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MASTER THESIS

Mitigating Wicked Problems Through Sustainable Technological Innovation? The Case of Liquid Natural Clay

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Abstract

The complexity and wicked nature of climate change and the wide variety of its effects has created high uncertainty, knowledge gaps and ambiguities in relation to how to deal, manage, and cope with these issues. The solution alternatives seem ill formulated and ambiguous, and a high variety of actors with different values and visions, enhance these ambiguities, creating more uncertainty. In the face of these problems, the following research study aims to improve the approaches related to the solution alternatives to tackle them, by exploring and applying different elements and embedded in risk governance principles and other recommendations obtained from risk science, and putting them in practice through the analysis of the development and implementation of sustainable technological innovation product, corresponding to Liquid Natural Clay.

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CHAPTER 1
INTRODUCTION
1.1 Background
Climate change can be understood as one of the most important and urgent problems of the 21st century, and while its notion of a global problem is widely accepted, the issue of what to do remains highly controversial and contradictory, with different disciplines providing a variety of recommendations for a problem that is complex, interconnected, contradictory, and uncertain, with multiple and conflicting inputs and multiple possible outcomes (Sun & Yang, 2016; Sardar, 2019). Therefore, the problem of climate change has been increasingly described as a wicked problem (Sun & Yang, 2016; Head, 2008.).

Climate change can be understood as a wicked problem due to its condition as a huge, complex, and systemic risk, difficult to define, and challenging to predict the potential consequences of solutions. In addition, a diverse variety of stakeholders provide conflicting information related to climate change, together with its relevance and effects due to different interests. Furthermore, the challenges present in the context of climate change, make it difficult to find efficient solutions to the problem or predict the potential results, enhancing the wicked nature of the problem (Lehtonen et al, 2018; Incropera, 2015).

Climate change constitutes a pressure that changes and endangers ecosystems, together with the goods and services they naturally provide, from which the environment and human systems depend. Considering the urgent relevance of climate change, the case that will be addressed in relation to this issue, is the one of desertification and soil degradation, due to human activities that have led to climatic variations (Sivakumar, 2007).

Soil represents an important component of land, with numerous functions and ecosystem services essential for life. Yet, when soil becomes degraded, the capacity of soil to support functions, and provide services for humans and the ecosystems is disrupted. When it comes to soil degradation and desertification, climate change affects and is affected by it through a circular feedback (Lal, 2012). Hence, restoration of degraded soils is vital for tackling climate change and reducing the threats to sustainable development (Gichuki et al, 2019). Therefore, by contemplating the wicked nature of the issues at stake, it is important to consider that in the attempts to solve a wicked problem, each proposed solution may carry with it the risk of creating new problems that may also be wicked, complex and surrounded by high uncertainty (Sun & Yang, 2016).

Thus, it is suggested that the wicked problem of climate change should be handled by means of multiple innovative approaches to governance, as well as new problem-solving techniques, such as innovation and the development of sustainable novel technologies (Sun & Yang, 2016; Sanderson, 2002).

This is why in the face of this challenge, the United Nations proposed in 2015, 17 Sustainable Development Goals (SDGs) to promote prosperity, while protecting the planet and the environment, recognizing that development must go hand-in-hand with strategies that build economic growth and address a multi-level range of social needs, while tackling climate change and environmental protection (United Nations, 2015).

Nevertheless, the concept and role of sustainability and sustainable development, has presented limitations and struggles when it comes to dealing with wicked problems, under the argument that sustainability represents a contested concept, highly characterized by its ambiguity, complexity and uncertainty, which creates more wicked problems. Nevertheless, the critics towards sustainability presented in the reviewed literature, seem to fall short in providing or proposing solutions for tackling this urgent issue, for which the emergence of technological sustainable innovations has been proposed to be the most crucial and relevant measure (Su & Moaniba, 2017).

1.2 Objectives

General Objective:

The main objective is to explore through systematic risk-based approaches that wicked problems related to climate change, and ill formulated and wicked solutions, such as sustainability and sustainable development together with their embedded complexity, ambiguity, and uncertainty, can be mitigated through the implementation of technological sustainable innovation measures, that are improved and supported by the inclusion of systematic risk governance based- approaches.

Specific Objectives:

1) Validate systematic risk-based approaches as a tool for supporting the mitigation wicked problems through the development and implementation of technological sustainable innovation.
2) Propose the improvement of technological sustainable innovation by integrating risk-based models to their development and implementation.

1.3 Content

Chapter 1 presents the Introduction to this research, with the background knowledge for the development of the thesis, and an outline of the general and specific objectives. Chapter 2 provides a Literature Review in which the concepts of wicked problems, sustainability, sustainable development, and innovation will be addressed, together with their challenges in relation to complexity, uncertainty and ambiguity, and how to cope with these challenges through the arguments and suggestions of different authors. Chapter 3 presents the Research Design, Methodology, and the selected Case Study. In Chapter 4 the Results provided by this thesis are presented. Chapter 5 includes The Case Study Analysis and the Discussion and Analysis of the Results. Chapter 6 provides the final Conclusions

CHAPTER 2
LITERATURE REVIEW
2.1 Addressing Wicked Problems
Climate change has been described as a wicked problem, embedded in elements of complexity, ambiguity, and uncertainty. These characteristics have also raised problems in relation to the potential solutions that are presented as "sustainable", concept that has been criticized for being limited when dealing with wicked problems, and therefore, sustainable innovations have been suggested to be a highly relevant and crucial measure for mitigating these issues. Yet, considering the critics and the lack of agreement and arbitrage regarding the necessary actions for mitigating the effects of climate change, how have these concepts been defined and addressed in the academia? What is so wicked about wicked problems, and what has made the potential solutions inadequate for dealing with these problems? To what extent has risk-science been suggested for understanding and supporting the ability for dealing with the complexity, uncertainty, and ambiguity related to wicked problems?

The following chapter, aims to answer these questions by defining and addressing the concept of wicked problems, together with its characteristics and features, followed by the definitions and role of sustainability and sustainable development for dealing with wicked problems, by generating some arbitrage in relation to the ambiguity of these concepts. In addition, systematic approaches to risk governance, are suggested, to address the different levels of issues generated by complex issues related to climate change. Finally, different risk-based approaches will be proposed for dealing and coping with the complexity, ambiguity and uncertainty embedded in wicked problems.

The sections are followed by a generic definition of the concept of innovation, and the approach to the concept that will be utilized throughout this study, corresponding to technological sustainable innovation. Subsequently, technological innovation will be presented as a mean for tackling wicked problems, while acknowledging the challenges related to the emergence of novel technologies with complex outcomes, and how to cope with these challenges through risk science.

2.2 Characteristics and Features of Wicked Problems

According to Rittel & Webber (1973), the term "wicked" refers to something of malignant, vicious, tricky, or aggressive nature, and every wicked problem can be a symptom of another wicked problem.

They refer to that class of problems which are ill-formulated, the information is confusing, and too many stakeholders with conflicting values are involved. The adjective "wicked" is supposed to describe the highly conflictive and even evil quality of these problems, where proposed solutions often turn out to be worse than the symptoms, as it has been argued for the concepts of sustainability and sustainable development (Churchman, 1967).

Wicked problems are also embedded with notions of complexity, which refers to the difficulty of identifying and quantifying causal links between a multitude of conflicting and cooperating clusters, their positive and negative feedback loops, and the specific adverse effects (Renn et al, 2011; Renn, 2008). Complexity related to wicked problems also defies conventional and simple solutions (FitzGibbon & Mensah, 2012). This is because wicked problems are not solved by using the tools and processes that are fixated in creating them, neither are they resolved by approaches limited on explicating the complex interconnections of the multiple causes, consequences, and cross-scale actors of the problem (FitzGibbon & Mensah, 2012).

In addition, the complexity of wicked problems assumes that the relationships among variables are not linear, and slight changes in the initial conditions, may produce significant deviations in the potential outcomes. On the other hand, systems embedded in wicked problems, are also unrestricted, which leads to the allowance of influences from the outside while at the same time, these complex systems tend to involve multiple actors, that can play either a causal role, a stakeholder role, or both, enhancing as well the complexities related to interactions (Peters, 2017).

Wicked problems are also linked to high uncertainty, which makes them so apparently troublesome (Head & Alford, 2008; Van Bueren et al, 2003; Koppenjan & Klijn, 2004). In these cases, three different types of uncertainty are identified, which are related to the complex characteristics of wicked problems. On the first place, there are substantive uncertainties, which refers to gaps and conflicting understandings in the knowledge base, as it happens both in the case of sustainability and climate change, which leads to no agreed nor clear understanding of the nature of wicked problems. On the second place, there is the strategic uncertainty, referring to the fact that many actors are involved, with many different preferences, having an unpredictable interaction between their perspectives. Finally, there are the institutional uncertainties, referring to the variety of organizational locations, networks, and regulatory regimes to which the different relevant actors are attached to, which turns and increases the likelihood of processes for reaching decisions concerning wicked problems, to be messy and uncoordinated (Head & Alford, 2008).

As well, complexity in wicked problems is likely to generate knowledge gaps, diverse interests and a high variety of stakeholder's perspectives, enhancing the creation of high levels of ambiguity that is added to the different types of uncertainty (Sediri el al, 2020; Rittel & Webber, 1973).

Another aspect that highlights complexity in wicked problems, is the fact that they concern global issues, as it occurs in the case of climate change, and the need for sustainable development in the face of desertification, soil degradation and its ripple effects on human life and the environment, issues that cannot be solved in traditional ways or by simple solutions (Blok et al, 2015).

Climate change represents a wicked problem, because it is a huge, complex, and systemic challenge, that cannot be easily defined (Lehtonen el al, 2019; Incropera 2015). Besides, it presents great scientific, economic, and social complexity and uncertainty, with solutions that have unforeseen consequences, together with conflicting information provided by different Stakeholders related to the relevance and impacts of climate change. This produces profound lack of agreements on what the problem is, what the potential causes and consequences are, and which possible solutions might exist. Therefore, and since linear and traditional models seem limited in the context of wicked problems, understanding and identifying the global and local perspectives and other interconnected phenomena, demand new strategies of learning, thinking, and acting (Lehtonen et al, 2019).

As a wicked problem, climate change and its ripple effects cannot be easily tackled, and although sustainability and sustainable development are broadly suggested to help reduce the consequential vulnerability, the uncertainties related to the rate of climate change raise questions about whether achieving sustainability could happen fast enough to make a difference (Beg et al, 2002).

2.3 Why Sustainability and Sustainable Development? Wicked Problems and Ill Solutions: The Wickedness of Sustainability

When it comes to sustainable development in relation to climate change mitigation, Robert et al (2005), argue that sustainable development and climate change interact profoundly on several levels. Furthermore, and as indicated by the climate change literature, reducing greenhouse gas emissions, and increasing adaptability will contribute to a range of sustainable development goals both related and unrelated to climate (Idem).

In terms of its definition, and according to Renn & Goble (2009), sustainable development corresponds to economic progress and environmental quality embedded in one vision. This vision corresponds also to an economic structure that meets all needs of the present generation, without restricting the needs of future generations, through the reconciliation of the economy with the ecology, which are terms often seen as opposites.

Sustainability may then be understood as the maintaining of well-being over a long or indefinite period, while covering largely the environmental dimension. Sustainability, then, is a matter of which resources are essential, together with the environmental quality bestowed and preserved for coming generations (Kuhlman & Farrington, 2010).

On the other hand, sustainable development, under the definition of the Brundtland Report (1987), corresponds to the ability to meet the needs of the present without compromising the ability of future generations to meet their own needs. However, and since the report, several different definitions have been articulated and promoted, leading to the lack of a clear, fixed, and unchangeable meaning (Robert et al, 2005).

Yet, and although the Brundtland definition for sustainable development has become the most accepted and generally agreed definition, it falls short in providing practical guidance. In addition, the attempts for specificity are likely to generate conflicts in values and interests, leading to strategic differences between stakeholders and other interest groups invested in developing a vision of the future, and those whose goal is to identify steps towards improving the future (Renn et al, 1998; Milbrath, 1989; Olson, 1994).

Though, and while the concepts of sustainability and sustainable development have been suggested as a mean for helping in reducing the vulnerabilities related to climate change, the concepts have also been highly criticized for presenting several elements embedded in wicked problems, hampering its potential for further development and application. This is because multiple stakeholders are involved in defining its scope, having different values and objectives, which leads to different views and definitions of sustainability. Furthermore, and by considering that wicked problems have no stopping rule, sustainability is presented as dynamic, and its time horizon is indeterminable, which raises the question whether it can happen fast enough to make a difference (Beg et al, 2002; Brønn & Simcic, 2018). In addition, and by considering that every wicked problem is a symptom of another problem, issues around sustainability are usually consequences of established and dynamic nature of the multiple systems involved (Brønn & Simcic, 2018).

Furthermore, Pryshlakivsky & Searcy (2012), argue that sustainability is marked by a high degree of stakeholder subjectivity, and often characterized by a lack of clarity, uncertainty, ambiguity, complexity, and limited understanding. Among other challenges, these characteristics make establishing appropriate analytical boundaries problematic.

Moreover, complexity regarding sustainability is enhanced by insufficient rules and regulations, since the preferred outcomes are not always clear, the norms to measure these outcomes can be contested by other stakeholders, and its future impact cannot always be foreseen because of the uncertainty of the wicked problems. Besides, insights and knowledge about sustainability are constantly and rapidly changing, and therefore the adjustments and regulations often come too late (Blok et al, 2015). In addition, and because sustainability is an ambiguous and argued concept, there will be disagreements about the direction of sustainability transitions (Stirling, 2009).

Therefore, and by considering that sustainability and its achievement is a highly contested topic because of its complexity, ambiguity, and related uncertainties, in addition of being infrequent long-term macro-changes, it is difficult to construct large databases that can be analyzed statistically for relationships between variables, and consequently, other types of theories and methodologies are needed. These theories should be multi-level, because it is unlikely that only one kind of causal factor or mechanism can explain entire sustainable transition processes (Geels, 2011).

2.4 Sustainability; From Normativity to Functionality and Deliberation

Considering that the concept of sustainability is highly contested and has been criticized for being theoretically ill-founded and lacking practical impact (Renn et al, 2009), there is also the issue that the idea of sustainability is intrinsically normative (Schmieg et al, 2018), and therefore, based on the literature reviewed for purposes of this study, the decisions are made in order to achieve sustainable outcomes, which as mentioned in the previous section, is an ambiguous and contested concept, instead of presenting sustainability as a decision- making approach *per-se.*

By taking into account the normative nature of sustainability and sustainable development, and in an attempt to give relevance to the concept for supporting a decision-making process, rather than just focusing in decisions directed to achieve sustainability, Renn et al (2009), suggested that the conceptualization of sustainability should be marked by a normative-functional understanding of societal development, because change and development for societies, is induced by the need for adaptations inspired and shaped by normative, goal-oriented visions of desirable 'futures' (Giddens, 1991; Cohen and Levinthal, 1990; Jaeger et al., 2001).

Therefore, and by acknowledging societal development and cultural change in relation to sustainable development and ecosystem protection, Renn (2012) argues that the future of humanity does not depend on the preservation of the original nature, but on the preservation of the anthropogenic ecosystems, in order for humans to thrive. These anthropogenic ecosystems we live on, need constant constructive interventions to make the environment a productive resource, otherwise it will not provide the services and goods that are expected from it (Renn, 2012).

These interventions can be sustainable solutions directed to deal with wicked problems, and thus, by combing normative standards and functional statements, the concept of sustainability aims at concrete, dimensions, criteria, and indicators for sustainable development (Renn et al, 2009).

Different from normative approaches, functional requirements are based on the idea that phenomena and institutions have functions within a societal or ecological system, having goals that are coinciding with normative ideas (Renn et al 2009).

Combining both approaches prevents the excessive application of one of them (Renn, 2012), which helps overcoming some of the issues discussed in relation to sustainability and sustainable development. In this way, the combination of normative and functional perspectives gives a clearer visibility to norms, leading to transparency in the decision-making processes, adding also the potential to formulate relevant dimensions of sustainability and to deduce adequate criteria and indicators leading to a coherent understanding of sustainability, therefore reducing its ambiguity (Renn, 2012) .

Transparency also acquires extra relevance when the public becomes part of the decision-making process, by defining targets of sustainable development due to the integration of expertise, interests, and public values, which is a rich contribution to the deliberation process, that also gives legitimacy to the decision-making process (Renn et al, 2009; von Schomberg, 1995). Henceforth, and as argued by Ward (2003) cooperation among actors in different levels is critical, so different levels and dynamics can be addressed.

2.5 Systematic Risk Governance for Wicked Problems

According to van Asselt & Renn (2011), wicked problems are not simple- risk problems, and cannot be treated as a linear or simple risk. Therefore, a systematic risk governance through a multi-level perspective is suggested, to help producing more reliable and valid judgments about the complex nature of wicked problems (Renn, 2015).

a. Multi- level Perspective in the Face of Wicked Problems

In complex cases such as the ones addressed as wicked problems, the appeal of applying a multi-level perspective, rests in engagement that this perspective has with the different dynamics of large-scale socio-technical systems, that are likely to present persistent sustainability challenges (Smith et al, 2010; Rotmans et al., 2001; Berkhout, 2000; Elzen et al., 2004). Additionally, a multi-level perspective provides a quite straightforward way of simplifying the analysis of complex, large-scale structural transformations related to the normative goal of sustainable development. However, and although a multi-level framework is attractive, it is not free of challenges (Smith et al, 2010).

On the first place, challenges related to this framework, are linked to plural regimes and niches in interaction (Smith et al, 2010). In this case, niches represent protected spaces where actors work on innovation that deviate from existing regimes, hoping that novelties are applied in the regime or even replace it. Yet this is not easy because the existing regime is stabilized by lock-in mechanisms and because sustainable innovations may mismatch the existing regime dimensions, such as multiple stakeholders' interest, regulations, and practices (Geels, 2011). On the other hand, the regime corresponds to the socio-technical 'deep structure' that accounts for the stability of an existing socio-technical system (Geels 2011; Geels, 2004). It refers to the semi-coherent set of rules that orient and coordinate the activities of the social groups that reproduce the various elements of socio-technical systems (Geels, 2011).

Yet, complexity confronts the multi-level perspective when a homogenous, uniform, and incumbent regime is involved and challenged by a sustainable niche, together with the competition with unsustainable practices in niches more aligned with the interests of the regime. In other words, the challenge is to understand whether the overall performance of different niches that interact with regimes, can be recognized on an early stage, to act against, and prevent a system lock-in, in relation to unsustainable developments (Smith et al, 2011).

Nevertheless, and although regimes are presented as homogeneous and uniform, they allow for the possibility of tensions between rules due to internal tensions, disagreements, and conflicts of interests, disagreement on specific issues, debate, and internal conflict, making them complex systems that also allow the emergence of niche-sustainable innovations to tackle wicked problems (Geels, 2011). In this case, and to achieve coherence related to sustainable development, it may be relevant to pay more attention to multi-regime interactions to enhance the growth of novel niche innovations (Geels, 2011; Raven, 2007; Konrad et al., 2008).

Therefore, and by considering that the wicked problem of climate change and sustainability is enhanced by multiple actors, with multiple interests and visions, due to the complexity of the issues at stake, long-term visions of sustainability can function as a guide for formulating short-term and mid-term objectives. Nevertheless, cooperation among actors should be of critical importance, as no single actor has the managing capabilities to fully address the issues that are present in different levels and dynamics. Following this logic, each actor should redefine their roles, competences and procedures in interaction and co-production with the other relevant stakeholders to formulate joint goals and common strategies, based on a multi-level perspective in which uncertainties and risks are acknowledge and governed (Ward, 2003).

b. Stakeholder Involvement Through Multi- Level Perspective and Risk Governance

While continuing to recognize the centrality of complexity and uncertainty, a broader approach would be of better use for helping to tackle wicked problems since, when related to sustainable development, there is a requirement for acting at several levels. On the other hand, and as it has been previously stated, the wicked problem of climate change and sustainable development becomes emphasized and enhanced by the role of stakeholder perceptions, values, and interests in regards of the issues at stake, with respect to how issues are scoped, priorities are set, and potential solutions considered. (Head, 2018).

Yet, Head & Alford (2015) argue that the issue of complexity and stakeholder divergence as aspects of wicked problems, can be tackled through novel approaches of collaboration and coordination, together with an adaptive-thinking approach, that includes a strong focus on taking into account problems from several perspectives, designing instruments and programs that include complexity and ambiguity, accounting for uncertainties, and strengthening the collaborative capacities.

Wicked problems may need to be approached on different levels of analysis and using a range of instruments, since there is no 'one best solution' (Head, 2018; Verweij &Thompson, 2006).

Therefore, and by considering that the handling of collectively relevant and complex risk problems such as climate change and sustainable development should be shifted from traditional approaches to a multi-level perspective that accounts for a multitude of actors, and their perceptions and evaluations that draw on a diversity of knowledge and evidence claims, value commitments and interests, the processes of risk analysis, decision-making, and risk management become influenced by these elements (Klinke & Renn, 2011; Jasanoff, 2004). In this case, the diversity offered by a multi-level perspective, can provide considerable advantages when complex, uncertain and ambiguous risk problems need to be addressed. This is because, on the first place, risk problems can be managed at different levels through different scopes. Secondly, this perspective opens a window for flexible, adaptive, and integrative risk governance systems, making them more resilient and less vulnerable. Finally, the larger number of actors facilitates experimentation and learning (Klinke & Renn, 2011; Renn, 2008).

Though, and when it comes to developing and selecting appropriate management options for risk mitigation in situations of high uncertainty, ambiguity, and complexity, challenges are found when related to the characterization and evaluation of the severity of a risk problem when the potential damage is unknown and highly uncertain. Therefore, various stakeholders ought to be involved in the risk characterization process to discuss and contemplate the trade-offs between over and under protection in relation to risk vs risk or risk superior options. However, if too much precaution is applied, innovative measures may be impeded or eliminated, and if too little precaution is applied, undesired consequences may occur (Klinke & Renn, 2011).

Yet, and although a high variety of stakeholder involvement has been presented as an enhancer for the issues related to the wicked problem of sustainability and climate change, their involvement in relation to a multi-level perspective and risk governance, could also help producing more reliable and valid judgments about the complex nature of a given risk. In addition, such an involvement process could aid finding the most accurate description and explanation of the complexity in question, as well as a helping clarify conflicting views. This might also generate a profile of the complexity of the risk issue based on intersubjectively chosen criteria and reveal hidden uncertainty and ambiguity. In terms of the ambiguity related to wicked problems, the involvement of different stakeholders can offer opportunities to resolve conflicting views and expectations through a process of identifying predominant common values, and to define options that will allow a desirable lifestyle without compromising the vision of others (Renn, 2015).

By understanding the Stakeholders involvement as a core feature in adaptive and multi-level perspective, and by adding risk governance features, these models in conjunction can aid to address challenges raised by complexity, uncertainty, and ambiguity. Hence, this is a crucial dimension to produce and deliver adaptive and integrative capacity in risk governance, especially when considering the social acceptance of any response of risk governance to risk problems associated with complexity, uncertainty and/or ambiguity, which is critical. Therefore, risk handling and response strategies need to be flexible and the risk management approaches need to be frequent and inclusionary (Klinke & Renn, 2011).

2.6 Coping with Complexity, Uncertainty and Ambiguity Through Risk Science

Considering that climate change, its ripple effects, together with sustainability and sustainable development are considered as wicked problems, they are surrounded by complexity, ambiguity, and uncertainty, together with multiple actors, individuals, and institutions involved, which contrasts with simple risk problems, where a probabilistic analysis can provide an optimal structure for analysis and mitigation (Aven, 2019).

Due to its complexity and wicked nature, climate change risk can be also understood as a systemic risk, which, according to Renn (2016), can be characterized by their global nature, together with a high interconnection and intertwines that leads to complex structures, as well as nonlinear cause-effect relationships, that are random in the structure of their effects (Aven, 2019). Systemic risks are not limited to national borders or single sectors, and do not fit the monocausal model of risk, being multi-causal, and encircled by complexity, uncertainty and/or ambiguity (Klinke & Renn 2002; Renn 2008).

Hence, and by considering the characteristics embedded in systemic risks and wicked problems, the analysis should set focus on the interdependencies, ripple, and spill-over effects that initiate impact cascades between other unrelated risk clusters (Renn et al, 2011; Hellstroem 2001).

It is due to the high uncertainty, complexity, and ambiguity, that risk -related decision-making in the face of wicked problems is not just about risks or a single risk. Evaluation requires risk–benefit assessments and risk vs risk tradeoffs, leading to a more multi-dimensional spectrum for risk evaluation (Renn et al, 2011).

When it comes to risk trade-offs, the general problem is that the efforts to tackle a target risk can unintentionally generate countervailing risks, better known as side effects or unintended consequences, and unless decisionmakers consider the full set of possible outcomes associated with each risk reduction effort, a systematic emergence for risk tradeoffs will occur. Therefore, the likelihood and severity of the countervailing risks should be evaluated against the target risk, to support decision-making in regards of the most optimal course of action, while also allowing long-term alternative seeking, to reduce the target risk, avoiding countervailing risks. These alternatives can be understood as risk-superior, which can reduce the overall risk, rather than trading one risk for another (Graham & Wiener, 1995).

Yet, Foss & Tickner (2008), suggest that, even in the presence of risk tradeoffs and countervailing risks, there should be acts to prevent them, through alternative assessments that pursue risk-superior alternatives. In other words, alternatives should be considered carefully to ensure maintenance of functionality, and cost effectiveness while minimizing the potential for causing countervailing risks. The alternatives assessment, together with the pursue of risk-superior alternatives may also help identifying solutions and opportunities for innovation (Foss & Tickner, 2008; Rossi et al, 2006).

Therefore, the recognition of complexity embedded in wicked problems could help to motivate the searching for risk-superior options, such as innovations with capacity to reduce multiple risks in concert (Wiener, 2004).

On the other hand, and by considering the wicked nature of climate change, soil degradation and desertification, solution alternatives and innovation should also have a focus on its potential for sustainability, which plays a key role for tackling these issues. According to Robinson & Herbert (2001), sustainable development and climate change interact on a high variety of levels, and sustainable initiatives can make a major contribution for mitigating global warming, even in the absence of explicit climate policy. Sustainable initiatives can also increase the desirability for going beyond narrow treatments of climate change and it is of critical importance for alternative development paths.

Together with the search for risk-superior options and alternative assessments, the importance of a sustainable approach, and by considering the complexity and the variety of elements of the issues at stake, governance principles have also been developed to achieve a new approach for the identification, assessment, management, and communication of risks related to complex and wicked problems (Aven, 2019). Risk governance includes the totality of actors, rules, conventions, processes, and mechanisms involved with how relevant risk information is gathered, analyzed, and communicated and how management decisions are taken, and it has particular importance for cases where the risk requires the collaboration and coordination between various stakeholders (Renn & Roco, 2006).

Yet, risk governance may present deficiencies, where elements are lacking, failures are present, or actions are not taken and/or prove unsuccessful. The potential consequences of these deficits can be severe in terms of human life, and the environment. There may be a failure to trigger necessary action, which may be costly, or, contrarily, inefficient action may be taken, resulting costly in terms of wasted resources leading to the need for flexibility (Aven, 2011).

Thus, and since tackling wicked problems requires the search for risk-superior alternatives, translated into solutions and opportunities for innovations capable of mitigating the target risk, while avoiding collateral damage, and ensuring sustainability, alternatives are sought to open windows of opportunity for the emergence of responsible sustainable innovation.

However, aiming towards sustainable innovation technologies also involves high complexity due to a variety of conflicting goals, and multiple perspectives of stakeholders on what sustainable development is and how to achieve it. Consequently, there is often no single optimum valued as sustainable by one group of people, since it can also be valued disastrous by others. Hence, finding common agreed solutions for wicked problems requires the exploration of solution scenarios, including the engagement of stakeholders (Zijp, 2017; Roberts, 2000).

In order to achieve the most optimal solution alternative, Zijp et al (2016), suggest the merging of key elements from risk assessment, risk governance, adaptive management, and sustainability assessment frameworks, while exploring solutions upfront the evaluation of risk vs risk tradeoffs, producing comparative levels of risk, and alternative solution scenarios, based on multiple metrics, such as people, planet, and profit/prosperity, followed by selecting the most promising solutions while adapting management when needed, and therefore, supporting decision-making.

Henceforth, and by considering the importance of finding risk-superior alternatives that can also ensure a certain degree of sustainability, the sustainability assessment plays a relevant role in directing decision-making towards sustainable alternatives (Bond & Morrison-Saunders, 2011).

Yet, for most multi-level wicked problems, the solution alternatives may imply trade-offs on sustainability metrics, leading to no single optimum (Zijp, 2017). Therefore, the management of trade-offs in sustainability assessment requires processes focused on optimizing sustainability outcomes (Bond et al, 2012).

Nevertheless, wicked problems are not simple- risk problems, and cannot be treated as a linear function of probability and effects (van Asselt & Renn, 2011). Hence, sustainability-oriented management solutions are especially needed when the carrying of an activity that has been banned based on a single risk metric evaluation, is allowed or stimulated by a multi-metric sustainability assessment, leaving a minimal a priory limit to alternative approaches to tackle those problems (Zijp et al, 2016). In an ideal case, the best solution is defined by all sustainability metrics being optimal, so this best solution can be implemented. However, for most wicked problems, the solutions imply trade-offs on sustainability metrics, so there is no single optimum. A management choice is thereafter made, by applying the agreed output (Idem).

2.6.1 On innovation

The concept of innovation comprises a wide variety of literature that includes different interpretations and understandings about the meaning of innovation (Taylor, 2017; Fagerberg et al, 2005; Linton, 2009). The concept of innovation is tightly coupled to change and providing solutions, as is it used as a tool to influence on the environment, or to react due to changing environments, internal or external (Bareghehet al, 2009; Damanpour, 1991). Nonetheless, innovation involves a wide range of different types of change depending on the resources, capabilities, and strategies, in accordance with the context in which is required, needed, or proposed, and common types of innovation involve new products, materials, processes, services, and new organizational forms (Baregheh et al, 2009; Ettlie & Reza, 1992). Therefore, innovation is involved in a high variety of disciplines for which each propose definitions aligned with the dominant paradigm of the discipline (Bareghehet al, 2009).

Yet, for this investigation purposes, innovation will be addressed in terms of novel technologies directed to climate change effects mitigation, specifically when it comes to soil degradation and desertification, and other related issues.

By taking into account these particular cases, the development and usage of technologies was suggested in the Conference of Parties of the United Nations Framework Convention for Climate Change, in which it was agreed in 2015 to limit the increase of global temperature to 2 °C above pre-industrial levels by 2020 (Su & Moaniba, 2017; UNFCCC, 2015), and the developing and deploying environmentally friendly innovation technologies was presented as one of the main actions needed by countries to achieve this goal (Su & Moaniba, 2017).

2.6.2 Sustainable Development and Sustainable Technological Innovations

Despite being criticized for presenting elements of wicked problems, the concept of sustainable development has been popularized due to its key principles, which aim to integrate environmental, social, and economic concerns into the different aspects of decision-making. In addition, it presents an inherent interdependence between the long-term stability of the environment and the economy, which is the foundation of the field of sustainable development (Emas, 2015). Is this interdependence which places the focus of sustainable development into the tackling of sources of environmental degradation, while still providing opportunities and creating incentives for economic advancement (Emas, 2015; Porter & van der Linde, 1995).

Hence, the overall goal of sustainable development, is the long-term stability and harmony of the economy and environment, goal that is achievable through the integration and acknowledgement of economic, environmental, and social concerns throughout the decision-making process (Emas, 2015).

Thus, due to these principles and objectives, the terms sustainable development and sustainable innovation are often used, even though the existing literature on the topic has concluded that there is no established definition of sustainable innovation, sustainability, and sustainable development. It is due to this ambiguity, and lack of a clear definition, that, in order to further develop this research, the proposed definition for sustainable innovation will be based on elements taken from Ottosson et al (2016) and Emas (2015), for which sustainable innovation, represent the development of long-term focus novel technologies, that are environmentally responsible, providing solutions for the society and its users, in order to mitigate the effects caused by climate change and generate win-win opportunities for the environment and the economy (Ottosson et al, 2016; Emas, 2015).

2.6.3 Innovation and Cooperation for Tackling Wicked Problems

Both innovation and wicked problems should be dealt with in a context of uncertainty and risk, and both require collective actions (Oksanen & Hautamäki, 2015; van Bueren et al., 2003). It is due to the high relevance that collective actions have, that the United Nations (2020), in the face of the wicked problem of climate change, has suggested that a systemic change is of the essence in order to achieve a low-emissions, highly-resilient and more sustainable future. Therefore, technological innovations are considered to play a critical role in this process, by enhancing and accelerating the implementation of Nationally-Determined Contributions, in order to keep global warming below 2°C, and other long and medium-term climate change strategies in order to provide opportunities to accelerate climate action.

Innovation is associated with problem solving and considering that most of its challenges are related to wicked problems, creative approaches together with collective actions are required, due to its complexity. Thus, when succeeded, cooperation may lead to the solutions that provide means to tap into a significant, long term innovation potential (Hautamäki & Oksanen, 2016).

Sustainable innovation has its roots in sustainable development, and it is based on ethically, socially, economically, and environmentally sustainable principles, aiming to combine competitiveness, the well-being of people, and sustainable solutions (Idem).

The core base of this concept is of critical relevance when considering that the global economy is experiencing an unprecedented, growth which is putting an enormous strain on global and local ecosystems. This has raised the demand for scarce natural resources, which has also depleted water, fertile soils, forests, and biodiversity (Altenburg & Pegels, 2012; Rockström et al, 2009)

Changing to sustainable patterns of development through technological innovation, while ensuring decent levels of resource access for all the world's citizens is the greatest challenge of our time. Also, and while the need for new generations of resource-efficient technologies is acknowledged, its development may also impulse a paradigm shift that could potentially entail a change in societal norms and values, motivating new life styles, and different ways of accounting for development and economic incentive schemes that systematically internalise environmental costs. However, the main challenge for sustainability-oriented innovation to try to disrupt firmly established, but environmentally unsustainable trajectories (Altenburg & Pegels, 2012), as suggested by Smith et al (2011) in regards to the niches and the need to understand the overall performance of different niches in their early stage, on the face of firmly established regimes, in order to be able to act against, and prevent an enclosure in relation to unsustainable practices and developments.

Finally, and considering that sustainable technological innovations are directed to tackle wicked problems taking into account the importance of a multi-level perspective due to the complexity embedded in these issues, the development of such novel technologies may prove to be useful in providing solutions that are needed when an activity is banned based on the evaluation of single risk metrics, whilst the same activity would be allowed or stimulated after accounting for its potential for mitigating the effects of wicked problems while contributing to sustainable development (Zijp et al, 2016).

2.6.4 Complexity and Uncertainty Risk Related to Innovation

While technological innovations may help tackling wicked problems and also be considered as a main driver of growth and sustainable development, they are also uncertain and ambiguous due their novel characteristics that lead to a lack of knowledge on potential risks of emerging technologies (Temel & Durst, 2020; Henschel and Durst, 2016). These perceived risks may also be reflected in the technological complexity of the project (Roper & Tapinos, 2016).

On the other hand, the uncertainty related to technological innovation and its risks, are associated mainly with the potential failure of novel technologies to achieve the desired outcomes, or issues related to the project development time (Roper & Tapinos, 2016; Menon et al., 2002), which also enhances the uncertainties related to the rate of climate change, and the wicked nature of sustainability, by questioning whether achieving it could happen fast enough to make a difference, hampering potential attempts to develop novel technologies (Beg et al, 2002).

This is mostly because the adapting of complex systems is intrinsically unpredictable, and innovation constantly changes the human impact upon the biosphere and can also increase the effects of these impacts in new and unexpected ways (Newman, 2005; Newman & Dale, 2005). In addition, innovations can give rise to new needs, and introducing new technologies, without evaluating and assessing its effects, may involve new hazards and generate reductions in resources spent on other measures implemented or planned for climate change mitigation (Abrahamsen et al, 2018).

Moreover, novel technologies often result in slow learning curves, and the need for training on its usage is generally underestimated. Furthermore, training is time consuming, and time is a limited resource, and training in the use of new technology may take time away from other activities that could also help mitigating the effects of climate change. Finally, it would be necessary to allocate time and resources for regular refreshing training to maintain or improve technical competences of the novel technologies (Gelyani et al,2014).

Similarly, Jalonen (2011), has pointed that, although innovation is required to contribute both to short and long-term results, its potential consequences cause uncertainty because they cannot be predicted in advance, especially when it comes to long term consequences.

One aspect that could be attributed to enhance the uncertainties related to technological innovations, is the fact that technology can also be considered as complex systems, due to its many interacting parts and elements, internal and external. In addition, technological innovation also represents a collective process in which actors and stakeholders are engaged in continuous process of mutual learning, which bears important implications for the efficiency and effectiveness of collective learning processes. Yet, complexity also allows to capture more realistic features of the innovation process, while avoiding the fall into rigid parameters (Frenken, 2007).

Novel technologies also present elements embedded in complexity in the sense that its emergence is a result of a non-linear and interactive process that is adaptive and unpredictable, and it coevolves, while also influencing, and being influenced by other actors in a shared environment, including multiple stakeholders with varying needs (Poutanen et al, 2015).

On the other hand, uncertainty becomes enhanced by considering that in complex systems, it is not possible to establish accurate predictions, and that complexity comprehends a high variety of intervening variables and feedback loops that do not allow the understanding or prediction of the system's behavior (Aven, 2019). Here is where uncertainty also becomes an issue, as it cannot be easily measurable in terms of probabilities along the whole innovation chain (Government Office for Science, 2014).

There is risk related to these systems, as the consequences of the activities generated by the systems are uncertain. Moreover, these systems are often considered to be complex (Jensen & Aven, 2018).

A main problem is the lack of linearity in complex systems. This means that a prediction model is established, but it is not accurate, as complex systems do not allow such simple modeling. Accidents may occur in surprising ways not captured by the models. Nonlinearity means that the "causal links" of the system form something more complicated than a single chain, for example feedback loops (Jensen & Aven; MacKay, 2008).

2.6.5 Coping with Uncertainty and Complexity Related to Innovation

Considering the risks related to complexity and uncertainties embedded in novel technologies, one method used to mitigate the uncertain and negative effects of new technological innovations, is to evaluate them according to the precautionary principle. However, the very complexity that makes the precautionary principle desirable also makes it contentious and hard to define. Complex systems are filled with uncertainty, and no amount of precaution will eliminate all risks (Newman, 2005).

If too much protection is sought, innovations may be prevented or hindered; On the other hand, if there is too little protection, unpleasant surprises may be experienced. Therefore, the question of 'how safe is safe enough', is replaced by 'how much uncertainty and ignorance the main actors are willing to accept in exchange for some given benefit' (Renn & Rocco, 2006).

When it comes to protection, the concept becomes supported by the cautionary and precautionary principles. On the other hand, sustainable innovation can be addressed in relation to development, which is promoted by cost-benefit type of analysis. Yet, the principle does not provide precise guidance on when it is applicable, leading to inconsistencies when used as a decision rule (Aven, 2019; Peterson, 2006; Stefánsson, 2019).

However, and by highlighting the risks related to complexity and uncertainty in relation to innovation, there will always be some costs associated to its implementation. Nevertheless, risk is not the main driver for the realization of the activity, and its rather something related to the activity that needs to be taken into account when making decisions, considering that generating benefits and value requires a certain degree of risk taking, as it is in the case of the implementation if sustainable innovation directed to mitigate climate change and its ripple effects (Aven, 2019).

Therefore, and by taking into account that risk is not the main driver for carrying out an activity, and that the protection based in the precautionary principle does not seem to suffice, risk assessments are needed in order to inform decision makers. Though, these assessments may fall short in covering all the concerns associated with the risk source, and do not address the resolution of conflicting values and the required trade-offs (Idem). Thus, there is a need for the decision-makers to go beyond the risk assessment to account properly for risk and uncertainties, as well as attributes and values not considered by the assessment (Aven, 2019; Edwards & von Winterfeldt, 1987; Aven, 2016).

Although for conventional and non-complex risk situations the risk assessments can prove useful, when it comes to particularly complex situations with trade-offs between them, a broader set of multi-level characteristics is required (Aven, 2019).

Yet, in the face of uncertainty and complexity, the need for strategies that highlight protection based on the cautionary and precautionary principles, are still not acknowledged, and in consequence, the focus on risk governance becomes considered as essential (Aven, 2019).

In several cases the governance of risks may involve precaution in the sense of flexible strategy, enabling the learning from restricted errors, new knowledge, and visible effects, so that adaption, reversal, or adjustment of measures becomes possible (van Asselt & Renn, 2011).

In addition, Van Asselt & van Bree (2011), argue that in the context of risk, governance principles also embody a normative ideal. Therefore, risk governance refers to a body of ideas of how to deal with uncertain, complex and/or ambiguous risks more adequately and responsibly, ideas that should also be merged with the functionality approach proposed by Renn (2012).

Yet, and as discussed in Aven (2011) in regards to measures for tackling wicked problems, risk governance may also preset deficits that can be particularly harmful to the development of new technologies, where they can lead to an overcrowding of innovation or to unintended consequences. Thus, the decision-maker’s capacity to respond to unexpected events, will depend on their flexibility and adaptability, such as their authority or willingness to reallocate resources when required, allowing the emergence of alternatives in the face of unexpected circumstances.

Furthermore, and as for tackling wicked problems, coping with uncertainty and complexity in relation to sustainable innovation, requires a dynamic process of continuous, flexible, and gradual learning and adjustment that allows a careful handling of complexity, and uncertainty, instead of treating the risk as if it was simple. This should also include a broad variety of means and mechanisms by which risks can be handled collectively in an integrative way. In practical terms, flexible and integrative capacity, should respond to the ability to design and incorporate the necessary steps in the risk governance process, to allow decision-makers to reduce, mitigate, or control the occurrence of harmful outcomes in an effective, efficient, and responsible manner (Klinke & Renn, 2011; Brooks & Adger, 2005). The adaptive and integrative elements embedded in the process, requires the capacity to learn from previous or similar risk-handling experiences to cope with current risk problems and apply these lessons to cope with future potential risk problems and surprises (Klinke & Renn, 2011).

CHAPTER 3
RESEARCH DESIGN AND METHODOLOGY

Complex, ambiguous, and uncertain risk problems cannot be tackled through simple risk approaches, since, as argued by Peters (2017), the relationship among variables is non-linear and minimal changes in starting conditions can cause extreme different outcomes. This is a feature that makes wicked problems especially difficult to solve, considering also that the proposed solutions aimed to tackle these issues, may carry the risk of creating new complex, ambiguous and uncertain wicked problems (Sun & Yang, 2016).

Therefore, to help tackle and mitigate the adverse effects related to complexity, ambiguity and uncertainty of the wicked problem of climate change and sustainability, different systematic approaches to risk governance are proposed, to validate and justify the emergence and implementation of technological sustainable innovations as risk-superior alternatives.

3.1 Problem Statement

Climate change can be understood as one of the most important and urgent problems of the 21st century, issue that affects and is affected by soil degradation and desertification among other factors, through a circular feedback (Sun & Yang, 2016; Lal, 2012).

It is because of this that land degradation has become also one of the most severe problems that humanity and the environment are currently facing on a global scale, problem that represents huge impacts on both the land and landscape, due to the impediment of plant growth (Kertész, 2009). In addition to plant growth, soil health is essential for the integrity of terrestrial ecosystems to remain intact or to recover from disturbances, such as drought, water scarcity, climate change and global warming, pest infestation, pollution, and human exploitation (Neiendam & Winding, 2002; Ellert et al. 1997), together with food safety and quality (Neiendam & Winding, 2002; Halvorson et al. 1997; Parr et al. 1992).

Therefore, and by considering the high variety of elements contributing to desertification and soil degradation, in addition to the circular feedback that occurs with climate change, these wicked issues fall in the categorization of systemic risks, being multi-causal, and encircled by complexity, ambiguity and uncertainty (Klinke & Renn 2002; Renn 2008). Nevertheless, and by contemplating the wicked nature of these issues, it is of high relevance to take into account that any attempt and proposed solution directed to help mitigating a wicked problem, may carry with it the risk of creating new problems that may also be wicked, complex, ambiguous and surrounded by high uncertainty (Sun & Yang, 2016), leading to a dynamic in which too much protection, could lead to the prevention and hindering of innovations with the capabilities or the potential for tackling issues related to climate (Renn & Rocco, 2006).

3.2 Research Questions

The following research questions are directed to help support arbitrage among contested concepts embedded in wicked problems and wicked solutions, by generating consensus and improving the proposed solutions through the application of risk science approaches.

1) How can risk science support sustainable technological innovation for tackling wicked problems?

2) How can the approach to sustainable technological innovation be improved to deal with wicked problems?

3.3 Methodology

The methodology utilized throughout this research, is based on a qualitative approach, in which primary and secondary sources were reviewed and analyzed, in order to generate a better understanding in relation to the systemic risks embedded in the wicked problem of climate change, which is framed in elements of complexity, ambiguity and uncertainty. For this issue, risk-based approaches to support and validate the role of sustainable development and sustainable technological innovations, are suggested to help mitigating the adverse effects of climate change, while also contributing to a clearer picture on how to better deal with complexity, uncertainty, and ambiguity of the problems and the potential solutions. Thus, and by considering the systematic characteristics of wicked problems, and the limitations of traditional risk analysis, the results of this research will be supported by the analysis of the case study of Desert Control, an innovative Climate Technology company, which aims to reverse and stop desertification and soil degradation, by turning degraded land and soil into fertile land through the application of Liquid Natural Clay.

3.4 Case Study

The case study utilized for this thesis, is based on a single organization, which corresponds to Desert Control, a climate technology company based in Stavanger, Norway. The case study will be utilized to obtain empirical data on how to deal with complexity, ambiguity, and uncertainty in the face of wicked problems, in a real-life context. It will also be used to test and support some of the theoretical claims and solutions presented and reviewed in *chapter 2*. This will also help address outcomes whose direct and indirect implications are too complex for theorizing. Finally, the case study will also help verifying the hypothesis that *"The wicked nature and elements of climate change and sustainability, can be mitigated through the implementation of technological sustainable innovations, that are improved by the integration of different elements obtained from systematic risk-based approaches, in order to support responsible decision-making capable of coping with complexity, ambiguity, and uncertainty".*

The data was collected from both primary and secondary sources. The data collection for primary sources, was based on digital and in-depth pilot interviews directed to members of the team of Desert Control. The pilot interview is based on 6 main questions with sub-questions and aims to understand how Desert Control has dealt and deals with complexity, uncertainty, and ambiguity related to the wicked problem of climate change, through different perspectives and in praxis. The analysis of the answers is carried out based on the literature review, comparing the different solution alternatives provided by the academia, with the processes and results carried and obtained by Desert Control, highlighting aspects related to complexity and wicked problems, related to desertification and soil degradation, and adding other recommendations that were not touched upon on *chapter 2*.

In terms of the collection of data through secondary sources, these will consist of different conferences, press releases and articles issued by the company, and third parties. Because of the diversity of the sources, the topics to be studied and addressed, will be the same as the ones obtained through the primary sources while taking into account the importance of different systematic risk governance-based elements that can be found and applied. Other recommendations obtained from these sources for dealing with wicked problems related to climate change will also be considered.

3.5 Desert Control

Desert Control is a climate tech company that is presented as one of the solution alternatives for helping to mitigate the effects related to climate change and global warming.

The company was chosen as a case study, as they have developed a sustainable innovation technology, that has competitive advantages in the market against other products with the same objective, and that has shown visible results in combating the problems of desertification and soil degradation, while also addressing and impacting on other complex issues related to climate change, such as reducing water consumption and issues related to water scarcity, as well as reducing fertilizer usage.

The vision of the company is to make the earth green again, by stopping and reversing desertification and soil degradation, and turning degraded land and sand into fertile soil, while reducing the water usage for green ecosystems up to a 50%.

This is achieved through a product built on 12 years of R&D, called Liquid Natural Clay (LNC), proved and validated by independent third-party organizations to reduce water consumption up to 50% and increase crops yields up to 62%.

3.6 Research Limitations

Climate change, global warming, and the rising of CO2 levels, have harmful effects on multiple levels of biological organizations, covering a wide range of impacts on individuals and ecosystems (Woodward et al, 2010). Therefore, and by considering that this represents a multi-level issue on different scales, this research study is limited to address the problems related to desertification and soil degradation, as a ripple effect and a wicked outcome of climate change. Other effects of climate change will also be addressed, but not covered in depth, due to the complexity of these issues.

On the other hand, the case study is limited to a single organization directed to stop desertification and soil degradation through the application of a sustainable technological product (LNC), but other novel technological alternatives will not be covered. Yet, relevant remarks taken from the development of LNC will be accounted for and merged with risk-based approaches to help improve the development and implementation of future technologies, directed to mitigate the effects of climate change.

Finally, the study is limited to address the role of technological sustainable innovations as a tool for mitigating the effects of climate change, together with some of the effects this may have on other levels. Yet, and although other relevant alternatives and roles are mentioned, they will not be further studied.

CHAPTER 4
RESULTS

This research study has shown that wicked problems related to climate change are global, transboundary, and multi-level issues, embedded in complexity, ambiguity, and uncertainty. These elements, characteristics and features make wicked problems and their effects extremely challenging to address, mitigate or solve. It is also because of these characteristics, that the solution alternatives become contested and ambiguous, and their related uncertainties are enhanced due to lack of knowledge on their potential outcomes. In addition, simple and traditional models have been proven to have limited capacity when it comes to predicting effects of novel technologies, due to the non-linearity related to the causes and effects of these problems, and the potential outcomes of novel solution alternatives. It has also been demonstrated that wicked problems related to climate change characterized by non-linearity and complexity, cannot be dealt with by applying simple and traditional solutions.

It is because of the characteristics and features of the issues at stake that the concept of technological sustainable innovations was suggested, to help mitigating some of the effects related to climate change, while also contributing to sustainable development in praxis. Yet, this study has also shown that the novel characteristics of technological innovations, make them uncertain and ambiguous, due knowledge gaps related to their potential risks. It is because of this knowledge gaps and the state of the art related to sustainable technological innovations, that this study proposed different approaches to improve these solution alternatives directed to tackle the effects related to the wicked problem of climate change.

These approaches were obtained after carrying out two in-depth pilot interviews and obtaining relevant data from other various secondary sources related to Desert Control, which provided factual examples of arbitrage and agreement in relation on how to cope with complexity, ambiguity and uncertainty, as well as the adverse effects and risks related to the effects of climate change, through the implementation of a sustainable technological innovation product.

In the case of the pilot interviews, the data yielded shed light on shared agreement from the interviewees, regarding the practicality of the application of the following elements, related to the literature reviewed:

a) Recognition of climate change, desertification, and soil degradation as a wicked problem.
b) The importance of combining normative ideals and functionality for the development of sustainable technologies.
c) The critical role that cooperation among different actors through a multi-level perspective has, in the face of wicked problems related to climate change.
d) Acknowledgement that there will always be risks related to the development of novel technologies, but that these risks can be mitigated through gradual and consistent learning.
e) Relevance in understanding and identifying global and local perspectives and needs.

By following the inputs obtained by Desert Control and the literature reviewed, and in carrying a systematic content analysis, the following lessons related to the development and implementation of the product were found, for improving the approach to sustainable innovation technologies:

a) *A knowledge-based strategy* should be applied since complexity cannot be coped through the application of simple and rigid traditional solution methods. A knowledge-based strategy would reduce knowledge gaps through continuous and gradual learning and adjustments, while increasing capabilities for handling complexity, and reducing uncertainties.
b) *A flexible approach to risk governance* should be immersed in an extensive R&D process for developing technological innovation measures, to allow for gradual learning and adjustments, so the capacity for adaptability related to the implementation of a technology becomes possible. Having the ability to adapt measures, can help reducing countervailing risks, and increase the resilience of the risk targets.
c) *Strengthen cooperation among different actors, through novel approaches of adaptive-thinking and collaboration*. Since the issues at stake are dynamic, prone to extreme variations in their potential outcomes, multi-level and complex, no single actor has the capabilities for dealing with transboundary issues of wicked nature, and

therefore collaboration should be strengthened. This way, complex problems can be addressed through different scopes supported by cooperation, to reduce ambiguities and complexity.

d) *Application of a multi-level perspective approach* to simplify the analysis and addressing of complex and transboundary issues and validate the development and implementation of novel sustainable technologies.
e) *Decision-making supported by approaches to risk governance, and agreed outputs obtained from different stakeholders after collaborative instances* for selecting risk-superior alternatives.
f) *Implementation of constructive and sustainable interventions in the environment,* to make it resourceful and resilient

On the other hand, and in terms of supporting the development and implementation of sustainable technological innovations for tackling wicked problems, this thesis has explored the following risk governance-based approaches that can help improve the creation and implementation of novel technological measures:

a) *Application of systematic risk-governance elements* that create capabilities for generating flexible and adaptable approaches for the decision-making process, to allow for the adjustment of measures, in order to deal with complex, uncertain and ambiguous risks more adequately and responsibly, while also allowing the creation of alternatives or new courses of action if necessary.
b) *Acknowledge that the generation of benefits and value includes a certain degree of risk taking*. Therefore, risk should not be the main driver for carrying out the emergence of technological alternatives, but rather a tool to improve their development and performance, and for supporting decision-making and arbitrage in the face of complex wicked issues.
c) *Application of precaution involved in risk governance principles*, that allows a flexible strategy that consents adaptation, or adjustment of measures.
d) *Inclusion of means and mechanisms to handle risk collectively in an integrative way,* enhancing cooperation and collaboration.

Nevertheless, the wicked problem of climate change has been demonstrated to be too much of a big issue, with too many wicked ripple effects. Therefore, the implementation of improved sustainable technological innovations does not suffice to mitigate the whole implications of the problem. However, they can be part of the solution by materializing positive impacts and by generating arbitrage regarding different visions and values. Henceforth, other macro and micro measures should be incentivized, developed, and applied.

CHAPTER 5
CASE STUDY: ANALYSIS AND DISCUSSION

Wicked problems are extremely difficult to solve, due to their complexity, ambiguity, and uncertainty. Additionally, the potential solutions seem ambiguous in their conceptual base, as it happens with sustainability and sustainable development, issue that creates more complexity, ambiguity, and uncertainty. Yet, in the face of the problem of climate change, failure to take action will overload the atmosphere's absorptive capacity, enhance global warming and lead to more complex and wicked issues in the future, since slight changes in the initial conditions, may produce significant deviations in the potential outcomes, due to the non-linearity of these problems (Peters, 2017; Altenburg & Pegels, 2012). Therefore, the main question is related to which actions and measures can be taken before major crises related to environmental degradation occur, or whether risk mitigating actions will be taken only under the pressure of critical crises and at a higher cost (Altenburg & Pegels, 2012).

5.1 Liquid Natural Clay (LNC)

Liquid Natural Clay (LNC) is created when water and clay are formulated and processed into a liquid compound, nearly as thin as water. This formulation process is done on the site where is required, and the LNC is spread onto sandy soil using traditional irrigation systems. The liquid percolates down the sandy soils, forming a soil structure with the capacity of retaining water, giving the sand particles a nanostructured clay coating. This process changes the physical qualities of the sand particles, allowing them to bind water and turn poor quality sandy soil into high yield soil, increasing water and plant nutrient holding capacity, while also reducing water loss due to evaporation. In addition, LNC functions as a catalyst for the symbiosis of Mycorrhizal fungi between plants, fertilizers, water, and the air in the soil, improving the plant uptake of nutrients (Olesen & Julseth, 2015).

Besides, and according to the International Center for Biosalin Agriculture’s results from August 2019 and September 2020, with the application of LNC, water and fertilizers are saved in an average range between a 20% and a 50%, crop yields are increased between a 17% and a 62%, and soil is improved, which also helps improving biodiversity and carbon uptake (Desert Control, 2021).

LNC is expected to play a highly relevant role for sustainable development by addressing at least 13 of the 17 United Nations SDG’s, directly and indirectly (Idem).

5.2 Discussion: Dealing with Wicked Problems Through Global Solutions and Local Implementation

Throughout this study, it has been shown that climate change and its effects can be conceptualized as a wicked problem, framed in complexity, and embedded in ambiguity and uncertainty. It has also been argued that the proposed solutions related to sustainability and sustainable development, can be framed as wicked problems too, due to its intrinsic normativity (Schmieg et al, 2018), that leads to ambiguity, which, in addition to the existence of multiple stakeholders and their multiple visions and values, enhance the lack of arbitrage in regards to objectives of sustainable agendas and how to achieve them, strengthening the ambiguity. On the other hand, the wicked nature of sustainability and sustainable development, is also a consequence of the dynamic nature of multiple stakeholders and systems involved, that in addition to the non-linearity of complex issues, makes extremely difficult to predict the potential outcomes of sustainable interventions (Beg et al, 2002; Brønn & Simcic, 2018).

Moreover, technological innovations are also raised as another potential solution that may play a critical role in the process of dealing with wicked problems related to climate change (United Nations, 2020). Nevertheless, and as it happens with the concepts of sustainability and sustainable development, technological innovations have also been argued to be flawed due to their complexity, uncertainty and ambiguity embedded in their novel nature, in addition to the knowledge gaps regarding potential and unknown risks (Temel & Durst, 2020; Henschel and Durst, 2016).

Therefore, and by considering the risks posed by wicked problems related to climate change, the wicked nature of sustainability, and the complexity and uncertainty related to technological innovation, different authors proposed a variety potential solutions to overcome these challenges in *chapter 2*, solutions that will be addressed and be analyzed by applying them in praxis through the work done by Desert Control, and their LNC.

5.3 Desert Control and LNC: Materializing the Role of Technological Sustainable Innovations

Before the development of LNC, the solution alternative was based on shoveling clay into the ground. For this process, approximately a 100 kg of clay per square meter was needed to be placed in depth, to be able to make that piece of land fertile and resourceful. Yet, that practice was extremely complex to carry on, also including the risk of being very intrusive and disruptive. However, this was the best-known alternative for treating degraded and sandy soil. Though, this process was not cost-efficient, due to its complexity of application and its high price, which lead to banning the practice (Olesen, 2016). It was due to these issues related to the 'solution', that Kristian Olesen and Ole Morten Olesen, found a particular way to mix water and clay, creating LNC, a product that only required 1kg of clay per square meter, and only 1/3 of the water that was used for the same purpose with the previous practice. LNC after its application, started showing extreme results, by increasing what could be taken out of the soil (Idem).

In this case, and based on the arguments provided by Zijp et al (2016), the development and creation of LNC, was presented as a novel alternative for providing a solution in the face of an activity that was previously banned, based on single and simple metrics, such as methods of application and cost-efficiency. Yet, with LNC, the same activity was stimulated after an innovation process, while also accounting for its potential for tackling part of the wicked problem of soil degradation, along with contributing to sustainable development. Nonetheless, how does sustainable development become materialized?

Considering the critics related to sustainability and sustainable development, and its intrinsic normativity, Renn et al (2009), suggested that these concepts should be marked through a combination of a normative-functional understanding of societal development, to prevent the excessive application of just normative or functional elements (Renn, 2012). In the case of Desert Control, this becomes a reality reflected on the impacts that LNC has on the soil, and other relevant aspects after its application. According to the lead soil scientist from Desert Control, Orn Supaphol (2021), LNC is a sustainable product that combines normativity and functionality, through short, medium and long term objectives joint with a learning process in regards to the development and improvement of the technology, that after its application, materializes sustainability on its results and main impacts, such as re-greening degraded soil, helping carbon capture naturally, reducing water losses, and re-foresting. Therefore, LNC can also be considered as a systematic multi -level solution because it deals with other issues related to wicked problems on different levels. As an example of this, after the application of

LNC, the problem of water scarcity is addressed since there is an average water savings between the range of 20% and 50% (Idland, 2021). Having the potential for tackling issues on a multi-level can also help creating and explaining a sustainable transition process, which is seen with the results provided by LNC, that contributes also to the creation of jobs, food production through crop yields, and energy production by turning part of the new bio mass into bio oil. This has also the potential to boost initiatives for creating emerging technologies directed to the development of green energy, that can be used to produce drinkable water in countries where desalination processes are used for providing water for the population. This has particular significance for locations in which the desalination of water is a vital process for ensuring drinkable and potable water for the population, which represents a highly polluting process, that while being a solution, is also a problem that contributes to the vicious wickedness of global warming and climate change (Olesen, 2018).

Going back to the critics related to sustainability and sustainable development, it was argued that the high variety of stakeholder involvement, with their multiple interests and different visions, created more ambiguity and enhanced the complexity of the process for finding adequate solution alternatives. Therefore, systematic approaches to risk governance where suggested to deal with these issues. On the first place, Ward (2003) proposed that a way to deal with the problem of ambiguity and conflicting values in the face of wicked problems, was through cooperation among actors, as no single actor has capabilities to fully address the complex issues related to climate change, on its different levels. Cooperation was argued to be of high relevance when it could be addressed through a multi-level perspective, in which joint goals and common strategies could be formulated, to acknowledge and govern risks and uncertainties.

In the case of Desert Control, and in relation to their view and acknowledgement of wicked problems, the company has recognized that cooperation is a crucial element for dealing with complexity related to climate change. According to their Chief Technical Advisor, Hege Kverneland (2021), cooperation among different actors is one of the most important elements for contributing to the mitigation of the problem of soil degradation and desertification. In addition, Supahpol (2021), also recognizes that cooperation among actors is of critical nature, since the problem of climate change, desertification, and soil degradation, are transboundary and global. To understand the importance of global and transboundary solutions, and as an example, according to the United Nations (2021), Norway is not affected by drought or desertification, and therefore, Desert Control has no “home” market. However, the market for LNC and the demand for the product is outside of Norway. This is because the wickedness of climate change and its effects, are global, and the creation of wicked problems, can symptom of another wicked problem (Rittel & Webber, 1973). Thus, having a Norwegian company with no local market, but with a global role, plays a relevant part in acknowledging the importance of the issues at stake, while reinforcing or promoting cooperation among actors on different levels and locations. Nevertheless, cooperation finds some barriers that become materialized for the company in terms of convincing potential customers that LNC works, process that is time consuming because it is very dependent on the time that the crops take to grow to show visible results (Kverneland, 2021). This also has relation with the challenges suggested by Altenburg & Pegels (2012) related to sustainability-oriented innovation in terms of its attempts to try and disrupt firmly established, but environmentally unsustainable trajectories.

In addition to cooperation, Renn (2012) argues that the future of humanity depends on the preservation of the anthropogenic ecosystems, for humans to thrive, needing constant and constructive interventions to make the environment a productive resource, interventions that this study has presented as sustainable technological innovations. Following this argument, LNC can be considered as a product that helps preserving and improving the anthropogenic ecosystem, due to its main features, and especially when compared to other alternatives with the same purpose, such as manually shoveling clay into the ground. These alternatives are very cumbersome to use, while also being intrusive and disruptive, requiring in many cases the removal of the existent vegetation, while LNC process of appliance is easy and non-intrusive (Sivertsen, 2021; Supaphol, 2021). Intervening aggressively in the soil includes an environmental cost, as sequestered carbon becomes exposed to oxygen and it is lost into the atmosphere as carbon dioxide (Sohi, 2021).

According Ole Kristian Sivertsen, Desert Control’s CEO (2021), LNC also makes the environment a productive resource, having an impact on water savings, and how resources are efficiently used. On the other hand, and as a result, the application of LNC has proven to increase the growth of watermelons on a 17%, zucchini on a 30%, and 62% on pearl millets, therefore turning untreated/degraded land into a more efficient resource (Idland, 2021). Yet, according to Supaphol (2021), intervening is not enough, and therefore preserving the anthropogenic ecosystem, will also depend on a learning process, and a socio-cultural change, in which individuals on different levels become aware and acknowledge the implications and adverse effects related to climate change, and the actions they can perform to contribute to its mitigation. Nevertheless, and in terms of the problem of desertification and soil degradation, this is an issue that is only visible and known depending of the location, making awareness more complicated. As previously stated, and using Norway as an example, the country is not affected by drought or desertification, and therefore the problem may not be widely visible. Thus, according to Kverneland (2021), desertification is seen and known in locations where Desert Control operates, such as Dubai, where the problem of desertification and water scarcity is seen and felt by the people, problem that is also felt in terms of water scarcity, and reflected in the process for water desalinization, through a very polluting method (Olesen, 2018). Therefore, LNC can also be acknowledged as a risk-superior alternative, since it has direct positive impacts in the target risk and has potential to reduce harmful outcomes related to other risk sources.

However, to achieve a risk -superior alternative, countervailing risks should be evaluated beforehand against the target risk, to support decision-making that aims for the most optimal course of action. As argued by Graham & Wiener (1995), this requires risk tradeoffs, which involve as a generic problem, the generation of unintended consequences or side effects, and unless decision-makers consider the possible outcomes, a systematic emergence of risk tradeoffs will occur.

Considering the risk tradeoffs, and the search for risk superior alternatives, it is also important to take into account the uncertainties and ambiguous elements related to the novel characteristics of emerging sustainable technologies, that also may lead to the lack of knowledge regarding their potential risks, in addition to the uncertainties related to their capacity of achieving the desired outcomes (Temel & Durst; 2020; Henschel & Durst, 2016; Roper & Tapinos, 2016; Menon et al., 2002). Nevertheless, as argued by Aven (2019), there will always be risks related to complexity and uncertainty associated with the implementation of technologically innovative measures, and therefore, risk should not be main driver for the realization of the activity, but it should be taken into account when making decisions, considering that generating benefits requires of a certain degree of risk taking. Is in these cases that, according to van Asselt and Renn (2011), the governance of risks should involve flexible strategies capable of enabling learning from restricted errors, as well as new knowledge, and visible effects, so that adaption, reversal, or adjustment of the implemented measures become possible.

Therefore, when taking these elements and suggestions into praxis, and by addressing the case of LNC development, it is possible to see that its creation process, was based on 12 years of R&D. The reason for this is because of the different properties of the soils, clay, and plants. Thus, custom mixes should be applied in accordance to the different local contexts; too little clay applied may have almost no impact. Too much, and a waterproof crust can be formed on the surface of the sand or making compaction more likely (Sivertsen, 2021). Hence, the process for finding a risk-superior alternative and for reducing the lack of knowledge on potential risks related to novel technologies, should be supported by a knowledge-based strategy. In the case of LNC, this approach was applied to understand that each type of clay has unique properties, different types of soils require custom liquid compositions, and different plants have different preferences. This knowledge and continuous learning also made the product prone for scalability (Desert Control, 2021). This knowledge based strategy, together with the pursue for a risk-superior alternative, also goes in line with what was suggested by Klinke & Renn, (2011) and Brooks & Adger (2005), in relation to tackling wicked problems through sustainable innovation, and the requirement for a process that allows continuous and gradual learning and adjustments capable of handling complexity, and uncertainty, in addition to the inclusion of relevant elements from the risk governance process, to mitigate the potential occurrence of harmful outcomes in an effective, efficient, and responsible manner.

Another aspect that makes LNC a risk-superior alternative, is the fact that the product has no competitors, although there are other alternatives with the same purpose in the market. This is because the LNC process of application is easy and non-intrusive, unlike other alternatives (Sivertsen, 2019).

It is of high importance to also consider that, as argued by Van Asselt & van Bree (2011), in the context of risk, governance embodies a normative ideal on how to deal with complexity. Therefore, and by considering that climate change is a wicked problem with negative effects on multiple levels and aspects, the handling of it is driven by normative ideas, that can be seen through the globally negotiated normative agenda expressed in the 17 SDGs and the compliance with them (Schneider et al, 2019).

For the case of Desert Control (n.d.), the handling of complexity in relation to these normative ideas, becomes materialized and functional through the impact the company has on some of these SDGs goals, both directly and indirectly. According to Desert Control (n.d.), the advantages of treating soil with LNC are directly linked to goals 2, 9, 13 and 15. Goal 2, corresponds to *Zero Hunger*, and is impacted by allowing for areas previously considered as unsustainable for farming, to be used for growing food crops. This is followed by goal 9 of *Industry, Innovation, and Infrastructure***,** for which building of resilient infrastructure, promotes inclusive and sustainable industrialization that can foster innovation. Therefore, LNC represents an innovation with the potential to expand industries into new areas, that may require new infrastructure, such as the creation of other green technologies. Finally, LNC impacts on goals 13 and 15, related to *Climate Action* and *Life in Land*. LNC allows plants to grow in areas that before being treated, lacked enough water to sustain life. Treated soil allows plants to thrive, while also reducing the amounts of water consumed, allowing for deserts to be reclaimed through the smart use of water resources. This also reduces CO2 emissions by 15-25 tons per hectare. In addition, a layer of LNC prevents fertilizers from running through the soil and polluting under-laying soil and water table. Finally, by replacing sand with plants, the surface temperature can be reduced by up to 15°C.

LNC has positive impacts on different levels, which, may help tackle wicked problems since, as suggested by Head (2018), and Verweij &Thompson (2006), these kind of complex issues need to be approached on different levels, while using a wide using a range of instruments, since there is no ‘one best solution’. Nevertheless, according to Kverneland (2021), and in regards to LNC and its role, the product does not mitigate climate change nor global warming as a whole, because of their wicked and global characteristics, and because they are too much of a big issue for being tackled through just one alternative. Yet, LNC is part of the solution for the problems that have been addressed, having the capabilities to impact on different aspects on multiple levels.

5.4 Improving Management of Wicked Problems Through Risk Science

The main objective of this research study, was to explore through systematic risk-based approaches, that wicked problems related to climate change, and ill formulated solutions, such as sustainability and sustainable development, can be mitigated through the implementation of technological sustainable innovation measures, that are improved and supported by the inclusion of systematic risk governance based- approaches.

Yet, the complexity, uncertainty and ambiguity of wicked problems related to climate change, have been demonstrated to be a huge global and multi-level issue, unlikely to be resolved or mitigated through actions of a single actor or single actors working independently, or single and simple solutions, due to the different levels and dynamics on which these negative impacts and risks are found.

Nevertheless, the case of Desert Control and LNC, has proven that issues of wicked nature, can be addressed and tackled to some extent, through sustainable technological innovation, that is supported and improved by extensive R&D processes capable of addressing and reducing the risks related to the complexity and uncertainty embedded in novel technologies and their implementation. In addition to the R&D process, and based on the data collected, systematic risk governance principles can also help improving the characteristics of technological innovations, while mitigating adverse effects and ensuring some degree of sustainable development, that becomes materialized on different levels of positive impacts that are found in normative ideals and ideas. Thus, it has been demonstrated that climate change represents an enormous challenge with global implications and transboundary effects, and therefore the implementation of one technology, is not enough to mitigate climate change as a whole, but it can be part of the solution, once certain elements taken from risk governance approaches and knowledge based strategies are applied, in order to avoid flaws or potential harmful outcomes. However, and although it has been shown that technologies such as LNC impact positively in the environment, having also potential for creating positive economic impacts for the areas where the soil is treated, it is still a single solution addressing just part of a bigger issue, and in consequence, the need for efficient and inclusive cooperation, among other initiatives that create incentives for mitigating these issues, are crucial. Nevertheless, cooperation and approval for usage of a technological innovation product finds some barriers when costumers or target groups present a certain degree of skepticism on the qualities and potential effects that the technology may present, delaying the process of application and the disruption of environmentally unsustainable trajectories, especially when the effects of the technology are conditioned by time. Yet, as suggested by Head & Alford (2015), issues related to cooperation can be dealt with by introducing novel approaches of collaboration and adaptive-thinking to account for problems through several perspectives, including complexity, ambiguity, and uncertainties of wicked risk problems, while at the same time, strengthening the collaborative capacities.

However, when it comes to developing and implementing novel technologies for mitigating wicked problems related to climate change, there will always be risk associated to this activities, that are enhanced by the complexity, uncertainty and ambiguity of the issues, and therefore risk should not be the main driver for carrying out an activity, or for developing novel technologies for climate action, since, the generation of benefits includes a certain degree of risk taking (Aven, 2019). Based on this, and by taking Desert Control as an example, the extensive process of R&D raises again as a process of crucial importance, together with a knowledge based strategy, and risk handling strategies based on learning from errors, and with the capability of creating new knowledge, and visible effects, so that adaption, reversal, or adjustment of measures becomes possible (van Asselt & Renn, 2011).

Nevertheless, the development of other sustainable technologies and alternatives should be boosted, since, as it has been mentioned, the capabilities of single actors are limited when dealing with the wicked nature of climate change, and therefore high importance should be given to a multi-level perspective in order to be able to address its issues through different dynamics, levels and visions on cooperative instances, in order to keep global warming below 2°C and ensure a certain degree of sustainable development beyond a normative ideal.

Complex problems of wicked nature are not easy to solve due to lack of linearity, the high variety of stakeholders and actors with different interest involved and the dynamics of their interactions, global nature of the issues, and conflicting visions on how problems can be tackled and mitigated.

In the face of these issues, the case study of Desert Control has shown relevant remarks in regards on how to deal with them, starting by materializing and arbitraging normative objectives, in order to reduce their ambiguities and uncertainties, and turn them into feasible, positive, and responsible impacts, that are visible through their compliance with some of the 17 SDG's. On the other hand, lessons related to the development process of LNC can be extrapolated to improve the development of other technologies which are looking to address complex problems related to climate change on different levels, while also reducing their adverse effects. For an improved achievement of these objectives, and for the better management and mitigation of wicked problems, this research has proposed that the development of novel technologies, should be based and supported by gradual knowledge based strategies that are merged with systematic governance of risks, in order to achieve, flexibility, adaptability, and integrative solutions, capable of avoiding inefficient and harmful actions, and achieve risk superior alternatives, that can contribute to sustainable development, by reducing vulnerabilities and increasing the resilience of the risk targets.

Yet, and as stated by Beg et al (2012) the uncertainties related to the rate of climate change raise questions about whether a sustainable transition can happen fast enough to make a difference, and therefore, isolated actions of single actors and simple solutions may not have the needed capabilities for mitigating this issues to a relevant extent. Henceforth, and according to Kverneland (2021), the development of sustainable technological innovations should be combined with the acknowledgement of complexity, and the role of industries, governance, and governments, to make a sustainable transition conceivable. This could be achieved through initiatives such as fees on CO2 emissions, financial initiatives to support the development of responsible novel technologies and by effectively communicating the implications of climate change, to generate awareness and modify some unsustainable socio-cultural behaviors.

CHAPTER 6
CONCLUSIONS

Climate change has been presented as one of the biggest and urgent challenges of the 21st century. Its wicked nature enhances the creation of other severe wicked problems that have adverse effects and impacts for the environment, ecosystems, biodiversity, and humanity. Moreover, the wickedness of the problems and its elements framed in complexity, ambiguity, and uncertainty, makes them extremely difficult to address and find solution alternatives to mitigate them, while avoiding the creation of additional countervailing risks or other unexpected, inefficient or harmful effects.

This is why, in order to reduce ambiguities and uncertainties, this study suggested that it is crucial to generate arbitrage based on multi -level cooperation and adaptive-thinking, in regards to the scopes of wicked problems, as well as for the contested concepts linked to the potential solutions. The generation of arbitrage can improve the approach to sustainability and sustainable development through responsible, efficient, and impactful decision-making, while reducing the ambiguities related to the normativity of these concepts and materializing normative ideals into impacts.

On the other hand, sustainable technological innovations, were presented as a novel alternative to help mitigate the wicked nature of climate change, when the development and implementation of these technologies is improved by the integration of different systematic elements of risk governance. Yet, it is concluded that, although the inclusion of systematic risk-based approaches can support decision-making for the better development and implementation of technological measures, capable of coping with complexity, ambiguity and uncertainty, these alternatives do not suffice when attempting to mitigate the wide variety of problems that climate change generates. This is due to the transboundary and global implications of the issues at stake, as well as their complex nature. Nevertheless, improved technological innovations are part of the solution, by having direct impact in specific target risks and by contributing to sustainable development. Henceforth the incentivizing of micro and macro socio-cultural changes is suggested after achieving agreements in collaborative instances, on national and local levels, to reduce ambiguities and to generate arbitrage regarding different visions, perspectives, and values, related to climate change.

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