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Evaluating the Effectiveness of Land-Use Policies in Preventing the Risk of Coastal Flooding

Case Study: Coastal Regions of Helsinki and Espoo

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Abstract

Today, urban environments face several wicked environmental problems. These problems respond to institutional and political approaches instead of technical solutions. Rising sea levels, for instance, put waterfront areas at risk of coastal flooding. To minimize this risk land-use regulations can be effective. Although many strategies have been developed for managing wicked problems, few efforts have focused on evaluating the effectiveness of land-use policies in regulating wicked environmental problems.

This study develops a framework for evaluating the effectiveness of land-use policies in preventing sea flood risks. The study area covers the coastal regions of Helsinki and Espoo, and the timeframe of this evaluation expands from 2000 to 2018. Through the developed framework, land-use scenarios are simulated based on specific values, which reflect the effects of a policy set. This framework can be adapted to assess the effectiveness of land-use policies on different land-use conversions. The data used to conduct this research include the CORINE land-use cover dataset and the sea flood risk dataset provided by the Finnish Environment Institute (SYKE), international land-use planning and regulation guidelines, national legislation, and other relevant documents. Furthermore, land-use simulations were generated by GeoSOS-FLUS software. According to the results, fewer vulnerable land-use types are located within the sea flood risk zones in 2018 compared to 2000. This demonstrates positive land-use planning performance in the target areas. This simulation also shows a strong similarity to actual land use in 2018, proving the framework's reliability.

Keywords Land-use policies; coastal flooding; wicked problems; policy evaluation

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Preface

Research, in my opinion, begins with a question. About a year ago, I was thinking about the wicked problems that challenge all of humanity, and as an urban planner, I questioned if there were any solutions to the wicked challenges that face mankind at the urban scale. After receiving guidance from my supervisor, I began to draft my research proposal. This study suggests a framework for evaluating the effectiveness of land-use policies in managing wicked environmental problems. Even though any study approach has its limitations, this work can be beneficial for planners, researchers, and others with related concerns.

This journey was incredibly rewarding in terms of learning new skills and collaborating with wonderful colleagues who are now my friends. I want to express my gratitude to my supervisor Kirsikka Riekkinen for her excellent advice and her positive and responsible attitude even when we were not in the same time zone. I would also like to thank my unofficial advisor Havu Pellikka who offered me help regularly and even during summer, and from whose constructive comments I gained a lot of knowledge. In the end, I would like to thank my spouse for his unconditional support and constant effort in building my faith.

I need to add that the last weeks of this journey were extremely difficult for me due to unfavorable conditions in my country, Iran. These days Iranian people, especially women, are standing against decades of discrimination, oppression, and injustice by the ruling regime. While I am about to graduate, dozens of students in Iran have been brutally beaten, arrested, or killed for their protests. The following lines are to acknowledge the "Woman, Life, Freedom" protests in Iran. And for myself to remember days when I used to break down in tears at my desk whenever I saw a free bird from the window. But our hope for a better future does not diminish with the pain we endure. The following are parts of lyrics from the national anthem of these protests.

"... For all the tears that seem to never end
For all the images that keep on turning in our heads
For a simple smile, to last a little while
For the future generations fighting for their time
For empty promises of heaven in the after-life
For all the imprisonment of beautiful minds
..."

In Otaniemi, Espoo
November 2022
Faegheh Amanifard

Operators and abbreviations

Operators

Σ_i	sum over index i

Abbreviations

CLC	CORINE Land Cover
GIS	Geographical Information System
FLUS	Future Land Use Simulation

1 Introduction

In recent years, urban planners and decision-makers have paid special attention to wicked problems due to the challenges of modern life. We live in a complex urban world that is undergoing emerging phenomena, intertwined development processes, and shifting connections (Mäntysalo, Kangasoja and Kanninen, 2015). Planners must face the evolving version of old problems (Rittel and Webber, 1973; Head et al., 2008; Duckett et al., 2016).

In the past century, massive population growth has occurred on only less than three percent of dry land, thus resulting in environmental degradation (Grimm et al., 2008; Lazarus, 2009). Another impact of population growth is an increase in demand for land within urban areas followed by changes in land cover, economic growth, and climate change. During the past century, growing demand for developable land led to a change in the human relationship to urban plots of land, with land being perceived as a scarce community resource. By contrast, land had been considered in the 19th century to reflect wealth (Enemark, 2010). Despite this change, these plots of land have been the units shaping the morphology of a city throughout time, and they affect almost all the urban functions from accessibility to climate adaptation. Therefore, mitigating land-use change is an important administrative tool utilized by municipalities and governments to attain their goals. Municipalities can regulate land allocation, land cover change, land value, land development, sustainable land management, and generate revenue by utilizing the land use planning system (Enemark, 2010; Krigsholm, Puustinen and Falkenbach, 2022). This study understands land-use planning as a set of actions taken by municipalities to achieve their aims. Depending on the objectives defined by the municipality, land policies will be developed to guide planners in utilizing land-use instruments to overcome potential problems.

Societies are facing multiple wicked problems, with wicked environmental problems being the most concerning problems. In addition, urban planning problems are inherently wicked because of conflicting opinions and genuine dilemmas, uncertainty, and complexity in every urban planning process (Rittel and Webber, 1973; Head et al., 2008). Climate change is often considered a super wicked problem that perpetuates several other wicked environmental problems (Lazarus, 2009). For instance, the rise in sea levels is a symptom of climate change, which puts coastal areas of cities at risk of flooding events. Wicked environmental problems and land-use challenges usually overlap; thus, it becomes vital to simultaneously tackle not only environmental but also planning problems.

1.1 Problem Statement and Research Questions

Recently, much research has been devoted to evaluating policies regarding wicked environmental problems (Mickwitz, 2003). Environmental problems, similar to other wicked problems, have no technical solutions, but rather institutional and political approaches (Perry, 2015). As a result, wicked problems can be addressed by making effective policies, and an effective policy usually covers a wide range of environmental concerns as well. Since many environmental problems are ultimately caused by changes in land cover, they release a wave of unpredicted consequences into urban areas. The impacts and functions of land-use policies must be evaluated to pave the way for improvements. Accordingly, this study seeks an answer to the following questions:

1. How effective are municipal land-use policies in preventing the risk of coastal flooding in waterfront areas of Helsinki and Espoo?
2. Why and to what extent is coastal flooding a wicked problem?

Tracking the effects of land-use policies becomes essential as a guiding tool for managing wicked environmental problems and improving land-use policies. However, despite the major influence of land-use practices on the urban landscape and socio-economic systems, few scholars have attempted to evaluate land-use policies. One reason for this gap is that efforts to evaluate land-use policies have been hampered by either the discontinuous effects of land-use policies in terms of location and time or difficulties in detecting causal mechanisms between either the effects of land-use policy or other factors involved in planning implementation. Furthermore, another impediment to policy evaluation is the likelihood of falling into the prediction path rather than recognizing the effects of land use (Mickwitz, 2003; Scott, 2007; Taylor, Brown, and Larsen, 2007).

One approach for evaluating policy effectiveness would be to use Geographical Information System (GIS) software as an evaluation tool for tracking the effects of policies and then comparing the effects against the intended goals that the policy aimed at achieving in the first place. Additionally, GeoSOS-FLUS software could be used to simulate multiple land-use changes (Wang et al., 2019); as well as enable users to make a relevant comparison between the intended goals of land-use policies and the actual results.

1.2 Goals and Methods

Developing effective land-use policies is beneficial for addressing wicked environmental problems. Although many strategies have been developed for managing the wicked problems reflected in land-use practices (Duckett et al., 2016), few efforts have focused on evaluating the effectiveness of land-use policy in regulating wicked environmental problems. Therefore, this thesis aims to evaluate the effectiveness of Finnish land-use policies in preventing the risk of sea floods in the coastal regions of Helsinki and Espoo. Another aim is to develop a framework for describing the floods caused by rising sea levels as a wicked problem in coastal urban areas. This thesis views policy effectiveness as a quality indicating a correspondence between the intended goals and the actual outcomes of the adopted policy, which can demonstrate whether the policy is working (Scott, 2007). To accomplish this goal, the thesis suggests a framework for tracking the actual effects of land-use policies by simulating land-use covers in a time period expanding from 2000 to 2018. Through the developed framework, land-use scenarios are simulated based on specific values, which reflect the effects of a policy set. This thesis utilizes GIS and GeoSOS-FLUS software as an analytic approach combined with reviewing policy documents and other relevant institutional publications to remove difficulties in detecting causal mechanisms as much as possible.

1.3 Scope of the Thesis

The scope of the thesis will be limited to municipal land-use policies and their contribution in tackling wicked environmental problems. To avoid difficulties in evaluating land-use policies, the thesis is restricted to the geographical area encompassing the Helsinki and Espoo coastal regions. This can help in narrowing down the land-use policies that are going to be evaluated. However, this work does not explore either the validity of land-use policies or the policy-making process. Nevertheless, the framework proposed in this thesis could be used to revise land-use policies by acknowledging the effects of the policy. The contribution of this thesis consists of presenting a clear set of land-use policy effects, which are distinguished from those caused by other factors, and then clarifying the ability of these land-use policies in managing wicked environmental problems.

1.4 Structure of the Thesis

The remainder of this thesis is structured as follows. Chapter 2 is devoted to literature review. Section 2.1 describes wicked problems, their common attributes, and categories as well as the common strategies used for managing wicked problems. Section 2.2 defines sea floods as a wicked environmental problem in coastal regions. In section 2.3, land-use policies in the target areas are reviewed in order to clarify their potential functions in preventing the risk of sea floods. In Chapter 3, research material and methods are presented, and a framework is developed for land-use policy evaluation. Chapter 4 presents and discusses the results from evaluating land-use policy effectiveness in the Helsinki and Espoo coastal areas. Finally, Chapter 5 concludes this thesis by reviewing the outcomes, discussing the limitations, and suggesting directions for future work.

2 Literature review

2.1 Wicked Problems

Before starting the land-use policy evaluation, it is vital to introduce wicked problems. This section describes definitions of wicked problems according to previous research and presents attributes and categories of them. In the last section of this chapter, the most common strategies for tackling wicked problems are presented.

2.1.1 Understanding Wicked Problems

For most of the world's population, urban areas provide all the necessities of modern life. Living in this environment poses many challenges to human lives by altering land use cover, producing urban waste discharges, carbon emissions, and climate change in general (Cajot et al., 2015; Grimm et al., 2008; Lazarus, 2009). Urban areas are dealing with several problems all around the world. Problems in an urban context cannot be easily detected, defined, and solved by conventional methods. A wicked problem is a term referring to the altered nature of simple problems. As the number of city dwellers grows at a constant pace, problems become more interdependent, uncertain, and circular (Lazarus, 2009). Energy planning is an example of a wicked problem. This is because it involves many key stakeholders, often with conflicting values, and involves different levels of scale, from a building to national and international. Meanwhile, concerns about climate change adaptation and greenhouse gas emissions require cities to reduce their reliance on fossil fuels by maximizing renewable energy resources (Cajot et al., 2015). On the other hand, for instance, mathematical problems such as resolving an equation, examining a chemical structure, or other tasks with a clear mission are examples of simple problems (Rittel & Webber, 1973). Yet, wicked problems in different contexts share some characteristics (Perry, 2015; Rittel & Webber, 1973), which are going to be discussed in this chapter.

The term 'wicked problem' was first used by C. West Churchman in 1967, although he gave credit to Horst Rittel (Krueger et al., 2014). Later in 1973, Rittle and Webber refined the attributes of wicked problems. There are other terms referring to similar problems. For instance, Ruhl and Salzman (2010) use the term 'massive problem' instead.

Wickedness is used to describe the nature of these problems as vicious, aggressive, untamable, and malignant which are in contrast with beingness, being tamable, and solvable; in another word, wicked problems are aggressive like a lion, in contrast to the docility of a lamb (Duckett et al., 2016; Rittel & Webber, 1973; Xiang W, 2013). The nature of an urban problem evolves with urban development and growth. As a result, the ubiquity of wicked problems in socio-ecological systems has become widely recognized in the literature, and it is evident in almost every pressing issue, such as global climate change, sustainability, resource management, terrorism, and urbanization, that it influences humanity lives (Xiang W, 2013). This situation draws attention to an insufficient understanding of problems, as the very first step in managing such problems. Since wicked problems emerge mostly in dynamic systems, there is a need for a growing understanding of these evolving problems.

Rittle and Webber made a great impact on scholars by publishing "Dilemmas in the General Theory of Planning" in 1973 because this article provides a holistic but simple explanation of emerging new versions of problems that require further efforts to be managed (Norton, 2012). According to Rittle and Webber (1973), which describe wicked problems in detail for the first time in academia, the preliminary characteristics of wicked problems can be represented in ten features as follows:

(1) ''A wicked problem is ill-defined and has no definitive formulation''. Problem understanding and problem resolution accompany each other. This means that along with exploring puzzling aspects of a wicked problem, the process of solution-finding must be followed, which requires anticipating future consequences and utilizing assets and skills planners might not have access to, thus formulating a wicked problem is almost impossible.

(2) ''Wicked problems have no stopping rule''. The wicked problem is continuous, so groups that are dealing with the problem would never realize that the problem is solved. This situation is logical since the process of understanding the problem and finding solutions to it must happen simultaneously. Of course, one can stop looking for solutions, but this decision is a result of external motivations such as budget or time limitations.

(3) "Solutions for wicked problems are not true/false but good/bad ". Several parties and stakeholders are involved in tackling wicked problems, yet none of them has the power to decide what is correct. They have the power of judging the solutions though. Comments on the level of good or bad solutions come from these judgments.

(4) ''Solutions to wicked problems have no immediate or ultimate test''. Solutions are being detected and actions are being taken meanwhile the problem is being defined and understood. During this process, every intervention causes a series of effects that might or might not mislead the primary process toward undesirable repercussions. Such consequences are sometimes profoundly damaging, thus dropping the process of managing the problem seems more reasonable rather than making any further attempts to solve it. Therefore, solutions to wicked problems cannot be tested in any phase of problem recognition or problem-solving processes.

(5) ’’Every solution is a single operation”. Because Trial and error is not an option in tackling wicked problems. When it comes to trying out solutions, it is crucial to understand the massive waves of irreversible consequences that last long. In most situations where a solution is applied to a wicked problem, the undesired consequences pose more wickedness to the original problem.
(6) Wicked problems do not have countable potential solutions and the criteria for these solutions are poorly defined. Deciding on a solution for tackling wicked problems is so complicated that one might think ‘A’ should, and at the same time, it should not happen. Exploring how well a wicked problem can be managed is highly dependent on the matter of judgments in magnifying a selected set of solutions.
(7) ’’Every wicked problem is essentially unique”. Although wicked problems have some traits in common, every wicked problem is distinguishable from one another. As a result, it is not possible to propose a set of solutions to be implied in a group of wicked problems.
(8) ’’Every wicked problem can be a symptom of another problem”. Considerable gaps between definitions of problems appear mostly from two perspectives. First from the perspective that a problem actually is, and from the point that the problem ought to be. Although these explanations are seeking causes to tackle the problem by removing the cause, any manipulation leads to another problem of which the premier problem is a symptom. In another word, every problem can be described as a symptom of a higher-level or broader problem.
(9) ’’The choice of explanation determines the nature of the problem's resolution”. Every problem can be described from various perspectives, and so many solutions can be proposed that no one can determine their correctness.
(10) ’’The planner has no right to be wrong”. Since the consequences of making any attempt to tackle a wicked problem might be devasting, the solution-finder has full responsibility for a proposed solution.

Backbone knowledge used by Rittle and Webber (1973), to explain wicked problems includes the challenges and dilemmas scientists introduce in other fields, including public policy. Even so, developing an informational and easy-to-understand framework for such a wicked concept is not easy. Their study, however, lacks the presentation of ways for improving the management of wicked problems. Relatively, Norton (2012) suggests we let go of our optimistic view of science and its applications in favor of seeking a productive direction in policy analysis. In addition, some wicked problems, climate change, for example, are difficult to be perceived optimistically. Climate change is subject to the “unavailability heuristic” meaning that climate change is an unimaginable problem (Lazarus, 2009). Because of cognitive limitations in human comprehension and other factors of the wicked problem itself, it is nearly impossible to imagine the effects and dynamics of this wicked problem. The causal sources and effects of climate change are discontinuous throughout time and space, and every action towards climate change in a particular location can affect other locations at any time with different intensities (Lazarus, 2009). Ideally, there is a need for a form of analysis that directs managers from recognizing messes to extracting problems; however, Rittel and Webber's argument is deemed depressing by some theorists because 'Dilemmas' recalls the idea of not responding to any form of analysis (Norton, 2012).

The characteristics of wicked problems developed by Rittle and Webber (1973), have been modified by other researchers. They believe some of the characteristics overlap with each other and could be merged for the sake of simplicity. Conklin (2006) describes the wickedness of problems using the three indicators mentioned in table 1 and the six characteristics of wicked problems which are summarized in table 2. Furthermore, Norton (2012) redefined the attributes of wicked problems by grouping the ten aspects claimed by Rittle and Webber into four categories representing several aspects of wicked problems. These categories include:

- Problems of Problem Formulation (1, 2, 3, and 9)
- Noncomputability of solutions (2, 4, 6, and 9)
- Non-repeatability (5,7, and 10)
- Temporal open-endedness (2, 4, and 8).

By recognizing these components of wickedness, we develop conceptual guidance that eventually translates into better communication and cooperation for resolving the problem (Norton, 2012). The wickedness of a problem could be represented by three main features, complexity, uncertainty, and divergence, which indicate the problem's level of wickedness (Head *et al.*, 2008). With complexity being the most-cited feature of modern problems, wicked problems tend to remain ill-defined because of unrevealed aspects like uncertainty and divergence. Complexity considers both internal and external mechanisms. When dealing with complex issues, there is a higher level of uncertainty and ambiguity due to knowledge gaps, diverse stakeholder interests, and numerous stakeholder perspectives (B. W. Head, 2019). However, a problem that has only this feature, or one of the three features defined by Head, 2008, would be responsive to policies. In contrast, a wicked problem is significantly less responsive to policies than a simple problem (Ruhl & Salzman, 2010).

Table 1: Indicators of wickedness.

Complexity- of elements, subsystems, and interdependencies	LOW	MODERATE	HIGH
Uncertainty- in relation to risks, consequences of actions, and changing patterns	LOW	MODERATE	HIGH
Diversity- in viewpoint, values, and strategic intentions	LOW	MODERATE	HIGH
Wickedness Degree	→		

According to Table 1, wicked problems are the ones that score high across all three dimensions. Nevertheless, this model does not provide any insight into how wicked problems respond to mitigations, nor does it explain the continuity of the problem and the discontinuity of its effects.

Table 2: Summarized attributes of wicked problems.

(Rittel & Webber, 1973)	(Conklin, 2006)	(Cajot et al., 2015)	(Duckett et al., 2016)	(Alford & Head, 2017)
No definitive formulation	The problem is not understandable before developing a solution	Lack of a unique problem statement	Indefinable	Structural complexity
No stopping rule	No stopping rule	Conflicting objectives	Ambiguously bounded	Knowability
No true/false but good/bad solutions	No true/false but good/bad solutions	Conflicting values	Temporally exacting	Knowledge fragmentation
No immediate or ultimate test of solutions	Every wicked problem is essentially unique	Dynamic contexts	Repercussive	Knowledge-framing (issues)
Every solution is a single operation	Every solution is a single operation	Scientific complexity/uncertainty	Doubly hermeneutic	Interest differentiation

Poorly defined criteria and solutions	There are no given alternative solutions	Political complexity/uncertainty	Morally consequential	Power distribution (issues)
Every wicked problem is essentially unique		Administrative complexity/uncertainty		
Every wicked problem can be a symptom of another problem		Multiple tactics to address the problem		
The choice of explanation determines the nature of the problem's resolution		Multiple stakeholders with the power to assert their values		
No right to be wrong				

This thesis considers massive problems as a form of wicked problems. Massive problems are recognized with three main attributes defined by Ruhl and Salzman (2010) including causal sources, causal mechanisms, and cumulative effects. Finding a solution seems impossible if the three aspects of wickedness, uncertainty, divergence, and complexity are not identified. However, as soon as a source is identified such as knowledge gaps about climate change, solutions will immediately emerge (B. Head et al., 2008). Causal sources can be grouped in different ways to bold incentives and help with recognizing hidden patterns contributing to the complexity and divergence of sources. Several sources and relationships contribute to the wickedness of a problem. A wicked problem may or may not have hidden cause-and-effect mechanisms. Causal mechanisms, as defined by Ruhl and Salzman (2010), are drawing a line between causes and effects which is not a simple task when trying to formulate a wicked problem. This difficulty is due to time lags that are consistent behind such problems as climate change. Climate change is a delayed harm problem (Biber, 2009; Perry, 2015). These problems often have irreversible, nonlinear, complex, and uncertain cumulative effects, and their effects emerge over a long period of time (Ruhl & Salzman, 2010). Environmental problems have a delayed harm attribute, and this attribute is related to the discontinuity aspect of wicked problems defined by Rittle and Webber (Biber, 2009). The most relevant aspects of causal mechanisms for testing policy effectiveness include scale, timing, and relationships between causal sources (Ruhl & Salzman, 2010). Table 3 summerizes the ideal conditions for causal sources, causal mechanisms, and cumulative effects to ensure high policy effectiveness.

Table 3: The ideal conditions of causal sources, causal mechanisms, and cumulative effects for high policy effectiveness.

Source attributes	Causal attributes	Effect attributes
Low number of sources	Limited scale (local and regional)	High level of detectability
Low diversity	High temporal limitation	High level of measurability
Clustered distribution	Direct and proportional relationship	Proportional distribution over time
Large size on average (relative to effects)		Proportional distribution over space
Alignment of incentives		High level of reversibility

In contrast to the conditions mentioned above, wicked problems might respond to the policies negatively when causal sources are small on average, large in number, parsley distributed, involved with mixed and conflicting incentives; and causal mechanisms are multiscalar, protracted, nonlinear; and cumulative effects are difficult to detect or measure, disproportional, nonlinear, and irreversible (Ruhl & Salzman, 2010). For a policy to be effective, it must take into account many factors, among them the specific characteristics of the problem that needs to be addressed. The effectiveness of a policy is defined in this thesis as a measure of how well it achieves its intended objectives.

2.1.2 Categories of Wicked Problems

Wicked problems can be classified for the most part based on their shared characteristics. However, classifying problems as complex as wicked problems is difficult for at least one reason. This is the otherness of wicked problems regardless of shared causal sources or other similar traces. In this section, two examples of categorizing wicked problems will be presented. Alford and Head (2017) have illustrated wicked problem typologies using a matrix (see figure 1) containing two main features of wicked problems: Complexity and Difficulty.

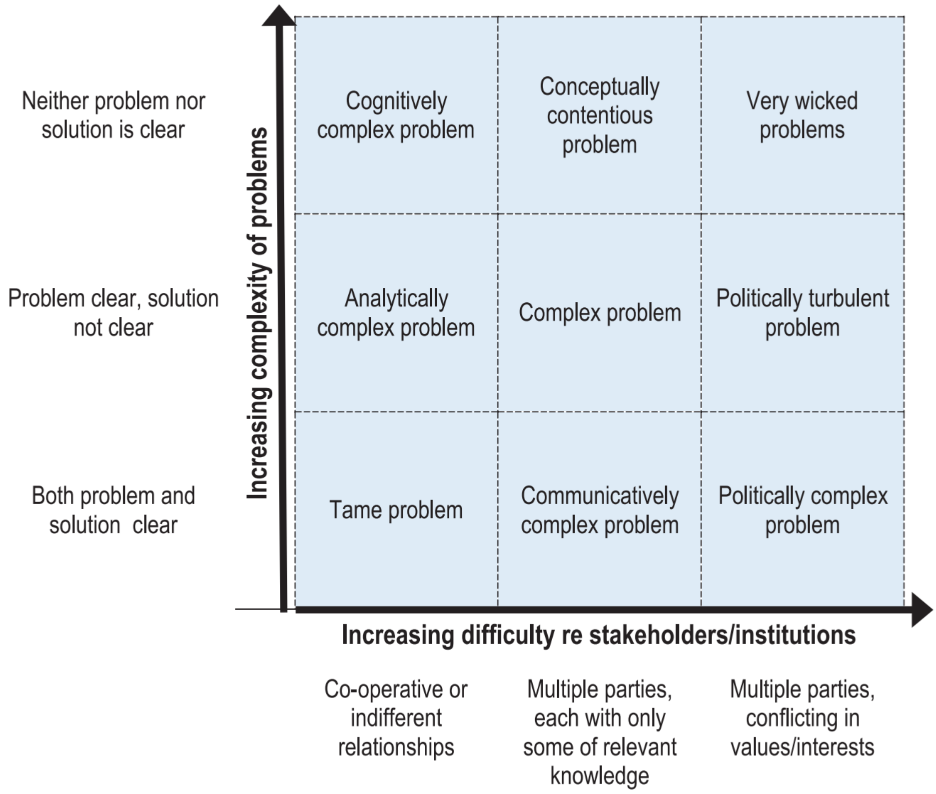

Figure 1: Typology of wicked problems (Alford & Head, 2017).

According to Ruhl and Salzman (2010), massive problems can be classified into five groups based on the attributes of the causal sources and effects of the problem. In table 4, examples of each type of problem help us understand their scope and complexity.

Table 4: Categories of massive problems.

Problem category	**Description**	**Example**
Simple aggregation problem	Different aspects of a problem are adding up in all dimensions	Wetland loss
Spaghetti bowl problem	Different sources respond to different and potentially offsetting incentives	Ocean governance
Feedback problem	There is high number of interactions between causal sources, causal mechanisms, or effects of the problem.	Biofuels
Discontinuity problem	The causes and effects of the problem are disconnected throughout time and space	Gulf hypoxia
Policy jungle problem	All the above-mentioned attributes add up together which create a policy jungle problem.	Climate change

As we move down the 'problem type' column of categories in table 4, problems become less responsive to a policy. Furthermore, for a simple aggregation problem, the relations between cause and effect are easy to determine. Therefore, solution finding is more feasible than for spaghetti bowl problems in which causal sources are large in number, have conflicting incentives, and differ in the direction of responses. Consequently, the next problem type would be more difficult to deal with. Feedback problem is a result of different strands in the bowl being dependent on each other. The fact that there are multiple causal sources at dispersed locations or time lags between cause and effect makes a problem discontinuous. This requires years, if not decades, for the effects to reveal themselves. Therefore, drawing a line between causes and effects is quite difficult. Hypoxia is an example of a wicked problem in marine ecosystems around the world. Some effects of hypoxia include fish kills and shellfish bed losses that occur in discontinuous time cycles. By combining all the characteristics of the above-mentioned problems, we arrive at the policy jungle. For example, feedback between two different strands contributing to a particular cumulative effect can be nonlinear, spatially and temporally discontinuous.

2.1.3 Common Strategies for Dealing with Wicked Problems

Since 1973, planners and engineers have been using conventional methods to deal with benign concerns so far (Rittel & Webber, 1973). Tamable or benign problems are definable and solutions for them are recognizable, unlike wicked problems that are infinite, ill-defined, knitted, and based on political judgments (B. Head et al., 2008). There has been an answer to these definable problems waiting to be found, while complex ill-defined problems have not been solved or well-defined but, at the best, addressed repeatedly by planners and politicians (Rittel & Webber, 1973).

Many scholars have been examining various methods to improve performance in wicked problems. Following Rittel and Webber's work in 1973, literature exploring strategies for tackling wicked problems became more prevalent and attracted special attention. In this section, some of the coping strategies recommended by scholars are discussed for taming wicked problems including wicked environmental problems. Coping with wicked problems requires an adaptive, multidisciplinary, and participatory approach in contrast to conventional methods searching for definite solutions and following a linear strategy (Duckett et al., 2016; Xiang W, 2013). Furthermore, it is impossible to design an algorithm to generate solutions to a complex problem, but it is better to use a contextual approach, because it takes into account aspects of the context of the problem that might affect problem formulation (Norton, 2012). A crude solution that combines different viewpoints and solutions in a flexible and creative manner is generally thought to be required to solve wicked problems (Artmann, 2015).

Literature has treated wicked problems differently over the past decades due to this evolutionary path that wicked problems have been through. The suggested mitigations advanced from 'taming', 'handling', and 'tackling', to 'working with', and 'living with' (Norton, 2012), and 'embracing' (Raisio, 2010), showing an increasing acceptance of wicked problems as an integrated part of socio-economic systems (Xiang W, 2013).

There are no technical solutions to wicked problems, but rather institutional and political approaches (Perry, 2015). Therefore, addressing wicked problems requires post-normal science approaches instead of normal science, since the latter science fails in dealing with complexity in a policy context (Batie, 2008). It is difficult to notice the extent and roots of the problem and identify insights and solutions to it in a unified framework of government or global organizations (Lazarus, 2009). It is possible, however, to minimize wicked conditions using strategies that are mostly applicable to policy contents. Addressing wicked problems using normal science approaches is doomed to fail because science produces novel technologies or ways of thinking, but science-based mitigation in policies and ways of management leads to effective actions (Batie, 2008). Even though there are multiple solutions to a wicked problem, none of the solutions are computable, meaning that there is no system that could accurately represent complex social problems in such a way that the best solution could be computed (Norton, 2012).

The wicked problem was often treated as a simple aggregation problem, where connectivity was considered stable and size was increasing (Ruhl & Salzman, 2010). It is cumulative effects that prevent wicked problems from arising as simple aggregation problems. These effects usually accumulate over time and space within complex adaptive systems. Moreover, adaptive systems that cause such effects have complex behavior, so mitigating the system would result in complete chaos. As the elements become more interdependent, the connections between them become more important (Ruhl & Salzman, 2010). There are several approaches offered by scholars for dealing with wicked problems. The strategies include envisioning and scenario-making, opportunities-driven mitigation through collaboration among stakeholders, and threshold delamination, which defines the limits of the resilience of a system that can never be crossed (Duckett et al., 2016). There are two main instruments to help tame wicked problems: methodological approaches for dealing with uncertainties such as scenario planning and non-deterministic participatory approaches (Duckett et al., 2016), and instruments and tools for dividing the problem into sub-problems or focusing on the goals (Duckett et al., 2016; Lazarus, 2009; Shindler, n.d.).

In the past decades, problem solvers have learned to consider the consequences of their actions when finding a solution to a wicked problem. This is a pre-decision assessment strategy in which the agency must make an estimation of future cumulative effects before making relevant decisions and utilize this estimation in policy development (Ruhl & Salzman, 2010). While considering future effects is critical, predicting their consequences is almost impossible. Since massive problems are subject to a great deal of uncertainty, firm predictions are unlikely to succeed. Moreover, consequences can appear in every phase of a problem-solving process, which is why the process should always be monitored. A general strategy that enables regular monitoring of the process is an adaptive management strategy. In order to avoid looking back at the process to fix problems, this strategy collects massive amounts of information and analyzes the data before making any decisions, which puts an enormous amount of effort into data collection, analysis, monitoring progress, and adjusting new approaches (Rittel & Webber, 1973). This strategy also needs more active learning, meaning that agencies should learn as they address an issue. In addition, the adverse set of consequences contains moral consequences that make it impossible for the planner to be wrong (Rittel & Webber, 1973). In order to deal with this aspect, some strategies are suggested as having moral consequences. For instance, Duckett (2016) cites strategies such as public participation, and increasing ownership through transparency, and collaboration.

Wicked problems are connected to internal and external components of other problems, and they usually represent symptoms of a greater problem, if not multiple problems. Therefore, drawing lines between the scopes of a problem is almost impossible and they are often recognized as ambiguously bounded. Multidisciplinary approaches can facilitate dialogue between public and private decision-makers to reduce ambiguity (Duckett et al., 2016; Xiang W, 2013). An example of a multidisciplinary and integrated approach is sustainability science, as a form of post-normal science, utilized in the developments of societies and the built environment which has established a positive example of dealing with wicked problems during past decades (Batie, 2008). Ideally, an agency should adopt multiple perspectives to engage effectively with wicked problems, adapt iterative approaches incorporating implementation and evaluation practices, encourage the participation of local, national, and international stakeholders, develop conceptual models to facilitate understanding of the problem, provide a series of alternative solutions rather than advancing just one, and take advantage of adaptive management practices (Perry, 2015). Other strategies such as systems thinking and boundary spanning also emerge when looking into academic literature related to strategies for coping with wicked problems (Duckett et al., 2016). Response-efficiency-assessment (REA) is another suitable approach for managing wicked problems which are based on system analysis and developed by a multi-attribute decision method in an analytical hierarchy process (Artmann, 2015).

Wicked problems require creative solutions, clumsy solutions are a form of solutions that stand in contrast to elegance in policy making (Krueger et al., 2014). REA tames wicked problem by generating a set of clumsy solutions which considers the level of efficiency in problem responses by involving different actors and influential spatial elements (Artmann, 2015). One of the practical aspects of the systems thinking approach which favors individuals dealing with wicked problems is considering different viewpoints, because the definition of a wicked problem indicates the way one will deal with them, and every wicked problem can be defined in more than one way (Rittel & Webber, 1973; Ruhl & Salzman, 2010). In addition, wicked problems are poorly defined. By defining wicked problems clearly, policymakers, planners, and urban administrative bodies can effectively manage problems and ensure urban resilience. To overcome difficulties in wicked problem definitions, some scholars also suggest using philosophical inputs, epistemic assumptions, and thinking beyond rationality; these strategies are labeled as theoretical innovation in Figure 2 (Berkes, 2012; Coyne, 2005; Duckett et al., 2016).

Massive problems can be managed by more than one institution only (Ruhl & Salzman, 2010). Therefore, participation among stakeholders, especially between those with conflicting opinions, is a crucial factor in indicating the level of success in addressing a wicked problem (Batie, 2008; Conklin, 2006; Duckett et al., 2016). Defining a wicked problem seems possible only after a solution starts forming (Duckett et al., 2016; Rittel & Webber, 1973; Ruhl & Salzman, 2010; Xiang, 2013). This aspect of the problem is usually managed by utilizing a holistic approach that tries to understand the systemic structure of wicked problems by considering connections between elements, and an atomistic approach which focuses on one solution and its development to a certain scale to deal with double hermeneutic characteristics (Duckett et al., 2016). A double hermeneutic characteristic of wicked problems describes an enduring interdependence between social context and proposed solutions that is constantly evolving. In such situations, some studies recommend repeating participatory processes to bring the dialogue and reframing of the problem to a constant pace (Duckett et al., 2016).

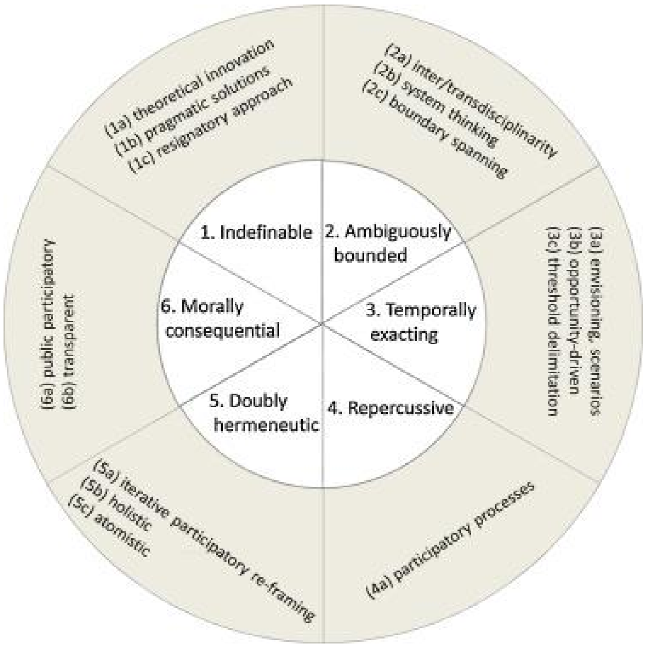

Figure 2: The wicked wheel of strategies (Duckett et al., 2016).

It has already been and will continue to be, a time when people have become aware of wicked problems and accepted their intractability, thus giving up the unrealistic hope that science will be able to tame the untamable, in order to shift their focus to the public process of solving wicked problems, as well as finding innovative solutions through action-based research (Xiang W, 2013).

2.2 Coastal Floods

In this section, climate change is explained as part of the broader picture of wicked environmental problems. After mentioning characteristics of climate change that shape a conundrum, diverse consequences of climate change are mentioned. These consequences, however, are only those that are directly or indirectly related to coastal flooding events. Figure 3 illustrates causal sources, causal mechanisms, and some effects of the coastal flood on societies. At the end of the section, the effects of coastal flood events in Finland are acknowledged, especially in Helsinki and Espoo municipalities.

2.2.1 Climate Change as a Super Wicked Problem

Several pieces of literature identify climate change as a super complex, interdependent, and uncertain problem posing multiple conflicts to society (Hamilton et al., 2015; B. Head et al., 2008; Hudson, 2019; Lazarus, 2009; Perry, 2015); however, very few refer to climate change as a 'super wicked problem' (Hudson, 2019). As a result of climate change, scientists and politicians have a dilemma, the former in developing scientific knowledge and the latter in managing the complexity and resolving conflicting incentives. Climate change is a shared responsibility, however. Human activities across the world contribute to global warming and climate change in general, which have an infinitely detrimental impact on our environment (Biber, 2009; B. Head et al., 2008; Lazarus, 2009; Perry, 2015; Rudberg, 2018). Acting against climate change requires responding in time, as the longer it takes, the more difficult it is to achieve the desired results (Lazarus, 2009).

Mapping the features of climate change would require a great deal of effort and time, which are not within the scope of this thesis. Nevertheless, it is beneficial to examine characteristics of climate change that correlate with wicked problems. These characteristics include having temporal dimensions, being a delayed harm problem, and having discontinuous effects.

Often, it is impossible to draw a line between the causes and effects of climate change due to its temporal dimension. Thus, the importance of time becomes increasingly evident. Climate change also manifests itself as a problem that is caused by those with the least incentive to address it. According to Lazarus (2009), emission reduction policies taken by US governments illustrate this aspect in that less is done to reduce the economic activities of polluting industries. However, others are expected to do so. Generally, wealthy nations fall into this category. They have the resources and budget to initiate actions, but fewer incentives.

Biber (2009) and Perry (2015), named climate change a delayed harm problem. "Delayed harm" is one of the key characteristics of environmental problems (Biber, 2009), which correlates with the discontinuity aspect of wicked problems as defined by Rittle and Webber. For example, “thermal inertia” in the oceans means that there is a significant time delay between atmospheric warming and increasing the temperature of the ocean, as water is a liquid of high heat capacity. This, in turn, leads to a slow response to rising sea levels, because the expansion of oceans and melting glacial ice need a long time and is not a uniform phenomenon (Biber, 2009; Poutanen & Steffen, 2014a).

Adding more attributes of wicked problems to a delayed harm problem makes the situation even more complicated. For instance, when symptoms of a problem disappear for a period of time and start again on an irregular basis, or there are cumulative effects piling up together (Biber, 2009). As climate change is a global challenge, it requires worldwide collaboration to be tackled. However, the symptoms are different all over the world: raising the temperature of the planet or changing the patterns of our climate will affect different regions differently (Lazarus, 2009), causing one region to suffer from a flood while another experiences droughts and other severe climate changes.

As the nature of the problem changes, a solution to climate change must be incomplete and grow as our understanding of the problem improves. Even though many attempts have succeeded in improving climate change mitigation, no one set of actions is 100% correct or effective, which is why there is no ultimate solution to the issue (B. Head et al., 2008; Lazarus, 2009). Every attempt to combat climate change often contains hidden disappointments. This makes it difficult to form solutions or try them out because trying out a solution is an expensive action, thus resulting in an essential need for evaluating the effects before taking any action toward climate change (Perry, 2015).

This list of climate change characteristics corresponding to wicked problems continues with several other examples, all of which are symptoms of this super wicked problem. In the next section, the relations between climate change and sea level rise, as its sub-problem, are defined in more detail.

2.2.2 Waves of Consequences

Sea floods are caused by several environmental transformations among which climate change is the biggest driver. Elements of coastal flooding problems are very interdependent and the relations between them are often non-linear, and discontinuous throughout time and space. This section redefines coastal flooding by going through climate change consequences from a wide perspective to its smaller impacts.

Despite the wickedness of climate change itself, every action toward tackling climate change alters the conditions of the problem significantly (Lazarus, 2009); therefore, the chain of consequences presented here contains both naturally caused effects and changes that are a result of human mitigations. Similarly, sea level changes are happening through both climatic and non-climatic processes (Rutledge, 2018).

Climate change in the bigger picture has severe consequences all over the globe. According to(Diez-Sierra et al., 2022), the global average temperature could rise at least 1.1°C or up to a maximum of 6.4°C by 2100. Nevertheless, it is unlikely that global warming will reach its most pessimistic scenario (Diez-Sierra et al., 2022; Hausfather & Peters, 2020). Yet, the major impact of climate change on most populated places is the sea-level rise and other damages caused by sea floods (Crane & Landis, 2010).

Considering greenhouse gas emissions as an enormous causal source of climate change, environmental policies were successfully formulated to reduce greenhouse gas emissions in the past decades; however, the effectiveness rate shows that aims were not fully achieved (Rudberg, 2018). This shows that the impacts of a wicked problem such as global warming are not reversible when high levels of warming are reached. They are also not compensable in a short period of time.

Climate change is associated with rising temperatures, which causes ocean expansion and the melting of glaciers and ice sheets (Rutledge, 2018). Besides these causal sources, changes in salinity, ocean currents, and wind systems also contribute to sea level changes regionally (Biber, 2009; Nicholls & Cazenave, 2010; Rizzardi, 2015; Rutledge, 2018). Sea levels in the Baltic Sea are relatively higher at times when westerly winds prevail because these strong wind patterns push more water into the almost enclosed basin of the Baltic Sea (Jarva et al., 2014). In some areas of Finland and Sweden, land uplift may prevent the level of the sea from rising despite most environmental processes contributing to sea level rise. Land uplift is a common process in the shoreline areas of the Gulf of Bothnia in Finland and Sweden which causes about 700 hectares of land to rise from the sea every year (Poutanen & Steffen, 2014b). With the accelerating rate of the sea level rising, land uplift will not be able to compensate for sea level rise in the future (Jarva et al., 2014).

The mean sea level is the baseline around which short-term sea level variations occur. The rise in mean sea level, caused by the above-mentioned sources, raises the baseline and therefore contributes to the increase in the height of coastal floods. Coastal floods are caused by different factors contributing to short-term sea level extremes (storm surges, seiches, meteotsunamis) that are driven by weather phenomena, mainly wind and air pressure. A significant coastal flood requires a coincidental impact of several such factors. Meteotsunamis or meteorological tsunamis are long waves occurring in shallow areas of waterbodies that can be very high and can last a maximum of a few hours (Pellikka et al., 2020).

2.2.3 Sea-Level Rise and Coastal Flooding

Sea-level rise has affected different areas around the world. However, it will affect all large regions except the polar regions (Adams-Schoen, 2016; Crane & Landis, 2010). As mentioned before, coastal flooding requires local knowledge to be properly understood. In recent decades local governments have sought solutions to overcome coastal floods such as constructing dikes, sea walls, and sluice gates. These solutions were effective to some extent, yet prone to new challenges. For instance, the presence of high dikes, flooding, and sediment exclusion caused productivity problems in two rice-producing deltas in Vietnam (Yuen et al., 2021). These kinds of mitigations can also alter the nature of a wicked problem and make problem definition more complicated than it already is.

The consequences of climate change extend to sea level rise and increasing coastal flood risks, but this chain does not have a stopping rule. Sea levels can rise between 0,2 to 0,6 meters by 2100 and the patterns of sea level oscillations show an accelerating behavior in the 21st century (Crane & Landis, 2010; Diez-Sierra et al., 2022; Yunita, 2010). Sea level rise may induce saltwater flooding and aggravate salinity intrusion besides posing other risks to the coastal regions (Yuen et al., 2021). Coastal regions have always been a population magnet because of their logistical competencies, their supply of subsistence resources, aesthetic reasons, and their mild climate (Moser et al., 2016). The concentration of urban population in coastal areas increases the exposure to the sea and relatively higher sea-flood risks. ‘Flood risk’ means the combination of the probability of a flood event and of the potential adverse consequences for human health, the environment, cultural heritage, and economic activity associated with a flood event (THE EUROPEAN PARLIAMENT, 2007). However, rising sea levels are not just a concern for the risks of flood and other natural hazards but also for the influences on socio-economic systems (Yunita, 2010). For example, land values might be affected by saltwater intrusion, drainage problems, and erosion of shorelines; however, real estate developers and land use planners expect waterfront property values to increase (Moser et al., 2016; Rizzardi, 2015). The consequences of a coastal flood must be considered in multiple ways. In Finland, for instance, the cities of Porvoo and Loviisa have experienced sea floods several times. The sea wall at Loviisa failed against rising sea water in 1986, resulting in severe damage to nearby buildings (Virkki et al., 2006).

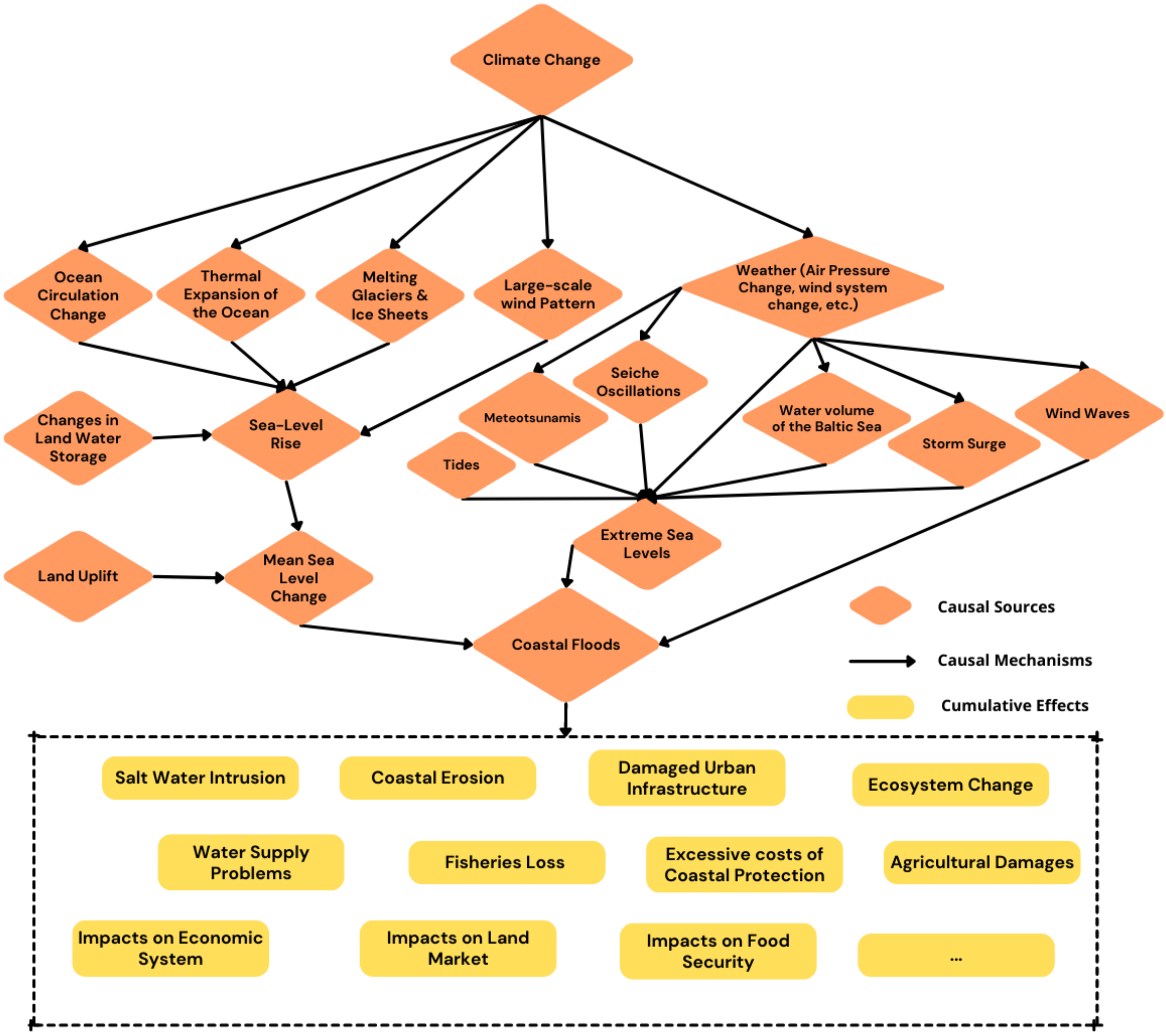

Figure 3: Causal sources, causal mechanisms, and cumulative effects illustrations of the Coastal flooding.

Coastal floods have multiple driving forces. These forces are depicted in figure 3. As we move further down the illustration, the main drivers of coastal flooding are distinguished more sharply. Moreover, mean sea level variations are distinguished from extreme sea levels in this figure because their driving forces are dissimilar in terms of time scales. Extreme sea levels are a result of short-term changes such as extreme weather events. Extreme weather events are the major driver of severe flooding events. Extreme sea-level variation is caused by wind-induced internal redistribution of water within basins, air pressure variations, storm surges, meteotsunamis, and seiches in the various sub-basins of the sea (Pellikka, 2020).

On the other side of the figure, long-term driving forces of sea level rise are displayed. Because sea-level rise is also driven by changes in land water storage, melting glaciers, thermal expansion of the ocean, and other forces included in the figure. The Baltic Sea has quite unique conditions due to being almost an enclosed sea (Jarva et al., 2014). Therefore, large-scale wind patterns contribute to the mean sea level changes in the Baltic Sea. However, these wind patterns have a small contribution to this variation.

Mean sea level change depends on other long-term drivers such as melting glaciers, thermal expansion of the ocean, and changing circulation of the ocean. The vertical land motion also contributes to mean sea level change on the coast, either counteracting sea level rise (if the land is rising) or intensifying it (if the land is sinking). In Fennoscandia land uplift started after the melting of a large ice sheet covering the area about 18 000 years ago, causing a rebound of the crust (Poutanen & Steffen, 2014b). With climate change and global warming, land uplift may not be able to compensate for the accelerated sea level rise of the future (Jarva et al., 2014).

Strong wind waves also contribute to sea floods. Interconnections between causal sources, high levels of uncertainty, a high number of causal sources, multiscalar and nonlinear causal mechanisms, discontinuous effects both locally and throughout time, having disproportional effects on several socio-economic systems make sea floods a wicked problem.

2.2.4 The Wicked Problem of Coastal Flooding

Sea-level rise is an unwanted child of the greater wicked problem of climate change. Therefore, some attributes of wicked problems are easily definable when analyzing coastal floods. Defining a problem indicates the way it will be treated, but climate change has no agreed-upon definition. A problem definition contains detected causal sources, causal mechanisms, and cumulative effects. These attributes can indicate our approach to managing a wicked problem. Relying on definitions of different attributes from different perspectives seems beneficial rather than leaving the problem ill-defined. Because the choice of explanation determines the nature of the problem's resolution (Rittel & Webber, 1973). This section examines sea floods from a wicked problem perspective.

Looking at the wicked problem characteristics listed in Table 5, there are several shared characteristics between sea floods and wicked problems. Firstly, coastal flooding is difficult to define, as multiple causal sources are involved. These sources can develop multiscalar and complex relationships with each other and the problem itself. Next, the problem of sea floods is ambiguously bounded with high levels of uncertainty and complexity. One of the deep uncertainties of sea level rise is related to the melting glaciers. We can expect the West Antarctic ice sheet (WAIS) to be much less stable in the decades to come, thus allowing it to disintegrate rapidly and demonstrating its deeply uncertain nature (Bakker et al., 2017). Another reason behind the great complexity of this problem stems from climate change which covers scientific, political, and administrative ranges of complexity and uncertainties.

The third attribute to be mentioned here is related to solutions to sea floods. Solutions to coastal floods are included in the spectrum of good or bad solutions. Additionally, every solution is a one-shot operation and has no chance to be tested. Mitigating coastal floods will change the dynamics of elements causing the problem, therefore continuing management requires extra effort to recognize new patterns. Environmental wicked problems like sea-level rise usually happen in a result of actions or processes that took place years or even decades ago. Thus, applying a solution to every aspect of the problem or trying to reverse the unwanted effects of the problem cannot be effective in a short amount of time.

Next, the importance of local knowledge in managing sea flood risks (Adams-Schoen, 2016; Crane & Landis, 2010); recalls another wicked problem characteristic that Rittle and Webber (1973), mention as being ''essentially unique". Accordingly, sea floods are a symptom of a greater wicked problem, such as ocean expansion, global warming, or climate change. Simultaneously, coastal flooding can be responsible for other symptoms such as saltwater intrusion.

Lastly, wicked problems are morally consequential. Therefore, whoever is responsible for mitigating a wicked problem is fully responsible for the outcome. This is one of the reasons that wicked problems usually get ignored by planners, politicians, and governments. For instance, developing residential real estate on a floodplain burdens planners with heavy responsibilities. Houston is a city in Texas in which many residential areas are built on floodplains. 2017 was the third year in a row that Houston had suffered a "500-year flood"—floods in 2015 and 2016 also damaged thousands of homes (Hudson, 2019).

Table 5 shows the conditions of causal sources, causal mechanisms, and cumulative effects of sea floods. By considering attributes of sea floods related to sources of the problem and mechanisms, its responsiveness to policies will be easier to anticipate.

Table 5: The conditions of causal sources, causal mechanisms, and cumulative effects of sea floods.

Source attributes	**Causal attributes**	**Effect attributes**
A high number of sources	Multiscalar (local and global)	Low level of detectability
High diversity	Protracted or uncertain time limitation	Unsatisfying levels of measurability
Scattered spatial distribution	Nonlinear and complex	

Large size on average (relative to effects)		Spatial and temporal distribution of the effects are disproportional and patchy
		Low levels of reversibility

The conditions of the problem show that sea floods are less responsive to solutions. We must accept that reversing the impacts of climate change or preventing natural hazards, like a flood, from happening is no longer possible, but adaptation is. The adaptation approach promotes strategies against wicked problems that try to ‘’live with the problem” instead of ‘‘ taming it ‘‘ and ‘‘ tackling it”. However, the scope of this thesis does not include the climate adaptation literature. This thesis reveals the importance of utilizing land-use policies to manage environmental wicked problems, particularly coastal flood risks.

2.2.5 Sea Floods in Helsinki and Espoo

Helsinki and Espoo are in the southern part of Finland with several densely populated districts. Since 2000, sea flood events have been more frequent in Finland as well as in other European countries. Sea level short-term fluctuations vary from 1.7 m in Degerby in the Archipelago Sea (Saaristomeri) up to three meters in Hamina (Jarva et al., 2014). Consequently, several studies have been carried out in Helsinki and Espoo regarding the sea flood risk assessment to better understand and plan for future developments and to improve environmental protection. As a result of these efforts, all Finnish ministries started to plan actions toward implementing national adaptation strategies.

The Ministry of Agriculture and Forestry has prepared a report on extensive flooding in Finland (Suurtulvatyöryhmän loppuraportti 2003). This report recommends seven actions among which the most central ones are protecting housing from flooding by suitable land allocation for new housing, only in areas that have a once-in-a-hundred-year flood probability and applying more strict regulations for services such as hospitals, plants with harmful substances, etc (Virkki et al., 2006). In Finland, 95% of the building codes set a minimum distance for residential or holiday buildings from the shoreline, the distance varies from 15 to 100 meters, 89% of the municipalities have also defined a lowest construction height for buildings near the shoreline, the most common height being 1.5 meters above the mean sea level (Virkki et al., 2006); however, considering a minimum of 3 meters above sea level was recommended for new constructions in both cities (Uudenmaanliitto, 2008). The lowest recommended building heights were updated once again in 2014, the minimum building elevation was required to be 280 cm in the N2000 system (Johansson, 2014).

At a national level, the EU Floods Directive has had a great impact on the effort put into evaluating flood risks in coastal areas. The highest authority in flood risk management is the Ministry of Agriculture and Forestry and the subordinated Regional Environmental Centres. Also, the municipal rescue authorities have an important role in flood risk management (Virkki et al., 2006). Climate adaptation policies in Helsinki are formulated by Helsinki's adaptation group (2016-2018), these policies illustrate a climate-proof Helsinki in 2050 (City of Helsinki, 2019). The "National Strategy for Adaptation to Climate Change" was adopted by the Finnish Parliament in November 2014 (Ministry of Agriculture and Forestry, 2014). But, in 2006, there was no regional cooperation concerning sea flood prevention in Finland, therefore the cooperation between city organizations only took place at the local level, especially in cases that experienced sea flooding previously (Virkki et al., 2006).

After winter storm Erwin/Gudrun in January 2005, the importance of being well prepared for flood events became completely obvious to everyone. Due to this event, decision-makers, researchers, and planners improved their knowledge, leading to better decisions. A specific group was run by the town major in September 2005 whose task was to report and map areas at risk of flooding (Schmidt-Thomé & Schmidt-Thomé, n.d.). In 2007, Helsinki carried out a project (Rakennusvirasto 2007) to detect high flood-prone areas and buildings at risk and proposes some actions for minimizing the risk. Although initiating such a project by paying attention to details was helpful to start preparing for extreme flood events, several areas prone to flood were ignored such as islands and newly developing areas. Additionally, monitoring flood-prone urban areas must be repeated regularly relative to the changes that happen in climate and mean sea levels. Currently, these aspects are covered by new measures taken, for instance, online map services (Tulvakarttapalvelu) provided by the Finnish Environment Institute (SYKE), which covers the whole areas of Finland and gives information on different probabilities of flood occurrence and the number of residents and buildings at risk.

2.3 Land-use Policies

This chapter explores the role of land-use policies in addressing wicked problems. The first section clarifies the relationship between land-use policies and wicked problems. Following this, the land-use planning system is introduced at various levels. The next section considers policy effectiveness as an influential criterion for evaluating a policy in achieving its intended goals. Next, policy effectiveness is discussed and the methods to measure policy effectiveness are reviewed. The chapter will close by introducing the land-use policies involved in the land-use planning system in Finland. Since the focus of this study is on the coastal areas of Helsinki and Espoo, only the land-use policies in these areas will be explored.

2.3.1 Land-use Policies and Wicked Problems

Urban land is one of the most critical resources for sustainable development. Urban planning and land-use planning are both linked to sustainability science which is an essential aspect to consider when mitigating a wicked problem (Mancebo, 2017). The land has been used in accordance with policies and decisions made by authorities and planners. Land management is the process by which the direction of these policies and decisions is defined to ensure the sustainable development of land (Enemark, 2006). This study focuses on land-use policy evaluation. Land-use policies differ from land policies; however, these two terms have been used interchangeably in some articles. Land policy is a framework that promotes economic development, social justice, and political stability (Enemark, 2006); therefore, it can affect a broad range of administrative procedures. Land-use policies fall into this range as well. However, land policy functions are understood differently in each country because of varying administrative approaches. There are no clear-cut definitions of land policy or land-use policy. Nevertheless, this study tries to acknowledge these concepts as dissimilar but interrelated. This study understands land-use policy as a component of the land management system. Land-use policies give direction to land-use plans and explain the ways in which land can be used and developed to meet the needs of citizens and promote the sustainable development of cities.

Land-use policies steer the types and extent of urban land usage at a general level. Land use is one of the three areas administered by the cadastral system, a system in which the whole information of a plot of land and its fiscal and legal purposes are recorded (Enemark, 2006). Urban plans are controlled by land-use policies at every level including regional and local scales. However, land-use planning practices might result in a different outcome because the functions of land-use planning systems vary from country to country. Policy contexts are highly dependent on the administrative system of a country. Thus, this study will focus on Finland's land-use planning system and land administration to avoid unnecessary complications.

Generally, policies are comprehensive principles regulating all spheres of governance in order to achieve the intended outcomes. Policies are guided by ultimate goals such as sustainability, well-being, prosperity, and socio-economic balance. According to Howlett et al., (2009), a policy framework consists of three main stages: policy design, policy implementation, and policy review. This thesis focuses on the last stage by assessing the effects of land-use policies. The main reason for restricting the scope of the thesis to this stage is the importance of making effective policies when dealing with wicked problems. There are no technical solutions to wicked problems, but rather institutional and political approaches (Perry, 2015). As reviewed in section 2.1, previous studies of wicked problems have rarely introduced management solutions to wicked problems. Instead, they offer useful and applicable tips for dealing with wicked problems. In fact, organizational approaches to wicked problems are quite vague because agencies tend to refine their approaches to complex problems as the circumstances evolve, resulting in developing an unclear understanding of the approach (Ruhl & Salzman, 2010). One way of taking a cautious approach to wicked problems is to restrain the elements of wickedness by adopting effective policies (Norton, 2012). Policy improvements can be done at any stage of the policy cycle, but the key message is that even small policy changes will redirect processes and maintain their effects for a long time (Adams-Schoen, 2016).

Dealing with wicked problems is challenging for policymakers. Many attempts at addressing wicked problems have led to creating more problems than they solve. However, considering the fact that wicked problems respond to political solutions, aspects of a wicked problem can be managed by improving policies. Kirschke & Kosow (2021), suggest using policy mixes for this purpose. Policy mixes are combinations of policy goals and the required instruments for achieving the intended goals (Rogge & Reichardt, 2016). According to the same study, some dimensions of wicked problems such as complexity and uncertainty can be addressed by improving specific aspects of policy mixes. These aspects include policy comprehensiveness and policy diversity for addressing the complexity dimension of wicked problems and policy adaptability. And policy reversibility, and policy robustness for managing the uncertainty of the wicked problem. As defined by them, policy comprehensiveness refers to the range of policy mixes, but policy diversity refers to the instruments used in policy mixes, such as regulations and economic instruments. To deal with the uncertainty of a wicked problem policy adaptability must be enhanced. Policy adaptability enables policy mixes to react appropriately to changes to maintain crucial functions (Feindt et al., 2020). Additionally, policy robustness helps policy mixes function in different scenarios and tolerate tensions (Kirschke & Kosow, 2021).

Climate change is a super wicked problem that has been addressed by political solutions in recent decades (Biber, 2009; Duckett et al., 2016). Nevertheless, there is no central institution to monitor environmental regulation and lawmaking processes, therefore policies directed at wicked environmental problems like climate change and its sub-problems are guided by governments only partially. As a result, these policies might not solve the problem but even give rise to new challenges (Ruhl & Salzman, 2010). To avoid unwanted consequences, for policymakers, it is necessary to acknowledge not only the confusing nature of wicked problems but also the intersections of wicked problems with the law, science, technology, politics, economics, and culture (Krueger et al., 2014). Climate change for instance intersects with land-use controls (Lazarus, 2009; Schönhart et al., 2018), therefore many wicked problems respond to land-use policies. Land-use policies have been used to mitigate climate change. Climate change adaptation has been an element of Finnish planning practices in recent decades. To continue, the land-use planning system in Finland will be introduced in the following section.

2.3.2 Land-use Planning System in Finland

The land-use planning system in Finland consists of three binding hierarchical tiers: regional land-use plan, local master plan, and local detailed plan (Granqvist et al., 2021; Puustinen et al., 2017). Land-use planning in Finland is regulatory meaning that they are firmly defined by legislation, and the legislation allows higher tiers to advise other tiers in land-use developments (Mäntysalo et al., 2015). Considering the scale on which regional planning functions and the geographical and temporal discontinuity of wicked problems, regional planning is the level that deals with wicked problems as directly as possible. According to the Land use and Building Act (LUBA, 132/1999), regional plans must follow the national land-use guidelines. Land-use planning, as well as central government activities, are guided by the guidelines with the primary aim of ensuring that nationally significant matters are considered. Moreover, the guidelines aim to ensure the appropriate actualization of national land-use solutions and to promote the implementation of international agreements and commitments (National Land-use Guidelines, 2017). Regional land-use plans represent the locations of land uses at a regional level while considering future impacts of zoning.

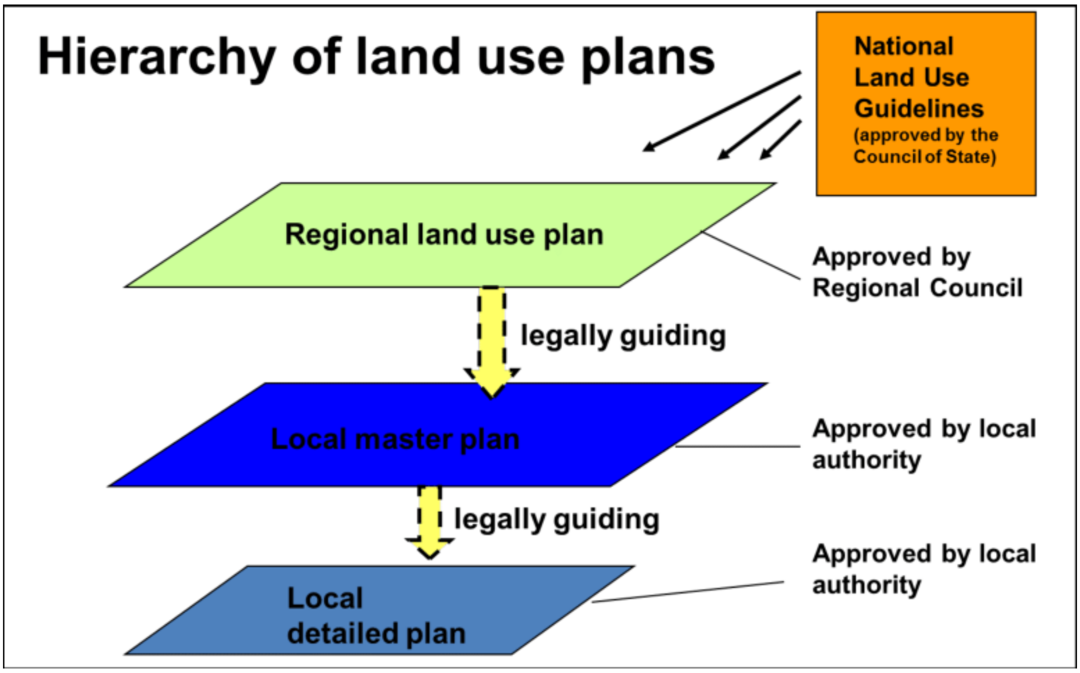

Figure 4: Hierarchy of land-use plans in Finland (Tihlman, 2018).

Local master plans are drafted under the supervision of municipal councils to provide long-term guidelines for land-use ordinances in the municipality (Puustinen et al., 2017). Municipalities are enabled, by LUBA 132/1999, to significantly affect local detailed plans for facilitating planning performance in contrast to planning bureaucracy; however, this autonomy creates tension between municipal and regional planning perspectives (Purkarthofer et al., 2021; Puustinen et al., 2017). According to the legal consequences of land-use planning tiers in Finland, all the tiers of the land-use planning system are legally binding and at the same time, they consider opportunities for non-binding and partially binding plans (Mäntysalo & Grišakov, 2016). Nevertheless, the local detailed plan should be referenced for the implementation of plans or interventions in the built environment. The local detailed plan determines certain land-use developments and distribution of development rights in line with the existing development trends, public needs, goals, and initiatives (Mäntysalo et al., 2015). Keeping all the aspects of land-use development under consideration is almost impossible. In fact, land development is a wicked problem that even might be more wicked than climate change since the majority of people support climate change adaptation strategies and participate in such actions, but the common understanding of land development challenges and consequences is much less than environmental concerns, thus resulting in rational support of urban development and economic growth without being aware of this untamable beast (Hudson, 2019).

With the help of a legal-institutional role and the autonomy granted to the municipalities, land-use policies are mostly decided within municipalities (Mäntysalo & Grišakov, 2016). Land-use policies can be used as a tool for attracting population and economic activities to a certain municipality. The Finnish land-use planning is criticized for having an ambiguous state of policy specifically at the municipal level to hide the contradictions, and ineffective cooperation within the municipalities (Hytönen et al., 2016). In the Finnish planning context, municipalities tend to compete for new jobs and taxpayers (Salo & Mäntysalo, 2017). Moreover, the Finnish land-use planning system seems to have a contradiction between organizing future land-use changes and ensuring a long-term investment in the land market (Mäntysalo & Nyman, 2001). Apart from the questionable relationship between economic purposes and land-use policies, policy evaluation is less investigated in the Finnish land-use planning system.

The Helsinki Metropolitan area, which consists of three municipalities of Vantaa, Helsinki, Espoo, and Kaunianen, is the most populated area in Finland and is estimated to have approximately 2,000,000 residents and 1,000,000 jobs in 2050 (Duman et al., 2022). Since this study concerns the land-use changes between 2000 and 2018, the Helsinki City plan in 2016 plays a central role. The changes envisioned in this plan enabled the expansion of central Helsinki, densifying urban areas, and meeting other needs of the growing city (Granqvist et al., 2021). Local master plans are not the only legislation affecting land-use changes. There are environmental projects that also monitor land-use changes by promoting climate change adaptation and environmental conservation values. For instance, FINADAPT was a project launched by the Finnish Environment Institute (SYKE) in 2003 for conducting a comprehensive research project that could help policymakers arrive at suitable policies (Carter, 2007). Policymakers need scientific outcomes to get a better definition of ill-defined problems like climate change, nonetheless, these outcomes are only useful when they are relevant to the policy question and its context, reliable, unbiased, clear, accessible, and relevant to the current issues concerning the context of the policy (Hamilton et al., 2015).

Policy making has several complications that make it almost as wicked as environmental problems. The wickedness of a policy issue refers to how difficult or impossible it is to resolve due to incomplete or contradictory knowledge, the large number of stakeholders and opinions involved, the large economic burden, and the interconnectedness of these issues with others (Hudson, 2019). Although assessment criteria for policy effectiveness and side effects of actions, in general, have been questioned by wicked problem literature, reviewing the literature on two subcategories of wicked problems and policy problems reveals that the knowledge of wicked problems has rarely been unified in policy contexts (Kirschke & Kosow, 2021). Scholars tend to focus on limited aspects of a wicked problem such as uncertainty, complexity, and conflicts of opinions. In addition, they interfere with the symptoms of the problem instead of its roots, thus failing to facilitate understanding of the wicked problem. For instance, when a municipality tries to reduce greenhouse gas emissions, they usually aim at mobile units producing CO_2, while uncontrolled land development under the cover of urban development causes vehicles to travel a greater distance than before and the aggregated emission is significant enough to be addressed by policy instruments (Hudson, 2019). On the other hand, wicked problems generate divergent, discontinuous, and diverse consequences, local level understanding is essential, and no general formula exists to integrate policymaking processes with wicked problems. Furthermore, local understanding is crucial in policymaking because an urban planner should consider how those policies and technological changes will affect the city's long-term welfare on a place-based rationale, rather than engaging in standard planning (Mancebo, 2017). Several policy tools have been used to interfere with wicked problems. In Scotland, for instance, there are several policy instruments for addressing wicked problems such as legislation, strategies, programmes, and frameworks, and in some cases implementing European directives (Duckett et al., 2016). Among the stages of the policymaking process introduced by Howlett, et al. (2009), this thesis discusses the policy review stage to facilitate the policy adaptation to the emerging problems we face in urban environments.

2.3.3 Policy Evaluation

Policy evaluation is clearly demanded by the 6th Environmental Action Program for the European Union (1600/2002/EC). The paragraph c in Article 10 of this decision states:

Box 1: Policy Evaluation as required by the European Union (1600/2002/EC).

> *[The objectives shall be pursued by] improvement of the process of policy-making through:*
>
> *• ex-ante evaluations of the possible impacts, in particular the environmental impacts, of new policies including the alternative of no action and the proposal for legislation and publication of the results.*
>
> *• ex-post evaluation of the effectiveness of existing measures in meeting their environmental objectives.*

Policy evaluation studies can be conducted at any stage of the policymaking process. However, fewer studies focused on tracking the impacts of policies and evaluating the effectiveness of policy measures. Policy effectiveness has been referred to as the degree of success that a policy achieves in delivering the intended results (Cetrulo et al., 2018; Mickwitz, 2003; Wang et al., 2019). Although some studies argue that policy effectiveness can be perceived in connection with not only the ability of policy to achieve intended outcomes but also with the values of stakeholders (B. W. Head, 2019), this thesis does not cover stakeholders' opinions in evaluating land-use policy effectiveness. The effectiveness evaluation described in the 6th Environmental Action Program is based on the oldest evaluation model, the goal-achievement model (Mickwitz, 2003). The goal-achievement model has some shortcomings. For instance, this model ignores the side effects and unexpected effects of a policy. In another study, Cetrulo et al. (2018), assesses the effectiveness of the Brazilian solid waste policy in terms of social changes by analyzing one group prior to and after policy implementation to compare interventions and presumed effects. Although focusing on the social aspect of various policy effects is wise, this comparison does not distinguish the effects caused by a policy from other effects caused by any other factor. Another method suggested for effectiveness evaluation is goal-free evaluation method in which the effects of the policy are determined without being aware of the primary goals (Mickwitz, 2003). When the impacts of the policy are undesirable then the policy has failed regardless of the extraordinarily perfect aims that were assumed to achieve. Brody et al. (2006), also faced some limitations in evaluating policy impacts on future developments, they determined how the policies were implemented after adopting a specific plan instead of revealing the actual results that the policies achieved (Taylor et al., 2007). In fact, effectiveness evaluation requires multidisciplinary collaboration since it is a complex issue intersecting with almost all socio-economic systems (Scott, 2007).

Among studies that are dedicated to policy evaluation, evaluation studies of land-use policies are very scarce, but a great amount of budget and time has been allocated for assessing the impact of regional or local master plans. The difference between these two attempts of evaluation lies in the implementation phase. Planning implementation is the step in which land-use policies face the greatest interpretation twist. As Finland uses a layered land-use planning system, national land-use guidelines and land-use policy regulations are translated repeatedly into goals and actions while passing from the regional to the local level of planning. The implementation phase in the policymaking cycle may also mislead attempts at evaluating policy effectiveness. Policy implementation refers to the transformation of policy intention into action for achieving the primary aims (Rudberg, 2018). The theme of effective implementation of policies is highly relevant for managing wicked problems, and, accordingly, many wicked problems can be understood better based on their responses to a policy (B. W. Head, 2019; Ruhl & Salzman, 2010). Like wicked problems, the effects of land-use policies are discontinuous in location and time. Although this is problematic for tracking the effects of policy, some solutions have been found. Taylor et al. (2007), have evaluated the effects of local land-use policies that are aimed at maintaining natural features within the community by implementing a GIS-based comparison of pre- to post-development land cover changes both before and after policy implementation. Geographical information systems (GIS) facilitate a proper understanding of land-use changes in different locations and enable users to compare these changes throughout time. However, land-use changes are a result of various policies including land management policies, nature conservation policies, fiscal incentives, and policies for promoting sustainable development of cities, therefore the main issue is to distinguish the effects of various policies from one another (Mickwitz, 2003; Wang et al., 2019). This issue could be addressed by using the back-casting approach in which after producing a future normative vision, looks back to explore the steps for achieving this future (Brunner et al., 2016). This approach has been used by Wang et al. (2019), to predict future land-use scenarios and find the causes fostering the existing problems. Back-casting is notable because it helps identify causes and facilitates seeking solutions, whereas multi-scenario simulations predict possible futures of land-use cover and are future-oriented.

This study considers coastal flooding as a wicked problem that can be managed effectively by land-use controls. Although this problem has been addressed by several other urban planning and management instruments, reviewing these approaches is not included in the scope of this thesis. As explained in section 2, sea-level rise is one main reason for more frequent coastal flooding compared to the past. Rising in the mean sea level increases the probability of flooding events in coastal regions. Evidently, a large portion of new developments will be located in waterfront areas (Adams-Schoen, 2016; Crane & Landis, 2010; Yunita, 2010). Urban planning suggests fostering sustainability values in waterfront development (Mancebo, 2017). This rule of thumb is valid in Finland as well because the population is centered in coastal regions (Duman et al., 2022). Urban planning that takes place outside flood zones will promote safety and alternative uses of land for public development. It is important for urban planners to adhere to restrictive regulations to meet sustainable values in coastal areas, but the wickedness of environmental issues, specifically sea flood risks, will force waterfront development policies to take flood risks into account (Adams-Schoen, 2016). Adopting restrictive regulations to mitigate coastal flooding is challenging mainly because there is significant uncertainty about the effectiveness of the policy instruments, especially when it comes to improvements in coastal defense and managing rising sea levels (Biber, 2009). Waterfront hazard mitigation attributes correlate with attributes of a wicked policy problem but there is often no central authority for mitigating waterfront areas, thus resulting in poor decision-making (Adams-Schoen, 2016). Land-use planning is one of the tools being utilized for climate change adaptation in Finland because it is believed that spatial planning and adopting suitable land-use policies play an essential role in reaching sustainable goals and more importantly sea level rise adaptation (Adams-Schoen, 2016; City of Helsinki, 2019; Virkki et al., 2006). Laws and regulations may not always be enough to achieve goals, and behavioral change and voluntary compliance with new social norms will be necessary to make a policy successful in some cases; however, even small policy changes will redirect processes and maintain their effects over time and scales, thus improving land-use planning practices can reform norms and values towards a resilient built environment (Adams-Schoen, 2016; Alford & Head, 2017).

2.3.4 Land-use policies in Helsinki and Espoo

Land-use planning in Finland is carried out based on national land-use guidelines and the Land-use and Building Act (LUBA 132/1999) which has listed a number of objectives land-use planning initiatives must follow. The land-use planning objectives include:

Box 2: Land-use planning objectives according to LUBA (132/1999).

1) a safe, healthy, pleasant, socially functional living and working environment which provides for the needs of various population groups, such as children, the elderly, and the handicapped;

2) economical community structure and land-use;

3) protection of the beauty of the built environment and of cultural values;

4) biological diversity and other natural values;

5) environmental protection and prevention of environmental hazards;

6) provident use of natural resources;

7) functionality of communities and good building;

8) economical community building;

9) favorable business conditions;

10) availability of services;

11) an appropriate traffic system and, especially, public transport and non-motorized traffic.

Almost all of the above-mentioned objectives are relevant to the development of waterfront areas; however, this study emphasizes objectives number 5 and 7. It is possible for wicked environmental problems to arise from countless land-use decisions and investments made based on contrary cultural values, and economic factors (Moser et al., 2016). Based on the decision made by the European Parliament in July of 2002, each member state of the European Union must develop descriptions of floods that have occurred or may occur in a specific area prone to flooding. This description must include flood impacts and the likelihood of future flood events. In Finland, the role of land-use planning in flood risk prevention was emphasized after renewing the land-use and building act in 2000 (Virkki et al., 2006). Chapter 10 section 72 of the land-use and building act (LUBA, 132/1999), considers special provisions for the development of shore areas; however, it exempts some required buildings from these provisions, for instance, buildings that are required by agriculture and forestry or for nature preservation purposes. Moreover, there is the Flood Risk Management Act (620/2010), which regulates the actions that need to be taken to reduce flood risks, prevent and mitigate the adverse consequences caused by floods and promote preparedness for floods. In order to gain a proper understanding of land-use policies applied to coastal regions of Helsinki and Espoo, this study also reviewed regional and local master plans from 2016, action plans for climate change adaptation, and several reports on climate change adaptation policies and research projects such as

FINADAPT. The following chapter presents the current situation of flood-prone areas and explains the method used for evaluating land-use policy effectiveness in reducing exposure of waterfront urban areas to the risk of coastal floods and rising sea levels.

3 Research Material and Method

This chapter explains the databases used in this study and introduces methods and tools for conducting research. The first part is dedicated to introducing datasets and the revisions that have been done to make the datasets reliable. The last section explains the methodology and software tools used in this study. The results will be interpreted in the next chapter.

3.1 Data and Material

To assess the effectiveness of land-use policies, multiple data types have been used in this study. These include the CORINE land-use cover dataset and the sea flood risk dataset provided by the Finnish Environment Institute (SYKE). The material used for tracking land-use changes and comparison analysis is derived from the mentioned datasets. For instance, land-use cover maps and driving factors for land-use simulations. The data modification and analysis methods will be explained in each section of this chapter.

3.1.1 CORINE Dataset

Corine Land Cover (CLC) is one of the oldest and most popular databases of the Copernicus Land Monitoring Service (CLMS) (Büttner et al., 2021). This programme was first proposed in 1985 by the European Commission in which geographical information related to land cover, biotopes, coastal erosion, and other factors were collected to support environmental policy development (Büttner et al., 2021; SYKE, 2005. The CORINE Land Cover data (CLC) has been produced in the Finnish Environment Institute (SYKE) every six years since the year 2000 (and is also available for 2000, 2006, 2012, and 2018). The CORINE land cover 2000 (CLC2000) project provides information on land cover (LC) and its changes in 24 European countries including Finland between 1990 and 2000 (Feranec et al., 2010). This study uses CLC2000 and CLC2018 as reference material for the purpose of this study. The CLC 2000 land cover data is derived from satellite images and integrated with the existing digital map (SYKE, 2005). However, the attributes of the CLC2018 dataset were improved in resolution and accuracy.

CORINE land cover dataset classifies land-use data into four major classes including artificial surfaces, agricultural areas, forests and semi-natural areas, and wetlands. Moreover, waterbodies are included in this dataset. The following table describes different classes of CLC nomenclature. This study considers classifying different land uses according to level 1, therefore other levels must be mentioned for a detailed analysis of land-use changes. In the following table, category 1.4.1 represents green urban areas and the maps in this thesis show the human-constructed green areas in red. However, other types of land-use cover maps might illustrate similar areas with green color codes.

Table 6: CORINE Land-use Classifications.

LEVEL 1	LEVEL 2	LEVEL 3
1. Artificial Surfaces	1.1. Urban fabric	Continuous urban fabric 1.1.2. Discontinuous urban fabric
	1.2. Industrial, Commercial and transport units	1.2.1. Industrial or commercial units 1.2.2. Road and rail networks and associated land 1.2.3. Port areas 1.2.4. Airports
	1.3. Mine, dump and construction sites	1.3.1. Mineral extraction sites 1.3.2. Dump sites 1.3.3. Construction sites
	1.4. Artificial, non-agricultural vegetated areas	1.4.1. Green urban areas 1.4.2. Sport and leisure facilities
2. Agricultural Areas	2.1. Arable land	2.1.1. Non-irrigated arable land 2.1.2. Permanently irrigated land 2.1.3. Rice fields
	2.2. Permanent crops	2.2.1. Vineyards 2.2.2. Fruit trees and berry plantations 2.2.3. Olive groves
	2.3. Pastures	2.3.1. Pastures
	2.4. Heterogeneous agricultural areas	2.4.1. Annual crops associated with permanent crops 2.4.2. Complex cultivation patterns 2.4.3. Land principally occupied by agriculture, with significant areas of natural vegetation 2.4.4. Agro-forestry areas
3. Forests and Semi-natural Areas	3.1. Forests	3.1.1. Broad-leaved forest 3.1.2. Coniferous forest 3.1.3. Mixed forest
	3.2. Scrub and/or herbaceous Associations	3.2.1. Natural grassland 3.2.2. Moors and heathland 3.2.3. Sclerophyllous vegetation 3.2.4. Transitional woodland-scrub
	3 .3. Open spaces with little or no vegetation	3.3.1. Beaches, dunes, sands 3.3.2. Bare rocks 3.3.3. Sparsely vegetated areas 3.3.4. Burnt areas

		3.3.5. Glaciers and perpetual snow
4. Wetlands	4.1. Inland wetlands	4.1.1. Inland marshes 4.1.2. Peat bogs
	4.2. Marine wetlands	4.2.1. Salt marshes 4.2.2. Salines 4.2.3. Intertidal flats
5. Water	5.1. Inland waters	5.1.1. Water courses 5.1.2. Water bodies
	5.2. Marine waters	5.2.1. Coastal lagoons 5.2.2. Estuaries 5.2.3. Sea and ocean

Due to following reasons, CLC2000 and CLC2018 could not be compared or used as their original versions. First, land-use classifications were different in these years. In the CLC2018 dataset, open-cast mines, Agro-forestry areas, and industrial units were added to level 3 of classified land uses. Additionally, the Sport and leisure facilities class was divided into more detailed types such as summer cottages, golf courses, and racecourses. Color codes used in these years did not match, thus comparison seems even more difficult. The second reason is that using satellite images for producing the CLC2000 dataset is less reliable than the newer technologies (ESA Sentinel-2 dual date Landsat 8 which is used for CLC2018) when it comes to data collection and mapping (Büttner et al., 2021). Another result of relying on low-quality satellite images for data preparation was gaining a lower geometric accuracy. The geometric accuracy of the CLC dataset was improved from 25 m in 2000 to 10 m in 2018. And the resolution of raster layers is different in 2000 and 2018, thus failing to form a uniform time series of land-use cover data. Lastly, the CLC2000 dataset deviates from reality due to the generalization process that has been carried out to make data processing easier. Generalization processes tend to aggregate small parcels into adjacent larger parcels (SYKE, 2005). The generalization process was first applied to each class of land uses in level 1; therefore, the land uses in this level deviate significantly from reality.

Due to the aforementioned problems with the CORINE database, SYKE carried out a project to unify CORINE land-use cover data from 2000 to 2018 (SYKE, 2021). This was done by utilizing the reverse methodology. The reverse process was started by resampling the CLC2000 and 2006 data as well as the change layers 2000-2006 from 25x25m resolution to 20x20m. Change Layers contain only land-use changes between target years, so these layers are more accurate than the original CORINE database. The reverse data layer of CLC2012 was then created by changing the pixel values of the year 2018 data to match the 2012 values in the change layer 12-18. Also, some values were extracted from the original CLC2012 data layer. As a result of this process, a revised version of CLC 2012 was produced. Next, using the same method, this dataset was reversed with the change layer 2006-2012 to create a new reverse CLC2006 layer and further a reverse CLC 2000 layer (with change layer 00-06). Land-use classification of the reversed version of land-use cover data at level 3 is slightly different from the classification represented in Table 6. Since this thesis considers classification only at level 1, discussing the changes in the reversed version of land-use cover data is not in the scope of this thesis.

Figure 5 and figure 6 illustrate land-use cover in 2000 and 2018 in Helsinki and Espoo municipalities. Although the classification of land-use types in this study is according to the level 1 classification of the CORINE database, the following maps illustrate land-use types according to level 3. These materials have been used to produce initial and target scenarios for simulating land-use patterns in which land-use changes can be traced to land-use policies. The simulation method will be introduced in the upcoming sections of this chapter.

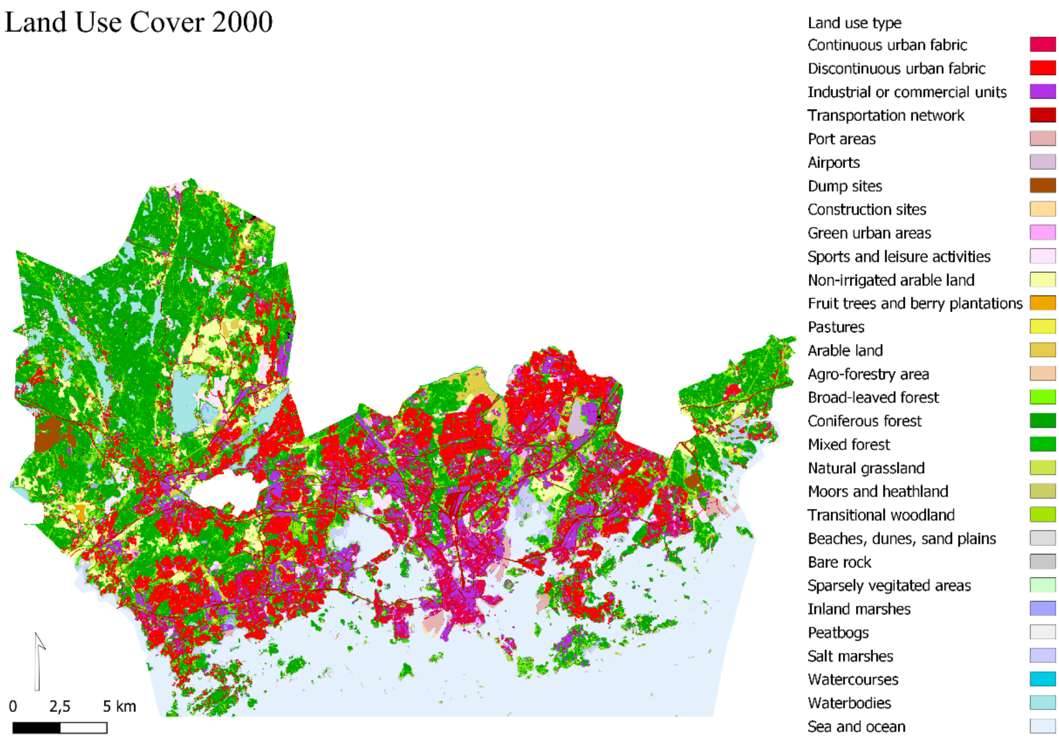

Figure 5: Land-use cover in 2000.

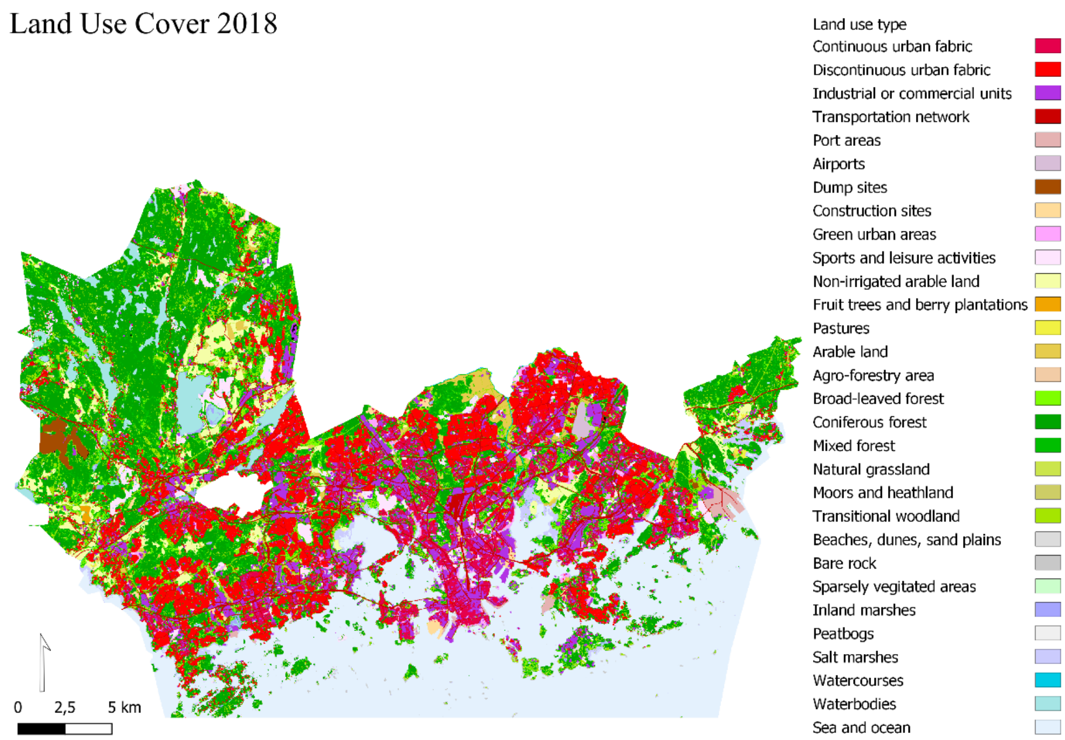

Figure 6: Land-use cover in 2018.

Table 7 represents the areas devoted to each land-use type. Urban land in 2018 is slightly higher than it was in 2000, because of urban developments. Artificial surfaces covered a much larger area in 2018 than other land-use types. The area of this land-use type has increased from 42 percent to 44 percent. The other three land-use types have decreased since 2000. Agricultural areas shrunk from 7 to 6 percent and natural areas from 49 to 47 percent respectively. Wetlands have experienced minor changes compared to other land-use types.

Table 7: Land-use changes between 2000 and 2018.

Land-use Types	Areas in 2000 (Km2)	Areas 2018 (Km2)
Artificial Surfaces	221 229	232 738
Agricultural areas	38 642	34 568
Natural Areas	259 377	252 947
Wetlands	12 836	12 453
Total Land	**532 5**	**533 5**

3.1.2 Sea Flood Data

The Flood Risk Management Act (620/2010) of Finland demands municipalities to keep records of areas at risk of flooding. Among the different types of flood events such as river floods, flash floods, urban floods, and floods from the sea in coastal areas, this study focuses on the last type. Due to the fact that sea level rise has accelerated the frequency of flood events in many regions, sea flooding is dependent on the mean sea level.
According to the Flood Risk Management Act (620/2010) of Finland, municipalities, the Ministry of Agriculture and Forestry, the Ministry of Transport and Communications, and the Ministry of the Environment are the main authorities charged with ensuring flood prevention and its adverse consequences. Thus, almost all of these authorities are in a way involved in producing maps, reports, surveys, and risk management plans for significant flood risk areas. This thesis utilizes sea flood data provided by SYKE, which identifies the areas at risk of sea flooding and presents different probabilities of flood events. Additionally, users can detect significant areas at risk of sea flooding through an online map service named 'Tulvakarttapalvelu' (in Finnish). Moreover, this online map service can be updated and revised as needed.

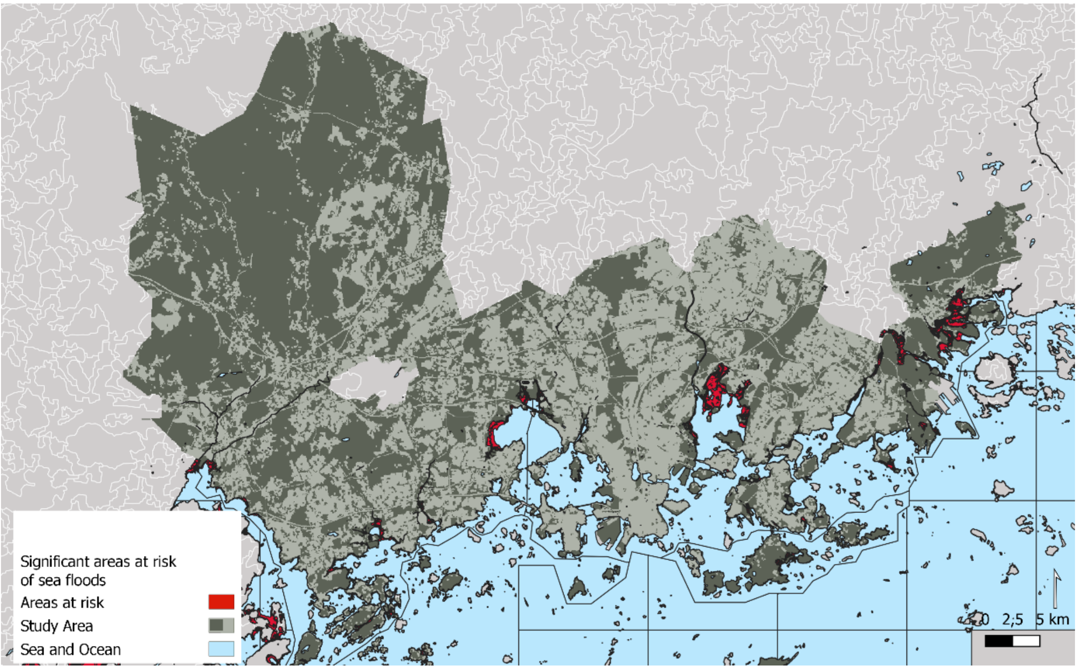

Figure 6: Significant areas at risk of coastal flooding events.

Figure 6 shows the areas at risk of sea flood events including areas with the least probability of occurrence. In this thesis, flood risk zones are assumed to be the same as in 2000, as sea flood data are not available for this year. The premier goal of the thesis was to investigate land-use changes that have happened within flood risk boundaries. Evaluating these land-use changes leads us to recognize the effects of land-use policies that were applied to these regions.

In total, 27 366 km2 of Helsinki and Espoo's coastal regions are at risk of sea flood events, but its frequency varies from once every two years to once every 1000 years. The following table represents shares of each land-use type that is located inside the sea flood risk zones. Based on this table, land-use changes over a time period of 18 years have improved the allocation of artificial surfaces and agricultural lands; however, land-use regulations have increased the exposure of natural areas and wetlands to the risk of sea floods. The greatest land-use change has happened in artificial surfaces with a 373 km2 reduction in the areas at risk of flooding events.

Table 8: Shares of each land-use type that is located within the flood risk zones.

Land-use type at risk of flooding	Area in 2000 (km2)	Area in 2018 (km2)	Performance (km2)
Artificial surfaces	7 232	6 960,4	Decreased (v 271,4)
Agricultural areas	3 234,2	2 861,2	Decreased (v 373)
Forests and semi-natural areas	11 890,9	12 208,8	Increased (^ 317,9)
Wetlands	5 008,9	5 335,6	Increased (^ 326,7)

3.1.3 Land-use Policies

The significant risk areas cover 57 different city districts throughout Helsinki and Espoo. To properly review the land-use policies applied to these areas documents from several levels of land-use planning and administrative levels must be included in the research materials. The present thesis utilizes international guidelines for land-use planning and regulations, national legislation, regional plans, local master plans, detailed plans, and associated projects. Besides guidelines and regulations that aim to support land-use planning, land-use practices were also outlined. Some land-use plans in Helsinki and Espoo have not been implemented for various reasons. Therefore, land-use policies that belong to this category have been excluded from this study. In addition, some of the areas that were at risk experienced interventions after 2018 or before 2000, considering the timeframe of 2000-2018 for this research these land-use practices were excluded as well.

The present study intends to investigate the effects of land-use policies applied to the coastal areas of Helsinki and Espoo. However, land use in these urban areas is impacted by a different set of policies including land management policies, nature conservation goals, climate adaptation plans, and economic development incentives. Therefore, a list of land-use policy actions and statements is compiled after reviewing the relevant documents. This list contains policies affecting coastal areas, especially those areas at risk of sea floods. Additionally, the collected policies seem to be changing land-use patterns in the target areas. These land-use policies are listed in table 9.

3.2 Method

To measure the effectiveness of land-use policies the actual effects of land-use policies must be identified. This enables us to compare these effects with the intended goals of the policy. Land-use planning in Finland seeks a set of objectives that were introduced in chapter 2, section 2.3.4. Keeping these objectives as a guide, this study utilizes a back-casting method to detect the effects of land-use policies. Back-casting method was first introduced by Robinson (1990), as a method for not only investigating desired future but finding pathways to achieving that future. The main distinctive feature of the back-casting method compared to other multi-scenario simulation methods that tend to predict possible futures of land-use cover is that this approach focuses on finding causes and solutions to a problem (Robinson, 1990; Wang et al., 2019). Using this approach, we can identify the factors that lead to a change under the influence of policies. Thus, the direct impact of policies on land-use changes becomes distinctive (Brunner et al., 2016). In this study, the envisioned future is defined based on the land-use cover in 2018. Land-use policy effects are detected according to the way this envisioned future has been achieved. The target scenario is referred to the envisioned land-use cover. The initial scenario is based on the land-use cover in 2000, the year when the investigation began.

To operationalize this method, a land-use scenario was simulated based on the initial scenario by using GeoSOS- Future Land-use Simulation (GeoSOS-FLUS) software. This software is the developed version of GeoSOS software to simplify multiple land-use change simulations. Another benefit of using this software is the opportunity to analyze the land-use simulation and test its similarity to actual land-use cover. For the purpose of simulating land-use change and analyzing scenarios, the software provides a multiple Cellular Automata (CA) allocation model. CA model consists of a grid of cells that change state with time, according to a defined rule set based on neighboring cells' states. In addition, this software exploits an artificial neural network (ANN) for taking multiple effects into account by finding the complex relationships between land-use patterns and other driving forces (Liu et al., 2019). The materials used for the land-use cover simulations have been produced via GIS based on the reversed version of the CORINE database. Following are the steps for conducting this land-use policy evaluation.

This study follows the steps taken by Wang et al. (2019). The process of tracking the effects of land-use policies has three stages including setting up initial and target scenarios, analyzing land-use policies, and simulating land-use scenarios. All stages are carried out under the supervision of experts and according to relevant data and documents. After successfully simulating the land-use model the results can be interpreted to reveal land-use policies responsible for the land-use changes in each group of land-use types presented in land-use classification level 1. Since this study focuses on the significant areas at risk of sea floods, the result of this attempt can shed light on how effective land-use policies can help in sea flood risk prevention.

The process of detecting land-use policy effects begins with setting up initial and target scenarios. The initial land-use scenario represents land-use type allocations within the boundaries of Helsinki and Espoo municipalities in 2000. And the target scenario illustrates the same information in 2018. The raster layers were then reproduced in GIS to match the properties of each layer of data. This is because running a simulation model needs the attributes of each raster layer such as resolution, dimensions, pixel sizes, and data types to be equal. The following figures demonstrate the initial and target scenarios.

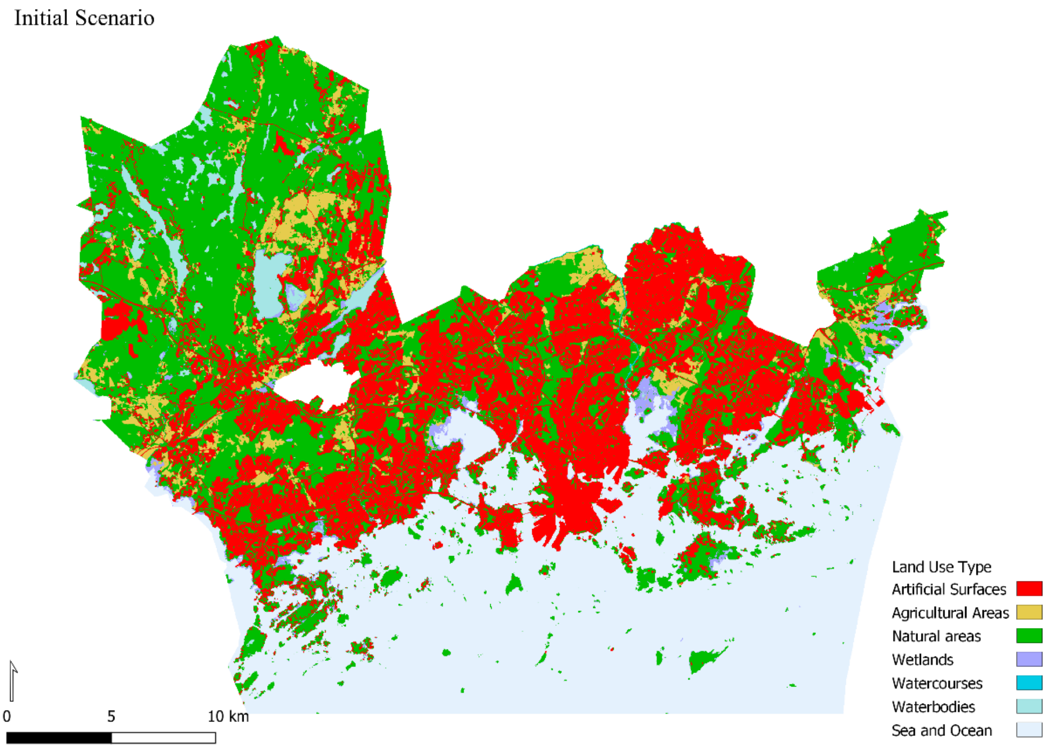

Figure 7: Initial Land-use Cover Scenario.

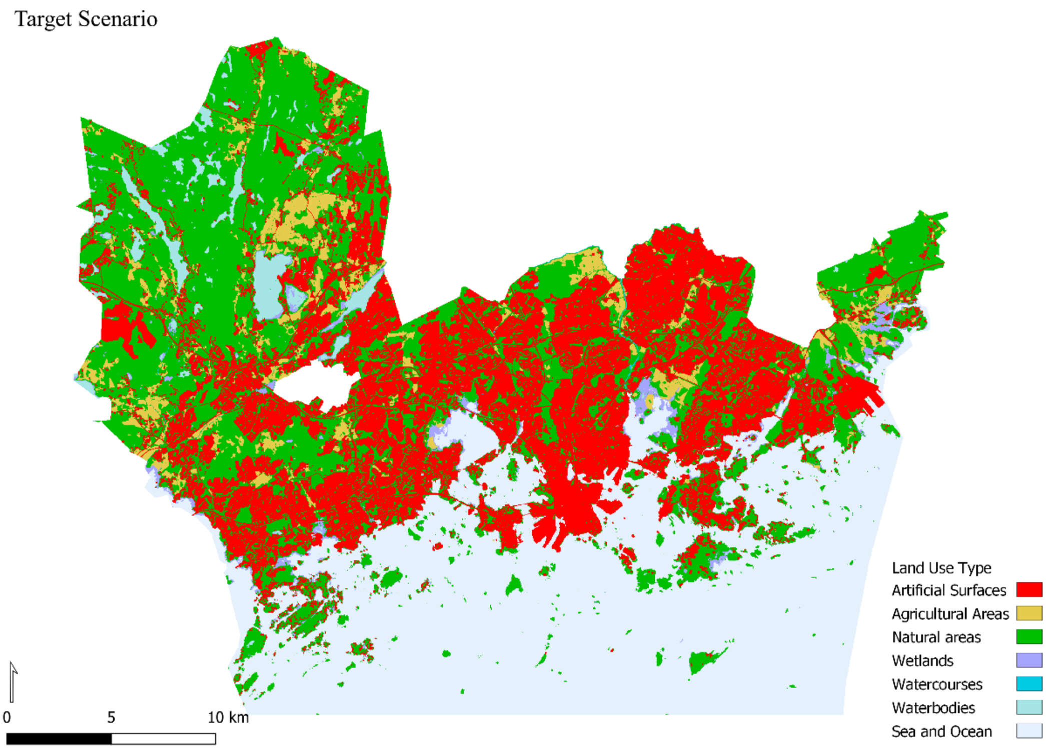

Figure 8: Target Land-use Cover Scenario.

In the next stage, a value was assigned to each land-use policy in the collection of policies that influence significant areas at risk of sea flooding events. The aim of this stage is to indicate the intensity and direction of land-use policy effects. Policy assignments are used to structure a conversion cost matrix which is the basis of CA simulation models. Policy assignment Q is dependent on the intensity and direction of the effects. The intensity of land-use policy effects (symbolized as P) is either Direct (D) or Indirect (I) and Strong (S) or Weak (W). The intensities are specified based on these conditions:

$$P = \begin{cases} 9, \text{ if the intensity is "Direct" and "Strong"} \\ 5, \text{ if the intensity is "Direct" and "Weak" or "Indirect" and "Strong"} \\ 1, \text{ if the intensity is "Indirect" and "Weak"} \end{cases}$$

The direction of the land-use policy function (symbolized as M) expresses whether the policy contributes to land-use change or prevents the change from happening. Thus, the direction would be positive (+) in the former condition or negative (-) in the latter condition.

$$M = \begin{cases} 1, \text{ if the direction is } (+) \\ -1, \text{ if the direction is } (-) \end{cases}$$

Policy assignment (Q) is calculated depending on P and M values according to the following equation.

$$Q = PM \qquad (1)$$

Corresponding land-use policies with policy assignments are presented in table 9. This table also represents a short description of land-use policies.

Table 9: Land-use policy collection and policy assignments.

Policy name	Policy action mechanism number		Policy assignment
	Policy number	Policy intensity and direction	
New residential areas are planned in Östersundom for which land elevation projects are needed to increase the height of land to prevent the risk of flooding (2012).	01-	D-S-+	9
Vegetation measures are planned in the coastal areas of Östersundom to reduce the speed of water runoff and the risk of flooding (2012).	02-	D-S-+	9
New developments include residential areas, business areas, green connections, and recreational areas including recreational islands in Merirastila-Vuosaari (2016).	03-	D-S-+	9
Residential areas and mixed land-uses are planned in Kruunuvuorenranta coastal areas (2016).	04-	D-S-+	9
Housing development in Pihlajisto with respect to natural and cultural values of Viikki old town bay and its surrounding (2015).	05-	I-S-+	5
Finnoonsatama will be a residential area, however, the recreational and conservation values of the area will be safeguarded (2015).	06-	I-S-+	5

Espoo's ecological network (EVN) is developed throughout almost all coastal areas to support biodiversity and sustainable use of cultural environments, ecological connectivity, and recreational network. (2008-2018).	07-	D-W-+	5
Developing a green network along the coastlines and naturally valuable areas, an environmental conservation plan, and supporting recreational uses for the city of Helsinki (2016).	08-	D-W-+	5
According to National land-use guidelines, municipalities must be prepaid for extreme weather events and new constructions must be located outside flood risk zone areas or otherwise ensure flood risk management (2008-2017).	09-	I-S--	-5
Mapping flood-prone areas started in 2007 and giving instructions for flood preparation started by The European Parliament and The Councils on 23 October 2007.	10-	D-S-+	9
Construction in the shore zones is allowed only according to local detailed plans or a legally binding local master plan. This provision does not apply to (Land-use and Building Act, 2003): building required by agriculture and forestry or fishery;	11-	D-S-+	9
building to serve the needs of national defence or frontier control;	12-	D-S-+	9
building required by navigation;	13-	D-S-+	9
building of an outbuilding within the curtilage of an existing residential building;	14-	D-S-+	9
repair of or limited extension of an existing residential building.	15-	D-S-+	9
flood risks must be considered during planning and construction, to ensure that new building developments are not located where they may be damaged by floods (Land-use and Building Act, 2003).	16-	D-S-+	9

Developments along the shores of the Baltic Sea should be located higher than the levels flood waters can be expected to reach once every 200 years on average, plus at least 30 cm to account for wave heights. This means the lowest recommended heights for the bases of buildings would be N60+2.60 m in Helsinki (2008).	17-	D-S-+	9

(+) Policy Direction	If the policy contributes to the land-use change	
(-) Policy Direction	If the policy prevents land-use change from happening	
The intensity of the effect	Direct OR Indirect	
	Strong OR Weak	

In order to discover a causal relationship between land-use policies and land-use changes, a conversion cost matrix was created. This matrix corresponds to a combination of policies. The value (V) of each cell in the conversion cost matrix is intended as:

$$Value = \frac{\sum_{k\in n_{ij}} Q_k}{max\left\{\sum_{k\in n_{ij}} Q_k\right\}} \quad (2)$$

Where, i represents the type of land-use transferred out; j represents the type of land-use transferred in; n_{ij} denotes a set of policy numbers for converting i-type land-use into j-type land-use; k denotes the policy number, and $1 \leq k \leq 17$; Q_k denotes the corresponding assignment of the policy number.

The aim of this formula is to organize the land-use policy assignment in table 9 into the land-use conversion cost matrix. The policy assignments in the same grid were accumulated according to the effect, and the accumulated results were normalized (0-1). In this formula, $\sum_{k\in n_{ij}} Q_k$ refers to the sum of the assigned values of all policies that stimulate or inhibit the conversion of land-use types. And $max\left\{\sum_{k\in n_{ij}} Q_k\right\}$ is the maximum value of the sum of policy assignments in the table of all land-use conversions. The purpose of this step was to normalize Values to a number between 0 and 1. However, there are some conditions to be considered in using the formula No.4. Since some policies were assigned negative values, it is inevitable to make $\sum_{k\in n_{ij}} Q_k$ negative. Therefore, the following must be applied when calculating V, so this value can take a positive number and represent different levels of land conversion costs at the same time.

$$\text{if } \min\{Value\} \geq 0,\ \ V = Value\ ; \qquad (3)$$
$$\text{if } \min\{Value\} < 0,\ \ V = Value + |min\{Value\}|$$

If V=0, land-use change is prohibited, and if V=1, land-use change is encouraged. Other amounts of V between 0 and 1 represent low to high costs of land-use changes. This conversion cost matrix (see appendices) contains the initial parameters for land-use simulations which are carried out by GeoSOS-FLUS software.

In the third stage of the process of detecting land-use policy effects, multiple rounds of land-use scenario simulations were run. This was until the final land-use cover model was close enough to the target scenario. The driving factors of simulations were demographic concentration and proximity, route proximity, Aspect and Slope maps, and distances from the city center and sub-centers of the study region. The following ANN-based estimation model was created using these driving forces. This estimation model demonstrates the probability of occurrence for each land-use type. Wetland is not included in this model as its variation in probability of occurrence is not significant enough to be resembled in the model.

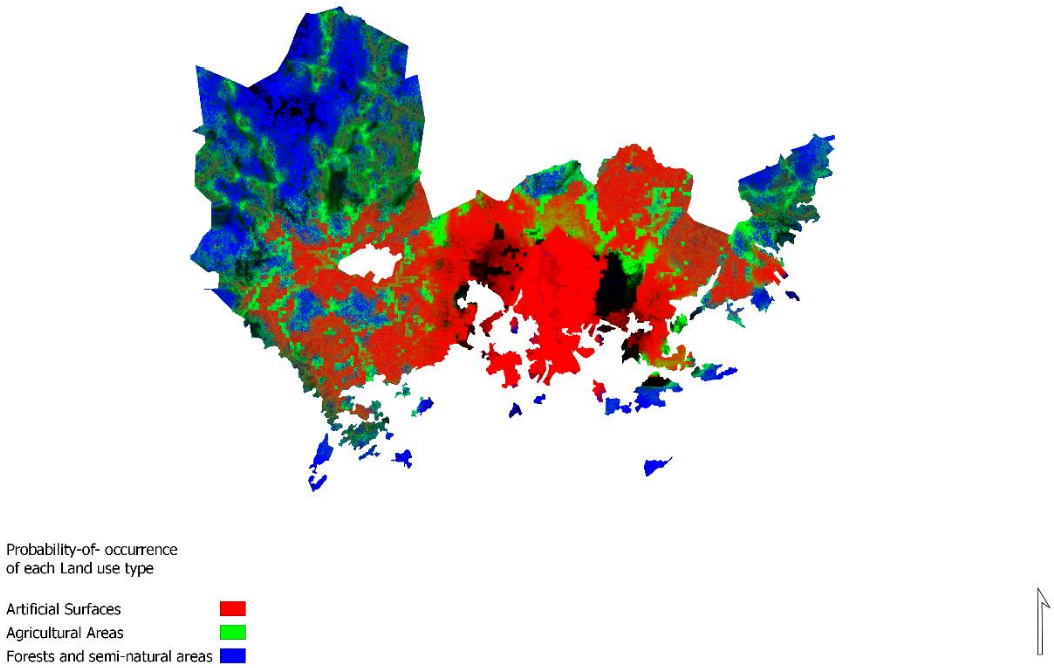

Figure 9: The ANN estimation model.

On the basis of the ANN-based model and conversion cost matrix, several rounds of simulation have been carried out until the outcome model became satisfying. The initial parameters of the conversion cost matrix were adjusted according to deviations in each round from the land-use cover areas in the target scenario. The adjustment criteria for land-use conversion from type A to type B, for instance, are as follows. Rule (1) states that if the simulated result of land-use type A was more than its actual amount and the simulation result of land-use type B was less than its actual amount, the corresponding value in the conversion cost matrix should be increased. Rule (2) says that if the simulated result of land-use type A was less than the actual amount and the simulation result of land-use type B is more than its actual amount, the corresponding value in the conversion cost matrix must be decreased. The first and the last round of land-use simulations are visible respectively on the left and right sides of Figure 10.

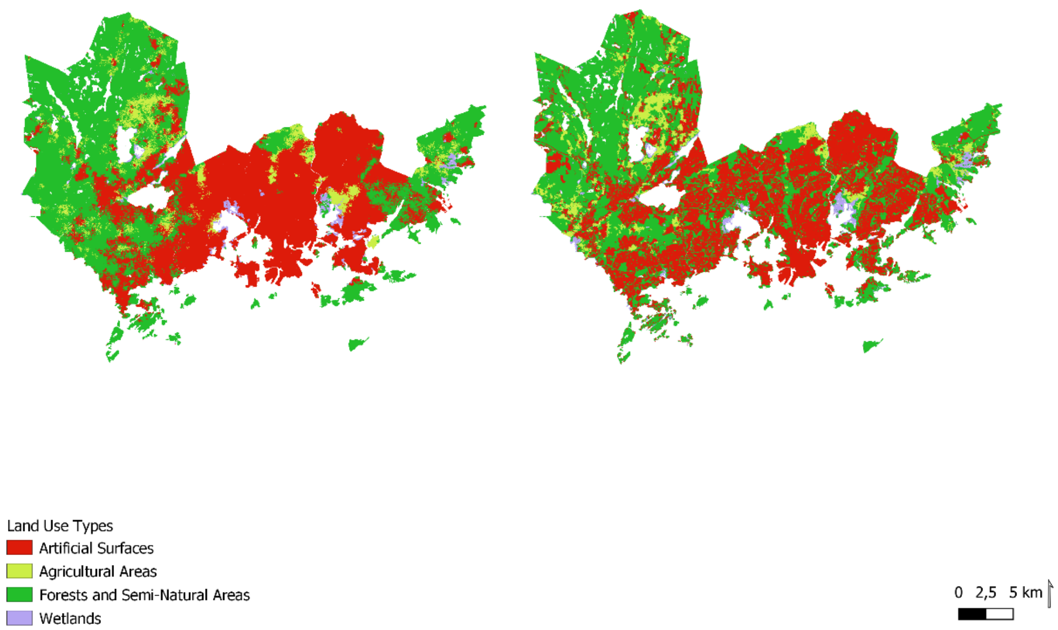

Figure 10: The first and the last round of land-use simulation.

GeoSOS-FLUS software enables users to check the similarity of their simulation to the actual land-use cover. The Kappa statistic tool was used to test the validity of the simulated land-use model, which indicates Kappa ecoefficiency and overall accuracy. The Kappa statistic tool measures the inter-rated reliability of variables, and the results of this test are only acceptable if they are greater than 0.4, otherwise the model is deemed unreliable. The final land-use simulation is illustrated in figure 11.

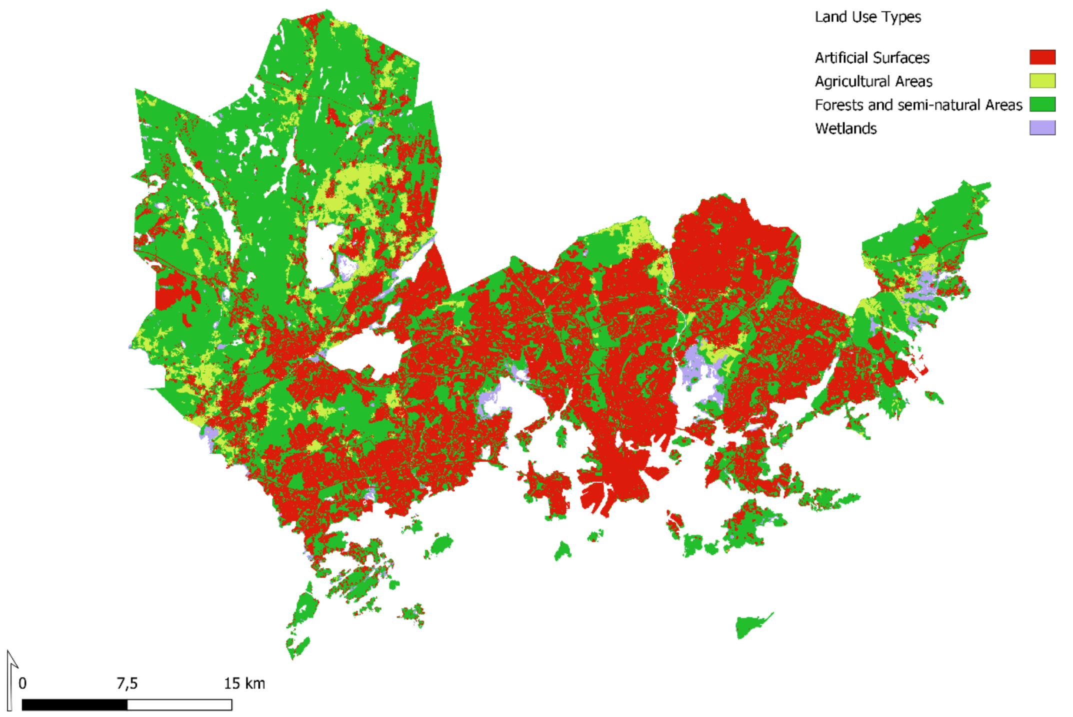

Figure 11: The final land-use simulation.

4 Results

This chapter summarizes the outcomes of this research. These results are obtained by working through the stages that were explained in the previous chapter. Moreover, the findings of this study will be evaluated and interpreted in this chapter.

The present thesis aims at measuring the effects of land use policies in the coastal regions of Helsinki and Espoo municipalities. The target area is further limited to areas at risk of sea flooding; however, land use policies are applied to much more extensive regions and have diverse effects. Thus, selected land use policies differ in the extent of their effects. The main results of this study are represented in table 10 and table 11. These outcomes are obtained by taking the steps described in the previous chapter.

Table 10: The final conversion cost matrix.

Land use (from)	Land use (To)			
	Artificial Surfaces	Agricultural areas	Forests and semi-natural areas	Wetlands
Artificial Surfaces	1	0,1	0,22	0,26
Agricultural areas	0,9	1	0,32	0,4
Forests and semi-natural areas	0,99	0,16	1	0
Wetlands	0.2	0,21	0,22	1

*The scale 0-1 reflects the degree of conversion. (0) indicates no conversion and (1) complete conversion.
*Red indicates undesirable conversions, and green shows desirable conversions.

The values in the above-mentioned matrix are the basis of the land-use simulation illustrated in Figure 11. The value in each cell corresponds to land-use conversions. These values are influenced by land use policies and their assignments. To translate these values into policy effectiveness we need to classify land use changes into desirable and undesirable groups of change. The desirability of a land use change is detectable by reviewing the main objectives of land use policies. Based on the national guidelines and the Land Use and Building Act (132/1999), the following objectives are relevant to the study areas of this thesis:

- Environmental protection and prevention of environmental hazards.
- Functionality of communities and good building.

To succeed in these objectives, it is better to position urban infrastructures and functional land use types, such as residential areas and main transportation routes, at a safe distance from sea-flood risk zones. This might help minimize damages due to environmental hazards. Because urban developments, which are portrayed as artificial surfaces in this study, require large budgets and labor, any damage to them interferes with their functionality. Additionally, natural areas and wetlands are helpful when dealing with natural hazards such as flooding events. Forests and semi-natural areas also support environmental protection aims, and non-motorized transportation systems are encouraged as green connection networks alongside the coastal areas of Helsinki and Espoo. Therefore, the land use conversions are divided into two groups indicated by green and red colors in the final conversion cost matrix (Table 10). This classification reflects better choices of land use types for areas at risk of coastal flooding. Green-colored land use conversions are aimed at reducing coastal flood risk and safeguarding the functionality of communities. Other land use changes colored in red do not affect or make little contribution to achieving the objectives listed in the Land Use and Building Act (132/1999).

To introduce effective land use policies, the values in each green cell of table 10 must be translated into a set of policy numbers. Accordingly, these policies listed in table 11 are labeled as effective at preventing the risk of coastal floods.

Table 11: Effective land use policies in preventing the risk of coastal flooding.

Desirable Land Use Conversion	Policy numbers	Policy names
Artificial Surfaces ⟶ Agricultural Areas	11	(02)- Vegetation measures are planned in the coastal areas of Östersundom to reduce the speed of water runoff and the risk of flooding (2012) (03)- New developments include residential areas, business areas, green connections, and recreational areas including recreational
Artificial Surfaces ⟶ Forests and semi-natural Areas	07, 08, 11	
Artificial Surfaces ⟶ Wetlands	02, 07, 08, 09, 10	
Agricultural Areas ⟶ Forests and semi-natural Areas	02, 07, 08, 11	

Agricultural Areas ⟶ Wetlands	02, 03, 05,07, 08, 09, 10	islands in Meri-Rastila-Vuosaari. (2016) (05)- Housing development in Pihlajisto with respect to natural and cultural values of Viikki old town bay and its surrounding (2015) (07)- Espoo's ecological network (EVN) is developed throughout almost all coastal areas to support biodiversity and sustainable use of cultural environments, ecological connectivity, and recreational network. (2008-2018) (08)- Developing a green network along the coastlines and naturally valuable areas, an environmental conservation plan, and supporting recreational uses for the city of Helsinki (2016) (09)- According to National land use guidelines, municipalities must be prepaid for extreme weather events and new constructions must be located outside flood risk zone areas or otherwise ensure flood risk management (2008-2017) (10)- Mapping flood-prone areas started in 2007 and giving instructions for flood preparation started by The European Parliament and The Councils on 23 October 2007. (11)- Construction in the shore zones is allowed only according to local detailed plans or a legally binding local master plan. This provision does not apply to the building required by agriculture and forestry or fishery.

In order to detect the degree of effectiveness we should pay attention to the degree of conversion in table 10. Among the desirable land use conversions, land use changes from agricultural to wetlands have the greatest degree of conversion. This means the policy combination involved in this change has made a wider impact compared to the policies that are involved in land use changes from artificial to agricultural areas. On the other hand, among the undesirable land use changes, the highest degree of change belongs to the land use conversion from forests and semi-natural areas to artificial surfaces. Among the policy combinations listed in table 11, policies related to the green network connection in Helsinki and to Espoo's ecological network (EVN) are the most frequently used to promote desirable land use changes. These policies could prevent coastal areas from the risk of coastal flooding, promote non-motorized ways of transport, and preserve environmental values and natural landscapes. Fiscal incentives, however, may be undermined by using the most demanded land in coastal areas to serve public needs, instead of putting them into more profit-generating uses in order to generate tax income.

Results indicate that land-use policies applied to the study area were effective in reducing the risk of coastal flooding. The majority of vulnerable land-use types, such as artificial surfaces, have been planned to be outside the flood risk zones. However, land-use changes cannot be separated by the boundaries of flood risk zones. As a result, policies that appear effective in this study might not work for other purposes. Land-use changes are blended into adjacent neighborhoods and can influence other parts of the study region as well. Furthermore, actual statistics show that the areas of artificial surfaces and agricultural land have declined within the boundaries of flood risk zones (see table 8). Therefore, the overall effectiveness of the land use policies applied to the study region is satisfying in terms of safeguarding the functionality of communities and preventing the risk of environmental hazards such as coastal flooding.

5 Discussion and Conclusion

5.1 Discussion

This thesis offers a framework for evaluating land use policy effectiveness. The risk of coastal flooding, one of the most concerning wicked problems in waterfront areas, is selected to frame the evaluation in a specific and clear manner. Evaluation of policy is a complex task, and land use planning poses wicked problems as well. More tellingly, urban planning generates wicked problems because it attempts to manage all the issues of urban living and the environment at once, just as what sustainability science is trying to accomplish (Mancebo, 2017). When facing conundrums like wicked environmental problems or land use planning issues, one reasonable way of handling them is to break the problem down into specific aspects. Land use policies and coastal flooding are the aspects covered by the present study.

Policy evaluation is demanded by several legislations to improve decision-making and policy outcomes. Yet, fewer scholars have attempted to evaluate land use policies. However, land use planners can benefit from the literature available on the evaluation of environmental policy instruments, and waste management policies (Cetrulo et al., 2018; Mickwitz, 2003). In both studies, statistical methods are suggested to measure the effectiveness of policies while in land use policy evaluation, location-based information and analysis can provide useful outcomes for planners and decision-makers. Because for improving the effectiveness of land use policies local knowledge is a crucial requirement, otherwise, the policy will fail either in implementation or in delivering the intended outcomes. Another tool used in related research is GIS which has been utilized to track land use changes and analyze the effects of these changes on various aspects of the urban environment such as preserving natural features (Taylor et al., 2007). This thesis refers to flood risk zones as a sample of local knowledge that enriches the application of land-use policies affecting coastal areas. Using software tools enables us to conduct explanatory research regarding policy effectiveness and actual outcomes caused by land use policies. Recently, several researchers used GIS and simulation tools for detecting land use policy effects (Brunner et al., 2016; Wang et al., 2019). Although software tools can be beneficial, researchers must be aware of their possible limitations. For instance, it is better to compare the simulated areas of each land-use type with reality to ensure the data has not been altered through different processes. In addition, the GeoSOS-FLUS tool uses multiple layers of data for simulating land-use scenarios and all the data layers must have similar attributes. In this equalization process, data layers might lose their quality. Therefore, it is better to find the optimal way to ensure the quality of data and meet the requirements of the software simultaneously.

The GeoSOS-FLUS software provides validity tests to compare the simulation model with actual land use cover. In the case of this thesis, the model starts with simulating according to the land use cover in 2000, and the simulation cycle will continue (according to variables set to the model) until areas of each land use type reach the demanded amounts in 2018. As a result, the areas of each land use type in the actual land use map for 2018 and in the final simulation model are equal. However, the allocation of land use types must be compared to reality. The Kappa statistic tool was used for this purpose. This test registered excellent results for the simulated land use cover. The overall accuracy is 0.93 and the Kappa coefficient is 0.88, both of which are excellent. Other detailed errors are listed in the table 12.

Table 12: The results of the validation test and simulation errors.

Land use type	**absolute error**	**systematic error**	**Kappa Coefficient**	**Overall Accuracy**
Artificial Surfaces	10174400	4,4 %	0.885631	0.933562
Agricultural areas	0	0		
Forests and semi-natural areas	0	0		
Wetland	1383200	11 %		

5.2 Conclusion

This thesis aimed at evaluating the effectiveness of Finnish land-use policies in preventing the risk of coastal floods in the waterfront areas of Helsinki and Espoo. Additionally, coastal flooding is redefined in order to indicate its relationship with wicked environmental problems such as rising sea levels. The direct answers to the research questions of this study are as follows:

1. How effective are municipal land-use policies in preventing the risk of coastal flooding in waterfront areas of Helsinki and Espoo?
   Municipal land-use policies applied to the study area were highly effective in preventing the risk of coastal flooding.

2. Why and to what extent is coastal flooding a wicked problem?
   According to the most definitions of wicked problems, sea floods have similar attributes to wicked environmental problems. Moreover,

Coastal flooding is a symptom of a greater wicked problem: sea level rise. Coastal flooding shares several attributes with wicked problems (see table 5).

Cities are hotspots of living areas that contain both wicked problems and hidden solutions simultaneously. Planners noticed long ago that traditional approaches to complex problems were no longer useful (Rittel & Webber, 1973). Repeated attempts to understand evolved versions of modern problems have led to a growing amount of literature on wicked problems. Wicked problems are known as complex problems that are impossible to define or solve because of having many vicious attributes such as dynamic context, conflicting aspects, diverse and multiple causal sources, discontinuous effects, and other similar features (Cajot et al., 2015; Duckett et al., 2016; Head et al., 2008; Rittel & Webber, 1973; Ruhl & Salzman, 2010). Yet, wicked problems respond to political and institutional approaches and not technical solutions, as there is an organized complexity behind the wickedness of urban planning dilemmas (Mancebo, 2017; Perry, 2015; Ruhl & Salzman, 2010).

Land use policies initiate political approaches in the urban planning context. Considering climate change as a super wicked problem, land use ordinances are an effective means of starting new norms and values that can maintain their effects over time and scales. Therefore, land use planning is a beneficial tool to mitigate climate change and promote resilient living environments (Adams-Schoen, 2016; City of Helsinki, 2019). Land use policies are the backbone of the land use planning system in Finland and evaluating these policies is mandated by the European Union and other national legislation. This study develops a framework for evaluating the effectiveness of land use policies in preventing sea flood risks. Sea floods have proven to be a wicked environmental problem, and land use policies can help prevent the risks of this hazard. The target application of this framework is to track the actual effects of land use policies. Through the developed framework, land use scenarios are simulated based on specific values, which reflect the effects of a policy set. A multi-policy analysis can be done using this framework to assess the impact of multiple policies on different land use conversions. The framework owes this functional capability to GeoSOS-FLUS software, as it produces simulations using ANN-based models and on the basis of CA theory.

The process of evaluating land use policies begins with setting up initial and target land use scenarios. The former scenario is based on the land use cover of the study region in 2000, and the latter represents the same information for the year 2018. There are four classes of land use (Artificial Surfaces, Agricultural areas, Forests and semi-natural areas, and Wetlands) and twelve possibilities for land use conversions. Furthermore, a list of land use policies that are applied to the study region has been collected. However, the boundaries of sea flood risk zones were considered when narrowing down the list of relevant land use policies. A value, based on expert knowledge, was assigned to each policy on this list indicating the intensity and direction of a land use policy. The process continues with making a conversion cost matrix by using policy assignments in formula (4) to calculate values in every cell of the matrix. This matrix represents the degree of change in each land use conversion. GeoSOS-FLUS considers this matrix as one of the main driving forces of land use change. The next stage of the process consists of simulating land use scenarios based on the conversion cost matrix and the demanded land use areas in 2018. The initial scenario was used as a starting point. The areas of each land use type in 2018 were inserted into the model as demanded land use areas. Thus, the iteration rounds continued until the simulated areas reached the required areas for each land use type. The outcome of the simulation was compared to the target scenario using the Kappa statistic tool. In case of a poor simulation result, the conversion cost matrix was adjusted. The simulation procedure was repeated until overall accuracy and Kappa ecoefficiency scores reached an acceptable rate.

As demonstrated by simulation results and validation scores, the developed framework outperforms existing methods for evaluating the effects of land use policies. The process ends with translating the values in the final simulation scenario into policy sets that have developed a causal relationship with land use changes. The results of the process specify the effects of land use policies on land use changes that happened between 2000 and 2018. These changes happened in the coastal regions of Helsinki and Espoo.

In order to evaluate the effectiveness of chosen land use policies in preventing the risk of coastal floods, land use changes were classified into two groups. The desirable land use changes are those that represent land use conversions from Artificial Surfaces to other types or conversions from Agricultural Areas to other types except Artificial Surfaces. Because natural areas and wetlands are the areas of the urban environment with less vulnerability. Depending on the purpose of using this framework, the classification of land use conversions might change. This is a valuable functional capability of this framework.

The results showed that land use planning performed well in the coastal regions of Helsinki and Espoo. Based on the results of the study, we can conclude that planners have been able to relocate vulnerable land use types outside the boundaries of sea flood risk zones. Both the simulation results and the comparison of land use types in 2000 and 2018 support this claim. However, future studies may focus on a detailed analysis of land use types based on criteria indicating the safe and sustainable development of waterfront areas. To accomplish this goal, it is suggested to reduce the expansion of the study area and increase the number of land use classes.

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Appendix

Appendix 1: the initial parameters for land-use simulations.

Land use (from)	Land use (To)			
	Artificial Surfaces	Agricultural areas	Forests and semi-natural areas	Wetlands
Artificial Surfaces	1	0,10	0,22	0,26
Agricultural areas	0,90	1	0,32	0,06
Forests and semi-natural areas	0,99	0,16	1	0
Wetlands	0	0,21	0,22	1