benefits/sacrifice helps to define end-users satisfaction. When the ratio equals 1, it is believed that satisfaction is accomplished since end-users perceive that the price they pay is fair given the benefits they gain. However, as showed by the dynamic model, perceived value might get to an equilibrium (i.e., benefits/sacrifice ratio = 1) although the innovation has a low performance level. This means that the solution was priced correctly, but indeed it has poor attributes to offer. Under a satisfaction perspective, developers might not continue working on innovation improvement. Such misinterpretation is likely to be made in a linear model.

Additionally, the model helped to describe relevant policy lessons for participants that can be synthesized as a guideline for innovation implementation. Those policies aim to reduce uncertainty at planning level by (i) managing sacrifices, which refers to the importance of fixing standards for fair pricing, (ii) improving benefits, advising that innovation improvement must be seen as a long-term goal for long lasting solutions, (iii) customizing policies, which refers to the need to adapt the previous lessons to each end-user group given variability of perspectives in the marketplace and (iv) planning carefully before innovation implementation, which refers to the fact that the way an innovation enters the market in terms of pricing and innovation readiness strongly defines a path for success or failure that becomes hard to change along the way.

The final step corresponds to analysis of the participatory model exercise for which a final questionnaire and observations were used to assess the process from the methodological perspective (Rouwette et al., 2002; Rouwette, 2011). This serves mainly, to illustrate the proposed framework's suitability to enhance value co-creation. In terms of the methodology, results of the CICC questionnaire supported the conclusions driven by observation, where in the evaluation revealed positive outcomes of the participatory modelling process in all aspects measured (i.e. communication, consensus, commitment, and insights). The individual concepts evaluation is also aligned to the overall efficiency of the process, where questionnaire's results reported a mean of 3,66 in a scale of 1 (very poor) to 5 (very good).

Results also suggest that participatory modelling is an appropriate tool to develop value co-creation. The need for supporting tools allowing end-users and developers to directly communicate and learn from their interaction, as pointed out by Martinez-Canas et al. (2016) and Yang and Sung (2016), is particularly well met with the developed collaborative modelling approach. These benefits of participatory modelling to value co-creation are associated to the fact that model building in a

cooperative environment contributes to share knowledge, align mental models and manage conflict while focusing attention to a common problem solving goal (Vennix 2016; Videira et al., 2003). Hence, by combining the knowledge and perceptions of end-users and developers, new ideas emerge and knowledge is gained, which is likely to improve the standing of sustainable innovations, as expected from a value co-creation perspective.

Concrete evidence of these benefits was observed as an immediate result of applying the participatory modelling process. Here two examples are worth mentioning, one is related to attributes identification and the second to uncover end-users needs. Not only new attributes associated with the innovation were identified, but they were also different from those defined by developers before the exercises. This tackles a common cause of innovation failure related with benefit identification and communication, including: (i) failing to recognize benefits that are relevant to end-users, (ii) failing to identify intangible benefits, (iii) benefits miscommunication and (iv) either undervalue or overvalue benefits (Gorveille, 2005; Repenning, 2012; Sterman, 2013).

Secondly, opening discussion and sharing ideas contributed to broaden the vision of both end-users and developers regarding the innovation. Accordingly, different needs (and priorities to solve such needs) were identified, leading developers to open up their initial perception. Before the exercise they argued that the innovation was ready for market uptake. However, after the first workshops developers recognized that it was still necessary to work on the attributes of the device to properly address end-users' needs by developing different device versions. This outcome can be associated to mental model alignment as it is claimed to happen in facilitated modelling sessions.

It is important to recognize that the results previously described should be taken as exploratory in terms of methodology adequacy for value co-creation. Future research should directly compare cases where other methods are applied to value co-creation, to be able to compare across methods and cases. It is also necessary to define under which circumstances different approaches are more beneficial to deploy in a value co-creation platform.

Overall results suggest that system dynamics methodology potentially improves the design of sustainable innovations by allowing value co-creation to emerge when using a participatory modelling approach. For this, using perceived value as a modelling concept may be a good manner to learn about innovation development and thus, to manage uncertainty related to innovation implementation. Moreover, perceived value used as a concept for dialogue may also be useful to create a common ground for discussion and mediation between developers' financial interests and end-users needs' satisfaction.





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## ANNEXES

### ANNEX 1. WORKSHOP SCRIPTS

The following scripts are organized according to the order in which they were used in the participatory system dynamics modelling framework, and they referred to general recommendations on their application to facilitated system dynamics modelling workshops.

Script's name	Concept model
<i>Context</i>	Used early at the start of a group model building project
<i>Purpose</i>	To introduce the process of modelling and symbolism of a model to participants
<i>Nature of the script</i>	Presentation
<i>Status</i>	Best practices
<i>Recommended timing</i>	180 minutes for preparation and 30 minutes during session
<i>Output(s)</i>	<ul style="list-style-type: none"><li>• Familiarity with stock and flow and causal icons</li><li>• Understanding that maps can be quantified and simulated</li><li>• Understanding that models can be created for the groups' problem(s)</li><li>• Understanding that the model is owned by the group and can be repeatedly modified and improved</li></ul>
<i>Steps</i>	<ol style="list-style-type: none"><li>1. Draw by hand the first version of the concept model on the white board. Demonstrate/draw the tub with faucet and drain to explain stock and flow icons.</li><li>2. Project the first quantified version of the concept model from the computer. The first quantified version of the concept model is identical to the first version drawn on the white board. Then, simulate and trace the behavior produced by the model.</li><li>3. On the white board add one or more elements to the first version to get an amended Concept Model (second version). The added elements are elicited by the experienced modeler from the participants. Project the second version of the concept model from the computer. Simulate the second version of the concept model and trace its behavior over time. The behavior should be different so as to demonstrate that "behavior is a consequence of structure."</li></ol>

4. Repeat step 3 one more time.
5. Summarize the lessons as follows: the icons that will be used, maps can be quantified and simulated, behavior can be generated endogenously, changing structure changes behavior, maps and models can be repeatedly refined, and groups can own the models they create.

#### *References*

Hovmand et al. (2015) and Richardson (2013)

<b>Script's name</b>	<b>Nominal group technique</b>
<i>Context</i>	Used at the beginning of a project in order to get an initial idea of central concepts or as a subscript script; for instance to develop a list of variables for the Graphs over Time script
<i>Purpose</i>	To generate an initial set of ideas, variables or dynamics
<i>Nature of the script</i>	Divergent
<i>Status</i>	Best practices
<i>Recommended timing</i>	10 minutes for preparation and 20 minutes during session
<i>Output(s)</i>	<ul style="list-style-type: none"> <li>• List of variables or ideas</li> <li>• Cluster of variables or ideas</li> </ul>
<i>Steps</i>	<ol style="list-style-type: none"> <li>1. Ask the participants to write down ideas about things that involve the problem variable. These might be causes or consequences of the problem, or any elements a participant feels are important to the issue at hand. Ask the participants to do this as much as possible in terms of variables. Explain that a variable is something that may increase or decrease over time. It does not already have a value on a particular scale - as in 'young employees'. In this case we would include average age of employees so that the value may increase or decrease over time. It is also not a categorical or nominal variable – as in type of holiday chosen. Duration of holidays or costs of holidays are aspects, which may be used in a model. If it is not possible to formulate an idea as a variable, it does not really matter; the facilitator and the rest of the group can work together to find a variable.</li> </ol>

2. Give the participants a few minutes to write down their own ideas.
3. Explain that you are going to gather ideas and show them on the board or computer screen for everyone to see. Ask each participant for one idea and write this on the white board or blackboard. Pay attention to the conversion into variables and check to see if the other group members know what the person contributing the idea means. Allow a clarification of meaning, but not a discussion on the relevance or importance of the idea. Explain that in this phase, the person contributing the idea has the last word: if he or she prefers a particular formulation even if other object, the proposed formulation will be put on the central board or screen. In the next phase, when starting to build the model, a relation will only be included when all participants agree. So while in NGT an individual participant ‘has the power’, in the phase of drawing relations we strive for consensus.
4. Stop collecting ideas after two or three rounds. Emphasize that the aim of this phase is only to create an initial list of variables so that model building can begin, and that variables that were not written on the board for the group are not automatically discarded. During the model building process, variables from the individual lists or even entirely new variables can be added.

#### *References*

Hovmand et al. (2015), Richardson (2013), Lopes and Videira (2015) and Otto and Struben (2003)

<b>Script's name</b>	<b>Graphs over time</b>
<i>Context</i>	Used at the beginning of a modelling session for discussion about the problem to be modelled.
<i>Purpose</i>	To engage participants in a modelling session in framing the problem, initiating mapping, eliciting variables and gathering input in deciding the reference modes for the study.
<i>Nature of the script</i>	Divergent
<i>Status</i>	Best practices
<i>Recommended timing</i>	15 minutes for preparation and 45 minutes during session
<i>Output(s)</i>	<ul style="list-style-type: none"> <li>Possible variables for the quantify model or the causal loop diagram</li> </ul>

- Reference mode definition, particularly when there is no data available from the real system
- Identified relevant variables for the quantify model or the causal loop diagram

### *Steps*

1. Based on group size, decide whether to break participants into subgroups. In smaller groups  $N < 10$ , allow individuals to work and present independently. In larger groups  $N > 10$ , divide participants into groups of roughly 10. Ask the subgroups to sit together.
2. Hand out sheets of white paper to each participant or group.
3. Give an example of how to draw a graph over time, carefully labelling X-axis "Time" with start time, end time, and now indicated with a vertical dashed line. The Y-axis is labelled with a variable name. The facilitator then sketches the behavior over time.
4. Ask participants to draw one variable over time per piece of paper. The participants should be given the option of including hoped for behavior, expected behavior, and feared behavior on the same graph.
5. Allow 15 minutes to complete the task.
6. Reconvene as a large group. A: If  $N < 10$ , the facilitator takes one graph at a time from each participant, holds it up in front of entire group and asks him/her to talk about it. Ask for participants to share the "best stuff" first. Clarify timescale, variable names, etc. B: If  $N > 10$ , instruct subgroups to share their graphs with each other and choose the ones they think are most important. The facilitator then goes to each subgroup and holds the first graph they have selected up in front of entire group. The subgroup spokesperson talks about the graph. Ask subgroups to share the "best" first and discuss.
7. Repeat steps 6 and 7 with each participant or subgroup, taking one graph at a time until all graphs are shown or time has run out. Finish by asking if any participant has something else that really ought to be shown.
8. During steps 7-8, each graph is posted on the wall trying to cluster the graphs meaningfully on the fly based on themes and variables.
9. Enable participants to talk about the clusters and the characterization

of the problem they imply.

10. Consider labelling the clusters based on themes or related variables. There is potential to close by highlighting the beginnings of feedback thinking in the dynamic problem.

*References* Hovmand et al. (2015), Richardson (2013), Lopes and Videira (2015) and Otto and Struben (2003)

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Script's name	Structure elicitation
<i>Context</i>	Used after exercises to elicit reference modes
<i>Purpose</i>	To captures the key endogenous mechanisms elicited during a discussion that have the potential to explain observed behaviors.
<i>Nature of the script</i>	Convergent
<i>Status</i>	Best practices
<i>Recommended timing</i>	20 minutes for preparation and 90 minutes during session
<i>Output(s)</i>	<ul style="list-style-type: none"><li>• Basic stock and flow structure</li><li>• Potential data for parameters quantification</li></ul>
<i>Steps</i>	<ol style="list-style-type: none"><li>1. Select a couple of key behaviors from the reference mode and elicit structure by suggesting two stocks, explaining that these stocks are initial simplifications of the system.</li><li>2. Ask the group to identify the variables that help to open or close the faucet of the stocks.</li><li>3. After adding a couple of variables and causal relations, summarize by telling the story embedded in the model so far and asks the group to add further causal explanations, stressing the importance of selective thinking about causality with the purpose of reaching a powerful and parsimonious explanation of the project success.</li></ol>
<i>References</i>	Hovmand et al. (2015)

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<b>Script's name</b>	<b>Ratio exercise</b>
<i>Context</i>	Used after a Graphs over Time and/or Concept Model exercise.
<i>Purpose</i>	To elicit feedback loops (especially minor loops), variables within a causal chain, and in some special cases, initiate mapping.
<i>Nature of the script</i>	Convergent
<i>Status</i>	Best practices
<i>Recommended timing</i>	10 minutes for preparation and 30 minutes during session
<i>Output(s)</i>	<ul style="list-style-type: none"> <li>• Closed feedback loops</li> <li>• Articulation and mapping of feedback effects</li> </ul>
<i>Steps</i>	<ol style="list-style-type: none"> <li>1. Pick out a pair of stocks to work with first.</li> <li>2. Asks the group to name the ratio or difference (caseload, class size, etc.). Add the ratio or difference variable using the exact name that the group has suggested (different groups use differing terminology for a similar concept. Additionally, some groups use differences and some use ratios--occupancy rate versus number of vacancies; it is important to use their terms).</li> <li>3. Map the ratio (or difference variable) with the incoming arrows marked with "+" or "-" as is causally appropriate.</li> <li>4. Ask the question, "what would happen if this ratio were to go to zero or get unusually small" or "what would happen if this ratio were to become very large—how would the system react?" The participants then start to tell feedback stories about how the system reacts when this key ratio (or difference) gets out of whack. When loops are completed, trace them out for the group adding appropriate "+" or "-", telling the stories of the loops. These loops are almost always balancing loops.</li> <li>5. Steps 2 to 5 are repeated with another set of ratios</li> </ol>
<i>References</i>	Hovmand et al. (2015)

<b>Script's name</b>	<b>Parameterized relationship between two variables</b>
<i>Context</i>	It can be used at any stage in a facilitated modelling process when the concept is well known (for example a learning curve) but is best employed when parameterizing the simulation model with the client as both variables in the relationship would have been developed within the facilitated modelling session.
<i>Purpose</i>	To quickly join experts views on such relationships in a clear way that makes use of individual views to produce a group norm representing consensus.
<i>Nature of the script</i>	Convergent
<i>Status</i>	Promising practices
<i>Recommended timing</i>	30 minutes for preparation and 30 minutes during session
<i>Output(s)</i>	<ul style="list-style-type: none"> <li>• Sketch most likely relationship between two variables to use as graph functions</li> <li>• Group understanding of quantified relationship with enumerated output assembled into a graphical system dynamics converter</li> </ul>
<i>Steps</i>	<ol style="list-style-type: none"> <li>1. Define scales and explain graph axes</li> <li>2. Hand-out pens and symbols</li> <li>3. Produce individual plots in pairs or groups</li> <li>4. Combine using overhead</li> <li>5. Discuss pairs/group logic</li> <li>6. Choose best representation of each x-y coordinate</li> <li>7. Summarize results on a new graph</li> </ol>
<i>References</i>	Hovmand et al. (2015)



<b>Script's name</b>	<b>Model Review</b>
<i>Context</i>	After causal structures have been developed, typically at the end of a session.
<i>Purpose</i>	To summarizing dynamic insights and stories, to clarify fuzzy ideas or capturing additional information about model structure needed to formulate the model and to eliciting feedback from participants o quickly join experts views on such relationships in a clear way that makes use of individual views to produce a group norm representing consensus.
<i>Nature of the script</i>	Convergent
<i>Status</i>	Best practices
<i>Recommended timing</i>	5 minutes for preparation and 15 minutes during session
<i>Output(s)</i>	<ul style="list-style-type: none"> <li>• List of main feedback loops and dynamics identified</li> <li>• List of insights gained from the connection circle exercise and subsequent model</li> </ul>
<i>Steps</i>	<ol style="list-style-type: none"> <li>1. Explain reinforcing and balancing loops by tracing examples within the model (if available).</li> <li>2. Reviews key insights and read back the stories associated with major reinforcing and balancing feedback loops, intervention points, etc.</li> <li>3. Initiate questioning regarding what didn't get recaptured or is missing from the diagram. Assesses confirmation of the adequacy of the diagram as a representation of the group thinking and document the insights shared.</li> <li>4. Point out subsequent, important changes in structure, help the group identify what is happening with the modeling, and highlight model based insights that emerge.</li> </ol>
<i>References</i>	Hovmand et al. (2015)

## ANNEX 2. COMMUNICATION QUALITY, INSIGHT, CONSENSUS AND COMMITMENT TO CONCLUSION (CICC)

The following questions aim primarily at the discussions that were held while making the causal models, in the reports (with questions) between sessions as well as during the meetings. These questions also refer to the results of the analysis of data and simulations. The answers on the following questions fall in one of five categories:

strongly agree	(sa)
agree	(a)
agree nor disagree	(a/d)
disagree	(d)
strongly disagree	(sd)

	sa	a	a/d	d	sd
My insight into the problem has increased due to the modelling process.					
I think that, because of these meetings, we have reached a shared vision of the problem.					
I support the conclusions/findings that were drawn during the modelling process, in general terms.					
The modelling process has given me more insight into the cohesion between the elements that compose the problem.					
The causal diagrams that were developed were the result of the integration of diverse opinions and ideas of the participants.					
If I, with some people from my organisation, were to use the same approach in planning, and in dealing with problems, all persons would loyally follow this plan to its natural conclusions.					
As a result of the modelling process it is still <i>unclear</i> to me what the causes of the problem, that play behind the scenes, are.					
The modelling process aided in the understanding of the opinions of the other participants.					
We could <i>not</i> reach a consensus.					

The use of causal diagrams has clarified the communication between participants about the problem.					
Our opinions are closer due to the modelling process.					
I will uphold the conclusions/findings of these meetings in front of other members of my organisation.					
The modelling process has given me more insight into the feedback processes that play a role in the problem.					
The modelling process has given me <i>little</i> insight into the opinions and ideas about the problem of other participants.					
Some persons dominated the discussions.					
The modelling process has <i>not</i> given me insight into the possibilities that my organisation has in 'steering' the problem.					
I will try to convince others in my organisation of the importance of these conclusions.					
Using modelling in approaching the problem is efficient.					
All in all I think these meetings were successful.					

If you compare these meetings, using causal diagrams, with *normal meetings or conferences* in which you discuss *similar problems*, would you say these meetings:

	sa	a	a/d	d	sd
give <i>more</i> insight compared with normal meetings?					
give <i>more quickly</i> insight compared with normal meetings?					
result in a <i>better</i> communication between participants?					
give <i>more quickly</i> rise to a shared vision between participants?					
give rise to a <i>better</i> shared vision between participants?					
give <i>more quickly</i> rise to commitment of participants?					
give rise to <i>more</i> commitment of participants?					

### Effects of different elements of Group Model Building

The meetings consisted of several aspects which may have contributed in different ways to the overall effect of the meetings. In the following questions you are asked to specify how much an aspect contributed to the overall effect. You can do this by scoring each element on a scale of -5 to +5, in which: -5 = was of no use whatsoever, obstructed the sessions;

0 = did not obstruct, but was of no use either;

+5 = contributed very much.

	score -5 to +5
The fact that the diagrams were projected/recorded in a way that was visible to everybody.	
The fact that an outsider was accompanying as a 'group facilitator'.	
The opportunity for open and extensive discussion.	
The use of causal diagrams.	
Written reports (with questions) between sessions.	
Gathering the data needed for the quantitative model.	
Analysing the data.	
Simulation, using the quantitative model.	
Others,.....	

### Quality of the Group Model Building project

The following questions aim at the quality of the modelling process. By 'problem' we again refer to the problem definition that was used in the modelling process: (*aim project*).

	sa	a	a/d	d	sd
The current situation of my organisation was well mapped.					
The description of the situation to be reached was correct.					
In the modelling process the right definition of the problem was used.					
In the modelling process all relevant information was used.					
The analysis of the information was correct.					
All issues or problem areas that needed attention were investigated					
In the modelling process <i>not</i> all useful solutions were discussed.					
In the modelling process the pros and cons of possible solutions were attended to.					
The choice of the most promising solution was based on sound arguments.					
In the modelling process the best solution was chosen.					

### **Suggestions for future sessions**

The following questions can be of great use in planning future sessions.

What were the three best features of the sessions?

a)

---

---

b)

---

---

c)

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What were the three most disappointing features or problems of the sessions?

a)

---

---

b)

---

---

c)

---

---

What specific suggestions would you make if meetings like these were to be organised or held again?

a)

---

---

b)

---

---

c)

---

---

Thank you again for your co-operation.



## ANNEX 3. MODEL'S PARAMETERS

### Variables of the model

#### 1. *Benefits sought*

*Units: Unitless*

Values: Continuous supply sought = 0.22; Safety sought = 0.21; Environmental impact sought = 0.14; Battery cost sought = 0.11; Alarm sought = 0.15; Status monitoring sought = 0.12; User friendly sought = 0.05

Description and comments: Variables represent the relative importance that benefits have for stakeholders, when compared to each other. Parameters represent a weighted average of parameters elicited during the workshop using the swing weight technique (Goodwin and Wright, 2014).

#### 2. *Time to improve innovation*

*Units: Months*

Value: 24.4

Description and assumptions: The variable represents the assumed time to improve the device's proficiency, calculated considering time to fix product defects and integrate product features that are part of the value promise but are not adequately reflected by the product's performance. As found in the literature, Schneiderman (1988) developed a half-life standard calculation of the time of manufacturing cycles required for a product to improve performance over time. From the different improvement and time standards described, "missing product features" category was selected to be the closest to describe innovation improvement ( $R^2 = 0.947$ ). Here, 24.4 months represent the standard time of improvement cycles to accomplish half-life improvements.

#### 3. *Time to perceive improvement*

*Units: Months*

Value: 6

Description and assumptions: The variable represents the assumed time that end-users need to perceive the new performance level of an improved innovation and it is based on the expert's interviews as the best educated guess available.

#### 4. *Breakeven point*

*Units: Euros*

Value: 170

Description and assumptions: The variable represents the break-even point price as calculated by inventors and manufacturers for a batch of 2000 devices in a basic version of the device.



### 5. *Time to adjust price*

*Units: Months*

Value: 8

Description and assumptions: The variable represents the assumed time that it takes to developers to change market price (2 months) after signs from the market indicate that adjustments are needed (6 months) and it is based on participants' perception, representative of their experience and understanding.

### **Initial stock values of the model**

#### 1. *Perceived benefits*

*Units: Unitless*

Values: Continuous supply = 0.110; Safety = 0.105; Environmental impact = 0.070; Battery cost = 0.055; Alarm = 0.075; Status monitoring = 0.60; User friendly sought = 0.025

Description and comments: Initial values of the stocks represent the first impression that end-users obtain when using the device, regarding the needs they require to satisfy. In other words, it describes stakeholders' expectations regarding the perceived benefits of the device. Values are based on participants' assumption of the device to comply with half of the described benefits. Accordingly the stocks initial values were set to half of the value of each sought benefit.

#### 2. *Price*

*Units: Euros*

Value: 200

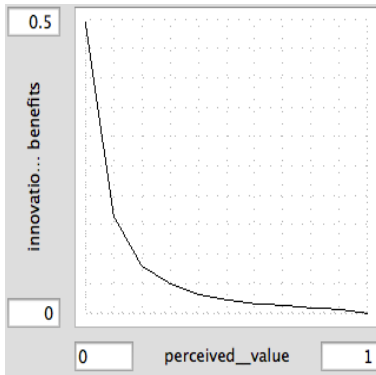
Description and assumptions: The variable represents the initial market price as defined by developers and manufacturers for a batch of 2000 devices in a basic version of the device.

## Graphical relations of the model

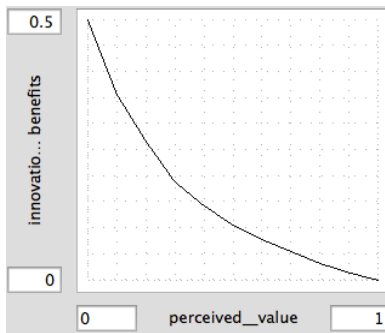
### 1. Innovation pressures

Units: Unitless

Graph: Innovation pressure for intrinsic benefits



Graph: Innovation pressure for extrinsic benefits



Description and comments: Innovation pressure represents developer's need to improve device's features responsible for the perceived sacrifice-benefits instability. The lower the perceived value, the larger the need to improve; hence, the higher the innovation pressure, the more improvement achieved in both extrinsic and intrinsic attributes. Typically, easy improvements are related to low technical complexity (Stermann, 2013) so that the slope for intrinsic benefits' graph is steeper than the one of extrinsic benefits. That is based on the assumption that intrinsic benefits or function related benefits, are harder to improve than those related to design and operation. Values in X-axis go from 0 to 1, since perceived value cannot be lower than 0 and 1 represents benefits-sacrifice equilibrium, so that at equilibrium there is no pressure to innovate. Values in Y-axis go from 0 to 0.5 following Schneiderman (1988) half-life model explaining how any defect measure can at best fall by 50% in one life cycle.

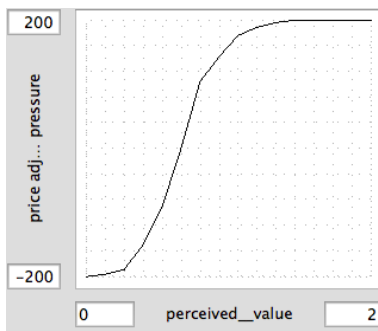
The concave shape of the graph follows the typical representation of improvement in operations literature (i.e. Repenning, 2012; Schneiderman, 1988; Sterman 2013), where the lower product quality (equivalent to perceived value to the model) the more improvements can be made. Namely, the more things are wrong, the more window for improvement and innovation. Also, the pressure to innovate translates to effective efforts that produce results depending on the number and quality of efforts. Effort quality and total efforts performed are represented in the curves as well.

Moreover, Repenning (2012) developed a model suggesting that differences between the easiness in which improvements can be achieved for deep change or product's operation are critical, which explains the two different slopes. The assumption behind the curves were based on discussion with participants and reviewed by the expert.

## 2. Price adjustment pressure

Units: Euros

Graph:

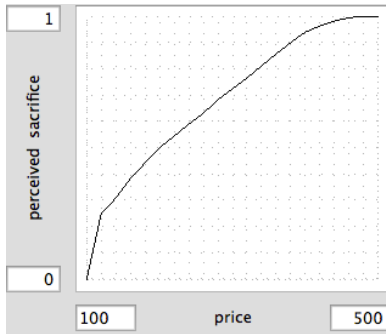


Description and comments: The graph represents the price policy set by developers, which allows for an adjustment of +/-200 Euros (Y-axis) according to the value being perceived and aiming for sacrifice-benefits stability. Graph function represents a non-aggressive price policy in which price decreases fast when performance is low and increases slow when performance improves, price adjustment is 0 when perceived value in X-axis is 1. Values in X-axis go from 0 to 2, since perceived value cannot go under 0 and mathematically can go until 10; nonetheless, 2 was used as a maximum given that any perceived value over 2 was assumed to be unlikely to happen in reality since it would mean that the product outperforms expectations. The values to the graph were calculated by participants using *parameterized relationship between two variables* script as explained by Hovmand et al. (2015).

### 3. Perceived sacrifice

Units: Unitless

Graph:



Description and comments: Represents risk aversion function of participants regarding the device. Values in Y-axis go from 0 to 1; 1 represents maximum sacrifice and 0 represents no sacrifice. Values in X-axis go from 100 to 500 Euros that is the price range stakeholders consider feasible of “neutral risk” for the device. Individual price-sacrifice relation given by participants was averaged to define the slope of the graph. Accordingly, values to the graph come from eliciting risk aversion function technique as explained by Goodwin and Wright (2014).



## ANNEX 4. MODEL'S EQUATIONS

### 1. *Innovating in attributes*

*Units: Unitless*

Equation:

```
If(innovation pressure =0)
Then(0)
Else(If(((perceived benefit *innovation pressure)+ benefit)<benefit sought)
Then(((perceived benefit *innovation pressure)/time to change overall perception)
Else((benefit sought-perceived benefit)/time to change overall perception))
```

Description and comments: Innovating in attributes equation is used in each bi-flow connected to the different attributes that constitute the overall benefits perception assessment, to keep track of perception changes in each benefit in the model. Accordingly, this equation is used 7 times in the model. The equation is composed of two parts, each of them with an If...Then...Else rule.

First part simply sets a decision rule defining whether changing perceived benefit stock is desirable or not. When perceived value equals 1, means that there is balance between perceived benefits and perceived sacrifice. There is no need for the system to change when value perception is in balance. Hence, perceived value of 1 takes innovation pressure to 0. In other words, if there is no need to improve perceived value, there is no need for innovating a benefit either. On the other hand, if there is need to innovate, If...Then...Else rule takes the equation to the second part. This first part of the equation appeals to the logic behaviour of developers. When stable product satisfaction is observed, there is no apparent need to improve the product. Yet, it was discussed during workshop that improving could be desirable for ambitious developers; however such behaviour would be a personal initiative not a systemic pressure effect.

Then, the second part sets a decision rule defining what would be a feasible rate of change to change a given benefit stock. Multiplying benefit stock's value times innovation pressure (benefit\*innovation pressure), represent the improvement achievable. Then, adding the current stock value to the achievable improvement (benefit\*innovation pressure+ benefit) results the new stock level representing the new benefit level after improvement.

Such result is compared to benefit sought, which represents the value that each attribute has for end-users. Accordingly, the value of the stock cannot be higher than the maximum end-users seek to obtain from the device. In other words, perceived benefit's ideal is to equal benefit sought so any value higher than benefit sought would be irrational.

Hence, **If** (benefit\*innovation pressure)+benefit < benefit sought **Then** (improvement rate according to innovation pressure) **Else** (improvement rate equal to benefit sought). The rule appeals to this logic

principle: it is not possible for a new improvement level to be higher than the value that end-users define for a specific attribute (benefit sought). This is based on the assumption that despite continuing to innovate end-users have a limit to appreciate improvement and thus additional efforts innovation will either be barely noticed or will not have an impact since attributes are satisfied at the expected level. Other external factors such as social, cultural and economy changes or general technology development are needed for end-users to readjust their needs and define new sought attributes (i.e. Kotler et al., 2005; Trout and Rivkin, 2000).

**Then** equation tells that is possible to improve according to innovation pressure, where  $((\text{benefit} * \text{innovation pressure}) / \text{sets the rate of change of the stock})$ . Then, the whole equation is divided by time to change overall perception indicating the time to improve performance in a given benefit, plus the time that takes to end-users to perceive such innovation improvement (time to improve innovation + time to perceive improvement).

**Else** equation tells that once innovation improved benefit's perception to end-user's highest standard, then any additional innovation will only keep perceived benefit to its best level. As in the previous equation, stock's rate of change is set; this time calculated by the difference between the maximum benefit performance (benefit valuation) and current stock level (perceived benefit). Result is divided by time to change overall perception.

## 2. Price adjustment needed

*Units: Euros*

Equation:

```
If(price adjustment pressure+price<breakeven point)
  Then((breakeven point-Price)/time to adjust price)
Else((price adjustment pressure)/time to adjust price)
```

Description and comments: Price adjustment equation is used in a bi-flow adjusting price and as an innovating in attributes equation, it is composed by an If...Then...Else rule and reacts to price pressure. The rule **If** price adjustment pressure+price<breakeven point prevents price from dropping below break-even point. Price drop happens every time sacrifice perceived is higher than perceived benefits. If adjustment pressure continues to lower the price, it will naturally go under the break-even point. However, this is not a realistic scenario since developers would decide to never sale under break-even point.

Given the case that suggested price results in a value under break-even point **Then** equation will take break-even as a minimum possible value to adjust the current price, in accordance to the time to adjust price as defined by developers  $(\text{breakeven point} - \text{Price}) / \text{time to adjust price}$ . On the opposite scenario,

if the new suggested price is higher than break-even point, the price is adjusted according to price adjustment pressure under the same time to adjust price.

The fact that price set is based on perceived value, might take the model to unlimitedly increase price in a scenario where benefits are initially higher than sacrifice and where innovation continues to improve faster than price rise. This is because the model does not take into account price elasticity, which in real life sets a limit to price rising. Hence careful attention should be paid to avoid misinterpretations when the equation produces a price that is too high to be realistic.

### 3. *Perceived value*

*Units: Unitless*

Equation:  $\text{perceived benefits} / \text{perceived sacrifice}$

Perceived value represents a ratio variable linking the two loops in the model where *perceived benefits* are the sum of all benefits (stocks) and perceived sacrifice is a price (stock) representation. The ratio has been mathematically and conceptually explained by a number of authors including Fleith de Madeiros et al. (2016), Heetae et al. (2016) and Zeithaml (1988). It simply indicates the relation between perceived benefits and perceived sacrifice as to define end-users' general impression of a product.