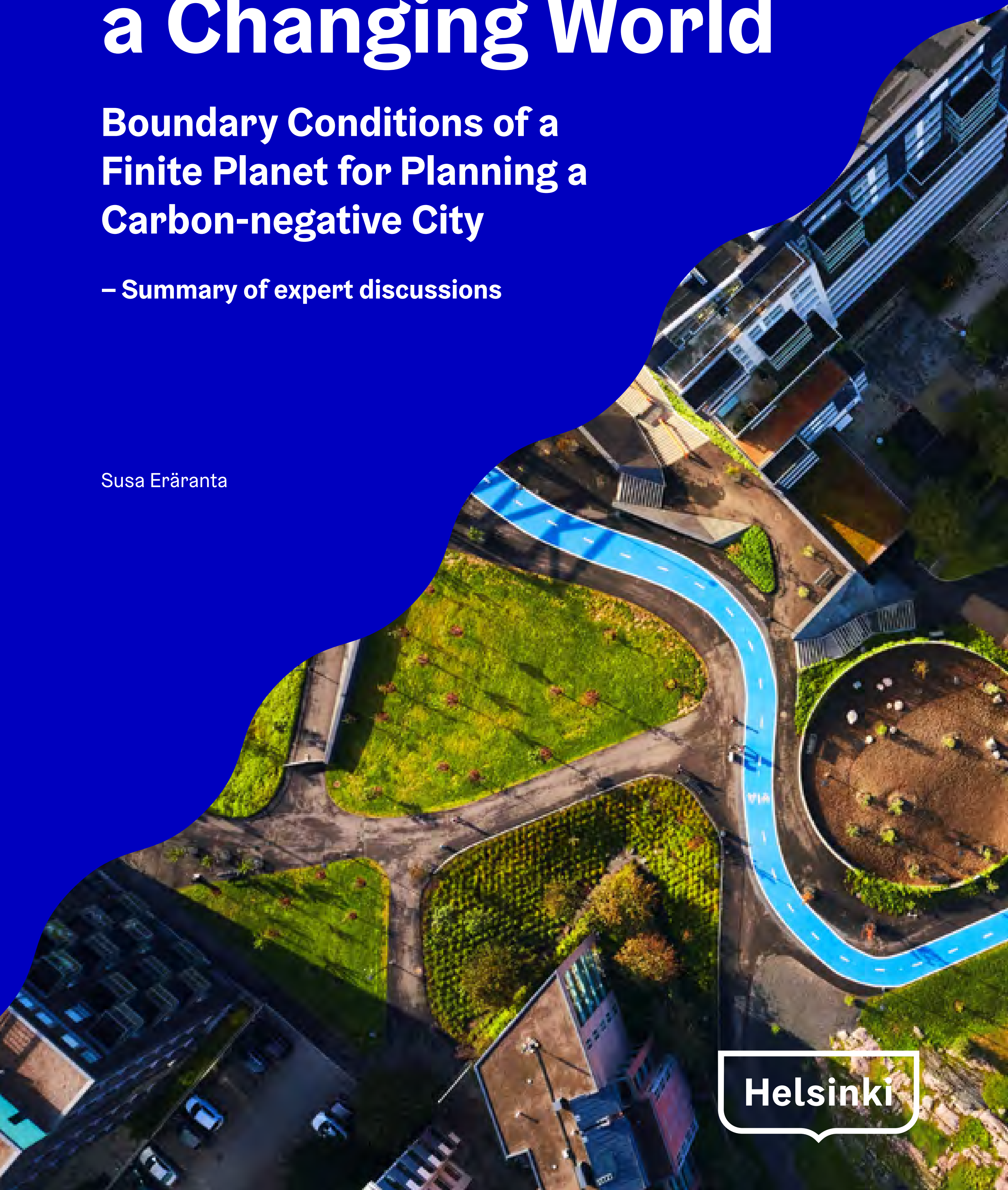
The City in a Changing World

Boundary Conditions of a Finite Planet for Planning a Carbon-negative City

– Summary of expert discussions

Susa Eräranta



Helsinki

**The City in a Changing World:
Boundary Conditions of a Finite Planet for
Planning a Carbon-negative City**

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Foreword

The past seven years have been the warmest period of time since measurements started being taken [1]. The changes have been more rapid than anticipated thus far. In 2021, four key climate indicators broke their respective records [2]. In early 2022, the temperatures in Antarctica exceeded their normal level by tens of degrees [3]. In the spring of 2022, we learned that land use in Finland formed an emission source due to increased logging and slower tree growth [4]. Over the course of 2022, vast areas across the globe were ravaged by wildfires caused by heat waves and drought. The 2022 World Cities Report [5] concluded that even the transition towards the carbon zero objective has been characterised by a lack of ambition. According to an assessment published the same year, the impact of the UN's sustainable development goals (SDG), which also pertain to the climate, is often discursive at best [6]. The current emission development trend is leading to a warming of up to 4 °C despite ambitious objectives. In addition to the warming, rapid changes have also taken place in terms of aspects such as biodiversity loss, soil degradation and the availability of critical materials. On the other hand, many improvements have taken place as well, but not enough. However, change is possible, and even major societal changes can take place within a relatively short time in an era, as history has shown us in the case of major societal transformations and crisis situations, for example [7].

Many cities have committed to the objectives of the Paris Agreement by setting more demanding emissions reduction targets in an effort to prevent dangerous global warming and secure living conditions in the future as well. The City of Helsinki is aiming for carbon neutrality by 2030, carbon zero by 2040 and carbon negativity after that [8] As the carbon neutrality objective set for 2030 means that the City's CO_2 emissions must be decreased by 80% from the level of 1990 and the remaining 20% can be compensated for outside the city borders, the mere transition to carbon zero requires that the CO_2 emissions produced and sequestered by the City are in balance within the city borders. In turn, carbon negativity means that emissions generated within the city borders must be lower than the City's ability to sequester carbon through its own actions.

Because the objectives set are still relatively new, practices for achieving them are yet to be established. The currently established practices and operating models are a contributory cause for the accelerating change, and they are constantly renewing climate challenges. However, being able to envision carbon negativity in more detail requires understanding of the world in which the envisioning is carried out. The city strategy states that in order to achieve the more demanding climate targets, a series of scenarios will be mapped out, to identify the possible paths to achieve the set targets.

The aim of this report is to support the concretisation of a carbon-negative future by providing information regarding both changes to be expected in our immediate operating environment and the most critical boundary conditions set by them for the City's planning operations and functions. The report paints a situational picture of the autumn of 2022 in terms of the themes examined, and it is based on literature analyses, expert interviews and expert workshops to concretise the aforementioned. The report does not assess how the identified boundary conditions may already be taken into account as part of planning or how it might be necessary to develop their further consideration.

Based on interviews and discussions with experts, the report examines seven boundary conditions to be taken into account in the planning of a carbon-negative city: the emissions reduction need, material limitations, biodiversity loss, global warming, increasing precipitation, windiness, and rise in sea levels and water bodies. In addition to the aforementioned, the conditions for achieving carbon negativity are also affected by other boundary conditions, such as the population of a specific geographical area and the notion of an acceptable minimum standard of living. However, examining these aspects requires broader value discussions and is thus excluded from this report. Unless stated otherwise, the change in each boundary condition is examined with regard to the current century.

In Helsinki 22.2.2023,
Susa Eräranta

1 Introduction

”Meaningful action in dark times is one that critically engages with possible futures”. (Halse 2022)

1.1 Climate targets and carbon negativity

Despite all the commitments and objectives in place, global climate emissions continue to increase (Figure 1). Due to accelerating urbanisation, city-level climate actions have been deemed to play a key role in achieving the objectives set in the Paris Agreement. Many cities have committed to the objectives of the Paris Agreement by setting more demanding emissions reduction targets in an effort to prevent dangerous global warming and secure living conditions in the future as well. For example, the City of Helsinki's strategy states the following [8]: *”We will move our deadline for achieving carbon neutrality up five years to 2030 [...] A goal to attain carbon zero status by 2040 will also be set [...] Helsinki will also start planning for a carbon-negative future”*. Figure 2 illustrates the differences between the climate objectives set for the future at the level of principle. The carbon neutrality objective set for 2030 means that the City's CO_2 emissions must be decreased by 80% from the level of 1990 and the remaining 20% can be compensated for outside the city borders. When transitioning towards carbon zero, the CO_2 emissions generated and sequestered by the City must be in balance within the city borders. In turn, carbon negativity means that emissions generated within the city borders must be lower than the City's ability to sequester carbon through its own actions. However, the ability of many cities to sequester carbon for example with forests and their soil, which are conventionally considered to be carbon sinks, will decrease in the near future as the amount of built land area increases, highlighting the need for major emissions reductions.

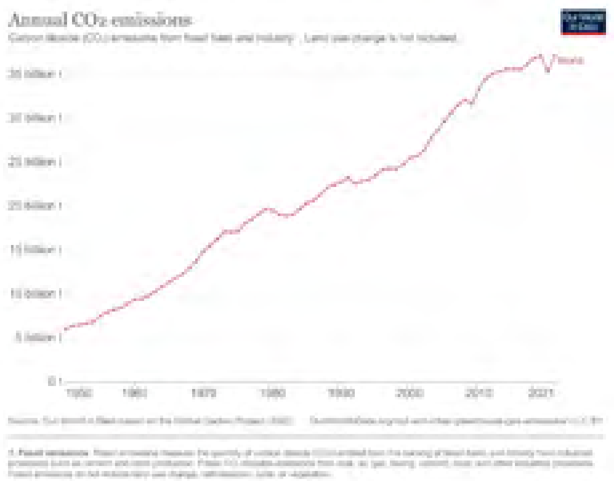


Figure 1. Despite ambitious objectives and commitments, global CO2 emissions keep increasing. Achieving the emissions reduction objectives set in the commitments requires increasingly effective actions [9].

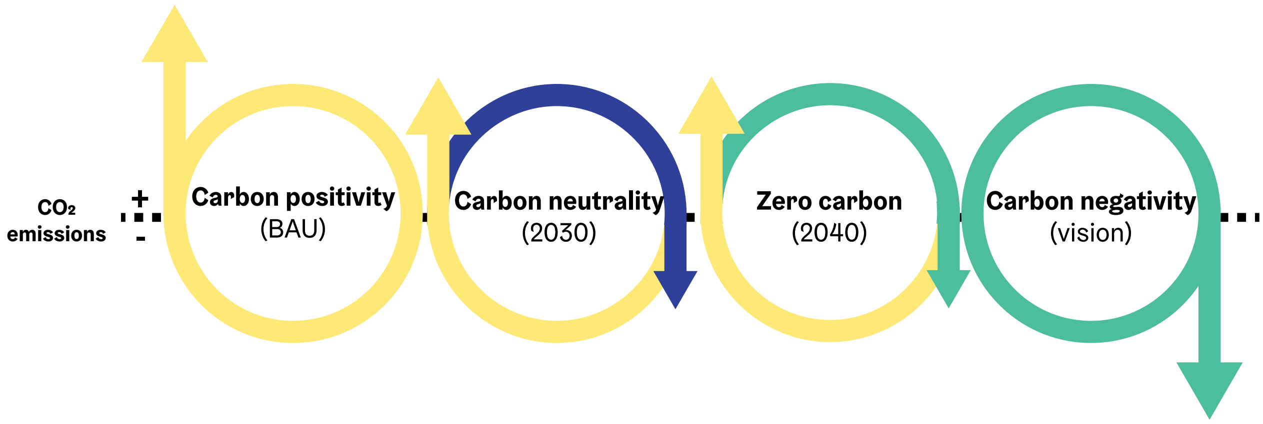


Figure 2. Main differences in the emissions reduction objectives set for the future after the current situation (BAU). The different planning levels target different aspects of the future and thus different climate objectives.

There is an urgent need to reduce climate emissions and no time for sub-optimisation measures anymore. Research has shown that cities have already fallen behind with their objectives [5] and the necessary measures have not been established as part of institutional practices and processes [10, 11, 12]. Even though the carbon negativity objective is set for further in the future, a carbon-negative city is already being planned for decades and centuries going forward. What we are planning and building now must also facilitate the achievement of more demanding carbon zero and carbon negativity targets in the future. In addition to increasing adaptability, it is important that the planning also results in emission-reducing actions, as only concrete actions count. The carbon negativity target no longer facilitates small-scale emissions reduction measures – instead, it requires a radical change in thinking [7]. However, in light of the development so far, it does not appear likely that significant emissions reductions can be achieved in a short period of time.

“The ship is sinking, and we need to use the same blocks to build a new one while it is going down.”

1.2 The aim of this report

Because the targets set are still relatively new, aspects such as the definition of carbon negativity are yet to be established in terms of content with regard to the boundary conditions and methods it sets, and they are not taken into account as part of current urban development and planning practices. The currently established practices and operating models are a contributory cause for the accelerating change, and they are constantly renewing climate challenges. Urban development continues to rely on sectoral and regional sub-optimisation with emphasis on one – or a few at the most – objectives at a time and the best interests of certain – or certain types of – areas [13]. The mitigation targets set cannot be achieved through currently applied practices or their incremental development, as the root causes for many challenges lie in the current economic and management systems [13, 14, 15]. The longer the current development trajectory continues, the more challenging it will be to achieve a change in habits within the limits of the carrying capacity of the planet [16]. However, change is possible, and even major societal changes can take place within a relatively short time in an era, as history has shown us in the case of major societal transformations and crisis situations, for example [7]. In any case, in the situation indicated by the targets, planning cannot be based on fulfilling only the current needs and must instead be based on taking the boundary conditions set by the future world more holistically into account.

Even though there has been discussion about planetary urbanisation [e.g. 13, 17, 18], directing attention increasingly towards the planetary impact of climate actions as well, preliminary surveys indicate that other cities have not established carbon-negative city visions as such, so there are no ready-made examples to learn from. Conversely, other scenario analyses requiring a transformative change have been carried out in other Nordic countries as well (see: Example 1, Example 2). What these analyses have in common is the observation that the change required is not possible through minor sector-specific actions, as it requires a systemic, consistent and target-oriented change that pertains to all sectors including the institutional context [19].

- **Example 1:** A research based degrowth scenario for the Oslo region [20, 21].
- **Example 2:** A research based degrowth scenario analysis by KTH [22, 23].

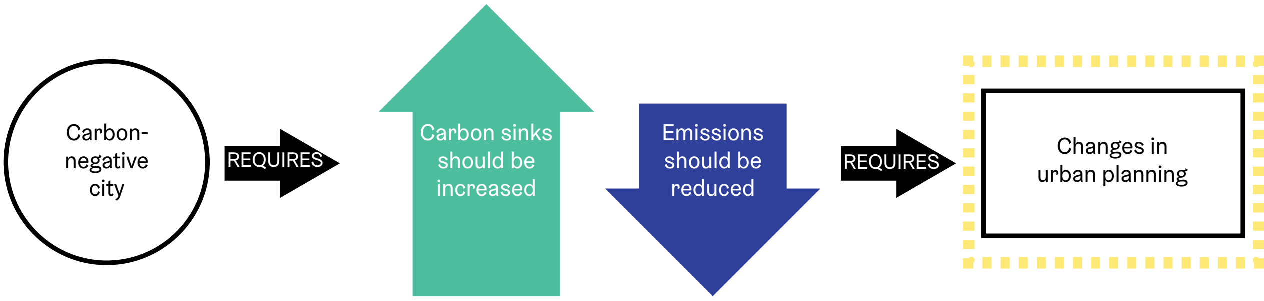
Carbon negativity requires seeing the big picture, implementing the most effective measures and making systemic changes (Figure 3). Concretising carbon negativity and promoting a carbon-negative future requires an ability and willingness to imagine futures that are drastically different from the current situation. Improving ways of thinking does not come equally naturally to everyone, and in addition to methods, it requires a robust knowledge base regarding both probable changes and their impacts – the boundary conditions of the world that we are imagining. The imagining needs to be supported with an adequate evidence-based situational awareness onto which targets can be built. Emissions reduction targets and the requirements set by other boundary conditions are not always codirectional. They can even be contradictory, making it important to examine the critical boundary conditions of a changing world as part of concretising the carbon negativity target.

Even though climate change is familiar to many as a phenomenon, understanding of the concrete boundary conditions it sets for planning continues to be lacking [24]. Many boundary conditions and the measures that they require are also place-specific, and it is important to examine them further at local level. The objective of this report is to support the concretisation of a carbon-negative future by providing research information regarding both changes to be expected in our immediate operating environment and the most critical boundary conditions set by them for the City's planning operations and functions. The report paints a situational picture of the autumn of 2022 in terms of the themes examined, and it is based on literature analyses, expert interviews (Appendix 1) and expert workshops (Appendix 2) to concretise the aforementioned. The themes were first exposed to expert knowledge outside the City organisation, which was later interpreted at the City's internal expert workshops with an emphasis on planning perspectives and methods. The report provides an account of the space delimited by boundary conditions, inside which the concretisation of a carbon-negative city can be promoted later. In addition to the actual boundary conditions and the needs set by them, the report aims also to identify their relationship with one another.

The report is divided into three key sections:

1. **The scales of analysis**, featuring brief accounts of the most important scales at which the impacts of the boundary conditions and methods for taking them into account are discussed:
   - Urban structure
   - Neighbourhood blocks and buildings
   - Individuals.
2. **The boundary conditions**, featuring a presentation of the most critical changes to be expected, based on expert interviews, that urban development and planning must adapt to, as well as ways to take them into account at different examination levels:
   - Emissions reduction need
   - Material limitations
   - Biodiversity loss
   - Warming
   - Increasing precipitation
   - Changes in windiness
   - Rise in sea levels.
3. **Steps towards carbon negativity**, featuring an outlining of the process of concretising a carbon-negative city and the institutional changes required for achieving the objective.

Figure 3. In a carbon-negative city, the number of carbon sinks must be greater than the emissions produced into the atmosphere. This requires changes to current planning.



2 Scales of analysis

This report discusses the boundary conditions of a changing world and ways to adapt to them through three scales of analysis, with their potential impacts on other boundary conditions identified taken into account as well. The scales of analysis are: the urban structure; neighbourhood blocks and buildings; and the individual.

The more demanding and long-term the climate targets are, the more systemic the ways to achieve them become. Carbon neutrality can be achieved fairly well though effective sectoral solutions, such as impacting the specific emissions of traffic and energy production, improving the energy efficiency of construction and using low-carbon construction materials. In turn, the achievement of carbon negativity requires systemic and even institutional changes in aspects such as the urban structure, circular economy in construction, and our mobility and consumption habits.

2.1 The urban structure

Examination at the urban structure level involves looking into matters related in particular to the placement of functions, mobility and accessibility, as well as the blue and green structure.

The urban structure as a whole is updated quite slowly. However, it plays a key role in the promotion of carbon negativity and in taking the boundary conditions of a changing world into account. Cities receive residents with a wide variety of backgrounds, diversifying lifestyles, needs and desires as well [25, 26, 27]. As such, it is important for cities to facilitate the diversity of life in the future as well, as sustainable solutions work only when they became part of everyday life. In addition to cleaner technology and low-emission fuel sources, attention must be paid to an urban structure that actively steers operators towards avoiding and reducing emission-intensive solutions, avoiding the so-called rebound effect and transitioning towards lower-emission choices [28, 29, 30, 31].

There is no clear-cut solution for the urban structure, as it is always connected to aspects such as the existing urban structure, networks and the regional location. However, it has been observed that an urban structure that inherently integrates different functions provides more opportunities from the perspective of viability and adapting to future changes than a structure that strictly differentiates functions [25]. A sufficiently dense and mixed structure has been shown to support aspects such as the activity of areas at different times of day and year as rhythms overlap and interlace. The density and diversity of an area are often key factors when talking about the sustainability of planning [32, 33]. Densification does not lead to direct emissions reductions, but it serves as a facilitator in the attainment of the emissions reduction targets set for transport, for example. According to research literature, densification efforts aiming at decreasing vehicle kilometres will eventually hit a wall [34] when the target is to also take the adaptability and comfort of the living environment into account [33]. The denser and taller an area is, the higher the probability of planetary effects outside the area becomes [35]. In recent years, there has been more and more discussion about concerns regarding the adverse effects of densification [36]. As cities grow denser, concerns are often voiced for example about the quality of housing potentially declining [37, 38]. In summary, density alone is not enough to ensure the achievement of climate targets. In particular, as the height of construction increases to a considerable degree, its energy needs and emission impact grow as technical systems increase [33].

In a carbon-negative city, operations are more optimised in many respects. In the urban structure, emissions and emissions reduction needs that affect the achievement of the carbon negativity target are largely caused by transport, which is affected not only by the structure and networks, but by the personal choices of individuals as well. Concrete means to take the emissions reduction target into account in the planning of the urban structure have been known for a long time. Such means include reducing transport needs based on private vehicles and vehicle kilometres by aiming to place additional construction along the existing infrastructure, overlapping different functions by mixing the urban structure, and ensuring sufficient efficiency with regard to the service structure [39], and they are also in line with taking material boundary conditions into account. Additionally, it is important to place construction in suitable locations in terms of aspects such as the soil, the microclimate and nature, maximising the amount of vegetative land area and renewing lost vegetation [39]. However, as regards transport, reducing unit emissions is not enough. Reductions are also needed in terms of vehicle kilometres and transport needs, as different transport needs are increasingly competing for the same space and energy [40].

Developing the urban structure and the service network is highlighted as a means to reduce transport performance. However, transport is not merely a source of emissions, as it plays a major role in urban life; not just in terms of moving from place to place and from the perspective of climate impacts, but also in the construction of the social environment [41, 42, 43]. Transport needs cannot be reduced infinitely, so it will be increasingly important in the future to take access to different types of areas into account: as everyday rhythms differ, aspects such as home, work, studies, social networks and services are not often located close to one another. As regards the remaining transport needs, the use of sustainable modes of transport must be promoted actively by paying special attention to aspects such as the passenger experience and the relative smoothness of transport chains in everyday life [44, 45]. In addition to developing the public transport network and the service level, it is important to create a pleasant and smooth walking and cycling environment. In light of recent research, the emissions reduction impact of car sharing, for example, may even be considerably lower than previously estimated (3–18% vs. up to 67%) [46], although the results regarding this are conflicting depending on the values emphasised in decision-making [47]. As such, the local-level mobility environment must be functional particularly from the perspective of sustainable modes of transport.

”Everyday mobility will be emphasised. I shouldn’t need to travel to Espoo from Eastern Helsinki to get a screw or something”.

Instead of density, actors increasingly often refer to intensifying the urban structure, which takes into account not only density, but diversity, connectivity and compactness as well [33]. In the future, a carbon-negative city must continue to provide opportunities for diverse life and different lifestyles. A sustainable city will provide different forms of density, housing and green structures in different parts of the city, while also taking their different impacts into account, as well as means to achieve climate targets and take the boundary conditions of a changing world into account. As society diversifies, the need for diversity in the city increases as well.

“As an increasing number of people want to be in the city or have to be there, the different people must also be provided with attractive places and conditions for living”.

2.2 Neighbourhood blocks and buildings

At the level of neighbourhood blocks and buildings, this report examines matters related to the immediate neighbourhood and individual construction projects.

Construction is a central theme impacted by the changing climate [48] and other boundary conditions. At the same time, construction itself is a significant source of emissions and difficult to make completely carbon-negative. Growth and the increasing construction brought about by it lead to higher and higher emissions with the current methods due to the increasing amount of construction. However, there has been a decrease in emissions per unit from construction. Even though buildings cover only one per cent of the surface area of our planet [49], more than half of global raw material needs are related to construction in particular [50]. In terms of quantity, carbon-intensive products are used the most in construction specifically [50]. There is no exact estimate with regard to Helsinki, but at the level of Europe and Finland, it has been estimated that up to one third of all CO_2 emissions are related to construction [51]. Load-bearing frame emissions typically make up roughly 35% of the product-specific emissions of buildings, while emissions from preparing the construction site make up roughly 16% [50].

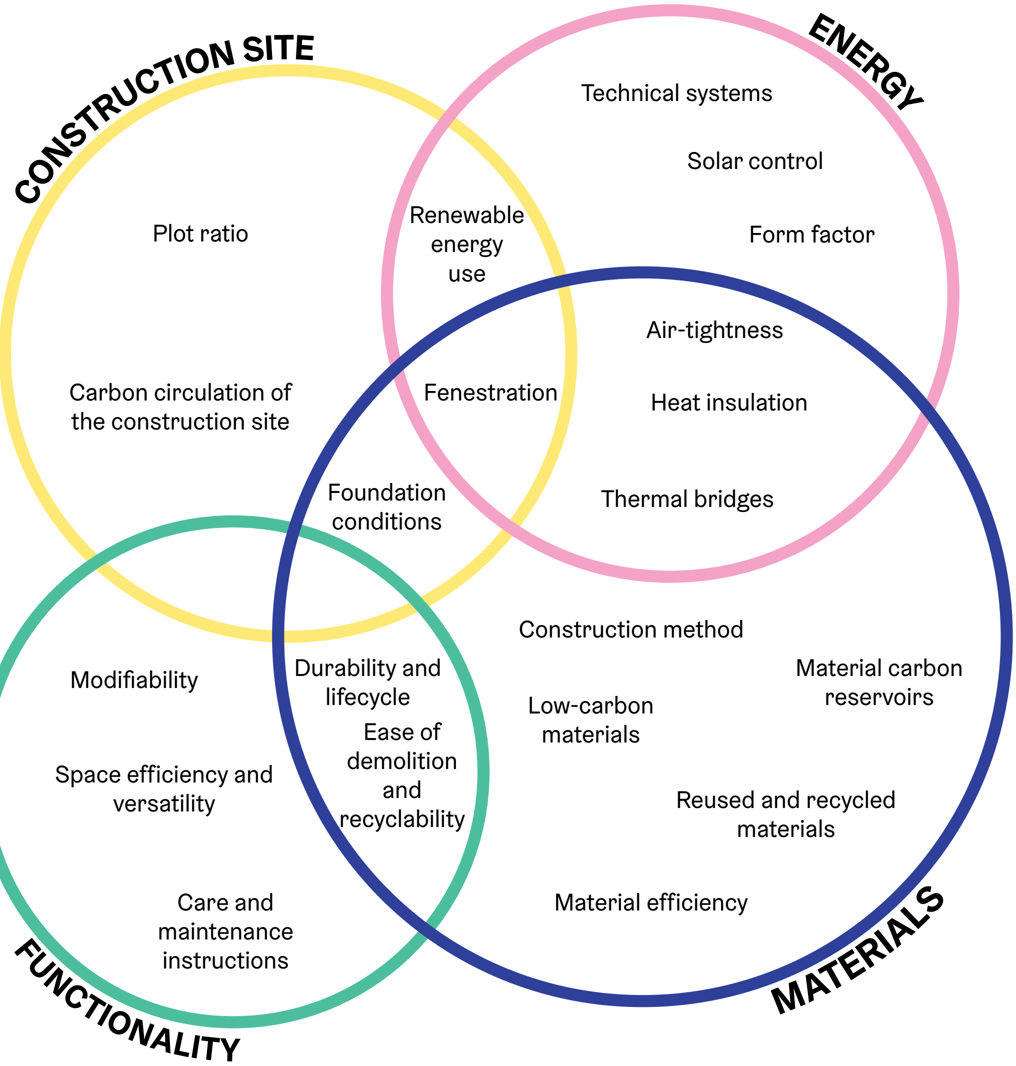
From the perspective of construction emissions, it is important to take the entire lifecycle into account. That is to say, in addition to the sourcing of raw materials, the manufacturing of products and transportation, emissions are also generated from energy consumption at the usage stage, the demolition of the building and waste disposal [50]. In repair construction, emissions are generated particularly from materials and the processing of demolition waste [50]. In addition to new and repair construction, the infrastructure and foundation construction required by construction projects are almost always a key source of emissions [50].

With regard to construction, ways to take emission targets into account, especially from the lifecycle perspective, have been known for a long time. Figure 4 presents partial factors in low-carbon construction, while Figure 5 shows the relative emission contributions of different building parts. One key method from the lifecycle perspective is designing buildings to be multi-purpose and flexibly modifiable, whereby they can be easily modified should their purpose of use change [39]. It is also important to take long-term durability, maintainability, reparability and the reuse potential of parts into account in the selection of construction materials and systems [39]. However, climate-wise construction is not merely a question of new construction, as it is also strongly related to the preservation, repair and reuse of the existing building stock. In terms of new construction, the situation is easier, as the planning process can be carried out with the future kept in mind from the start [52]. Conversely, the solutions implemented in repair construction must always be reconciled with the existing structural solutions [52]. When making changes to the existing structure, factors that must be taken into account include for example any changes to the moisture technology and indoor air quality of the buildings [52].

”A carbon-negative city looks different when there are more elements assembled from old pieces. What we have now is new and sleek”.

Circular economy based construction changes not only the lifecycle of building elements, but the aes-

Figure 4. Factors of low-carbon construction [based on: 50]



thetics of our urban environment as well. As a result of the combined impact of the changing conditions and emissions reduction requirements, fulfilling the aesthetic and functional objectives of buildings may become even more difficult in the future [52]. Structures can often be made functional in terms of needs caused by change, but this requires changes [52], causing an increase in construction emissions. It may also cause an increase in construction costs as the cost-efficiency of construction decreases [52]. As such, the current expectations regarding the cityscape and materials may need to be re-examined.

2.3 The individual

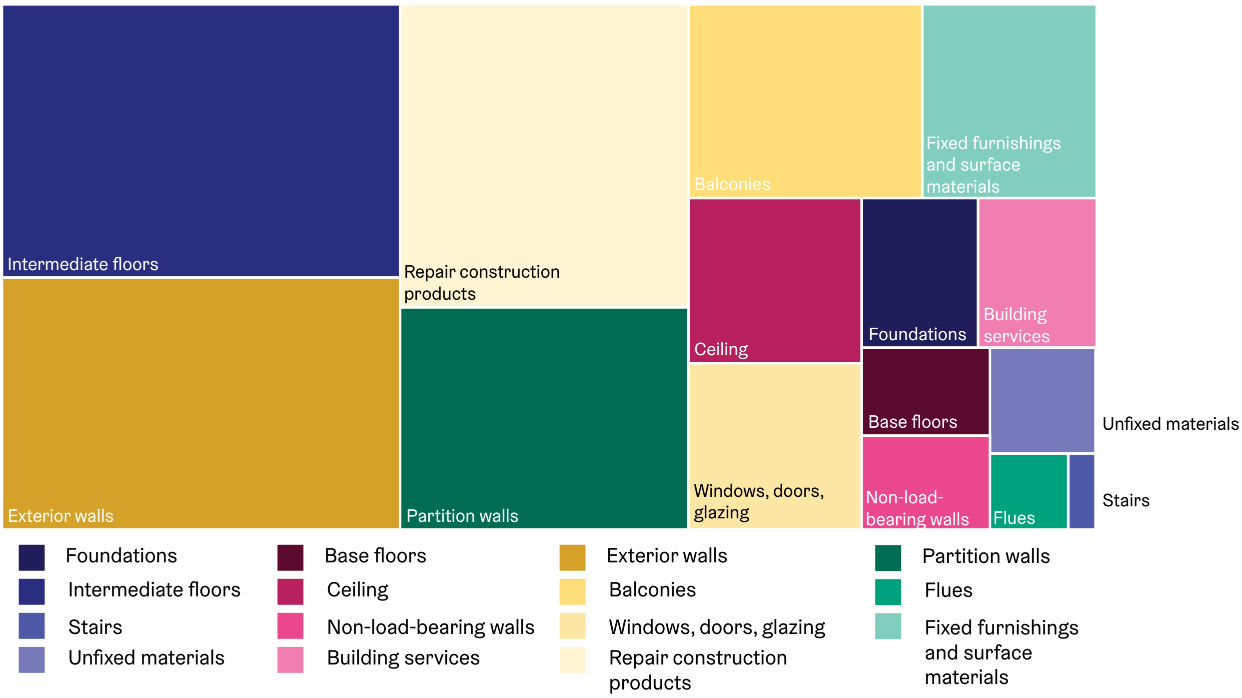
At the individual level, this report examines psychological, physical and social impacts particularly from a human perspective.

At the individual level, emissions are currently divided fairly evenly between housing (20%), transport and tourism (29%), food (18%) and other consumption (33%) [53]. It has been estimated that lifestyles and people's everyday choices play a major role in the achievement of climate targets in the long term [54, 55, 56, 57]. Lifestyle emission impacts are affected by three factors in particular: attitudes, facilitators and the infrastructure (Figure 6) [58]. The urban structure, services and other infrastructure provided by the city ultimately play a major role in whether low-emission choices are possible for residents and how attractive and easy such choices are found to be [59, 16].

According to studies, lifestyle-related emissions should decrease in Finland, for example, by approximately 60–80% in order for the 2030 targets to be achieved and by 80–90% for the 2050 targets to be achieved [60]. Emissions reductions of up to 95% in the current average lifestyle emissions are possible in order to maintain an adequate quality of life in countries of high personal consumption levels [61], as studies have shown that wellbeing does not follow increases or decreases in the standard of living linearly [62, 63, 64, 65]. Accordingly, several recent studies have challenged the idea of continuous growth in relation to the changes required by planetary boundary conditions [e.g. 66, 67, 68, 69, 70]. However, discussion regarding change needs related to growth targets and minimum and maximum standards of living is excluded from this report, as it requires broader societal discussion and changes. Nevertheless, changes are needed, as continuous growth on a finite planet is not possible.

In addition to emission impacts, demographic and socio-economic features have a major effect on where the human impacts of climate change take place, how they are experienced and who is in the

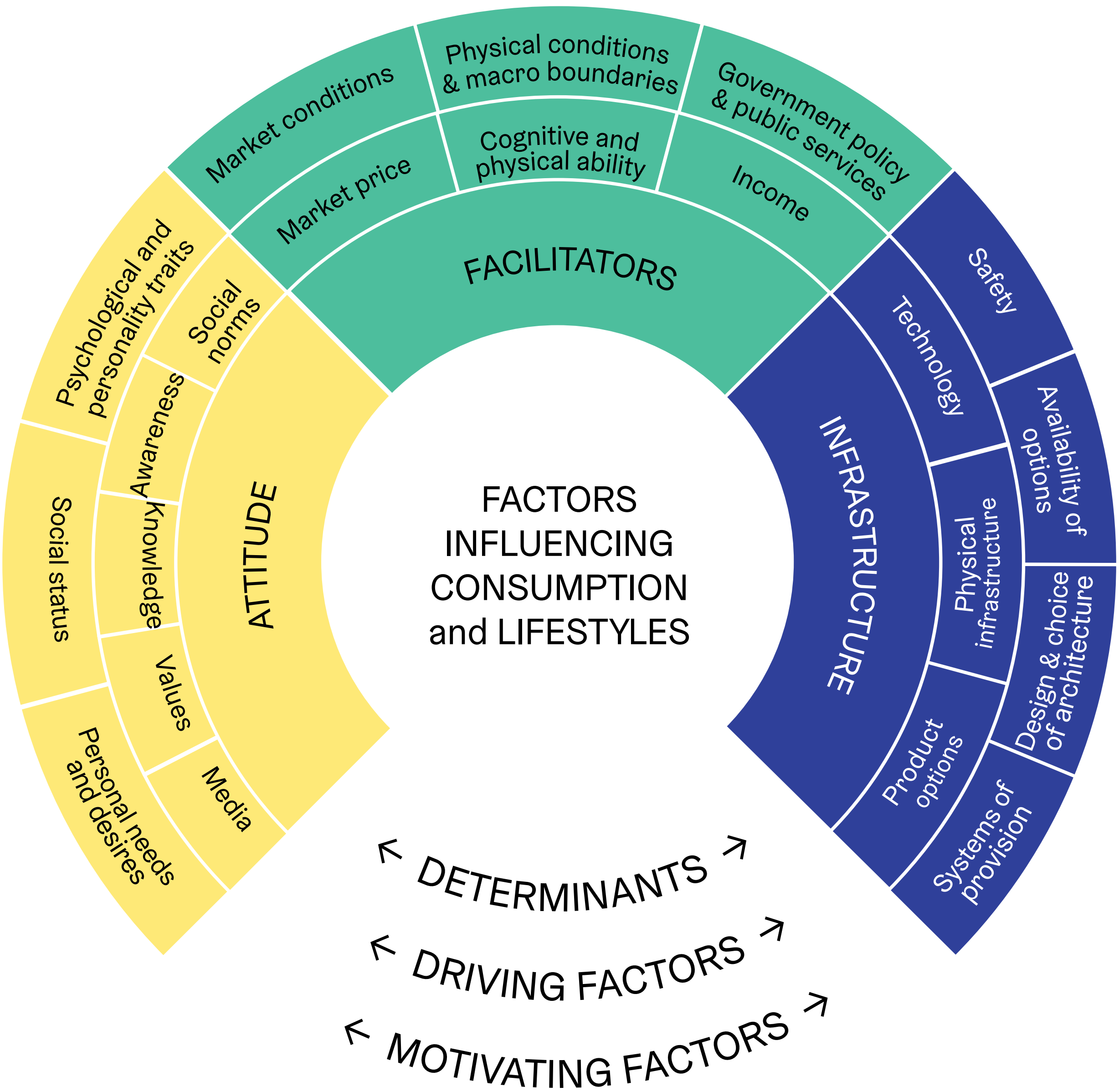
Figure 5. Relative emission contributions of building parts [based on: 50]



most vulnerable position in the midst of the change [71]. In addition to increasing physiological health risks, the changing world may have an impact on psychological and social wellbeing as people's everyday environment and conditions change [72]. However, emissions reductions can also lead to positive health impacts [73] due to factors such as physical activity becoming more common.

Accordingly, a key analysis perspective in terms of the human impact of the changing world of the future and a carbon-negative city is health and wellbeing [74, 75]. For example, the significance of urban nature to people's health has been studied a lot [76]. A pleasant and easily accessible environment helps with aspects such as recovering from stress [77, 78, 79], while biodiversity has significance in terms of promoting physical health [80]. Even brief visits to a green environment have been observed to have a positive impact on psychological wellbeing as well [78]. Green areas also prevent the occurrence of the urban heat island phenomenon by affecting the microclimate of areas. Even understated green elements can be important in supporting diversity and sequestering heat [81, 82].

Figure 6. In addition to attitudes and facilitators, infrastructure plays a key role in the formation of emissions [58]



3 The boundary conditions of a changing and finite planet for a carbon-negative city

The world is constantly changing and a stable "normal" situation can no longer be expected. In the future, we will live in a world where the boundary conditions have changed at the global and the local level alike. In addition to the emissions reduction target, the planning and design of a carbon-negative city must take at least material limitations, biodiversity loss, global warming, increasing precipitation, changes in windiness and rises in sea levels into account as critical boundary conditions. The boundary conditions, their impacts and ways to take them into account are examined in this report particularly from the perspective of changes affecting Helsinki, Finland.

Slightly less than half of the carbon dioxide released into the atmosphere due to human activity remains in the atmosphere after the rest has been dissolved into oceans and absorbed by plants and the soil [83]. The impact of the carbon dioxide remaining in the atmosphere will continue to change the climate for a long time. The change would not have been as rapid as it currently is without the impact of humans. The impact of human activity on the climate has been highlighted particularly due to the use of fossil fuels, deforestation and land modification [83, 84]. As regards the climate, a stable, "normal" situation can no longer be expected, as we are instead moving increasingly clearly into a time of constant change. Aside from the changing climate, many other things are also changing. The coming changes are strongly systemic. The operations of cities are based on a model that crosses the geographical boundaries of cities, which is why it is important to also take the overall impacts and needs of their operations and maintenance into account from the perspective of emissions and depleting resources alike [85].

The emissions reduction target, climate change and the boundary conditions related to the planetary carrying capacity require changes to our established operating models and lifestyle as well. Operating models based on the overconsumption of finite resources are not possible within the boundary conditions set by nature and materials. Planning must create the conditions for a carbon-negative future right now in the present, as the carrying capacity of Earth is about to reach its limit in many different areas at the same time [86, 87, 88] (figure 7).

Changes in different factors and their relations can increase or reduce impacts in ways that are difficult to predict. Many changes are connected to aspects such as the progress of global climate work. Accordingly, it is important to plan how the emissions reduction need is taken into account in a situation in which adapting the city to the changes required by other boundary conditions is taken into account as well. However, proactive preparation is more worthwhile in terms of risk management compared to a situation in which change needs are not responded to until the first realised risks or instances of damage have occurred [90]. Taking the risks related to climate change into account is illustrated in Figure 8. Examples of potential risks with economic significance include floods in urban areas, disruptions in energy and transport infrastructure, impacts on agriculture and forestry and the impacts of extreme conditions and increasing diseases on public health [91, 92, 93].

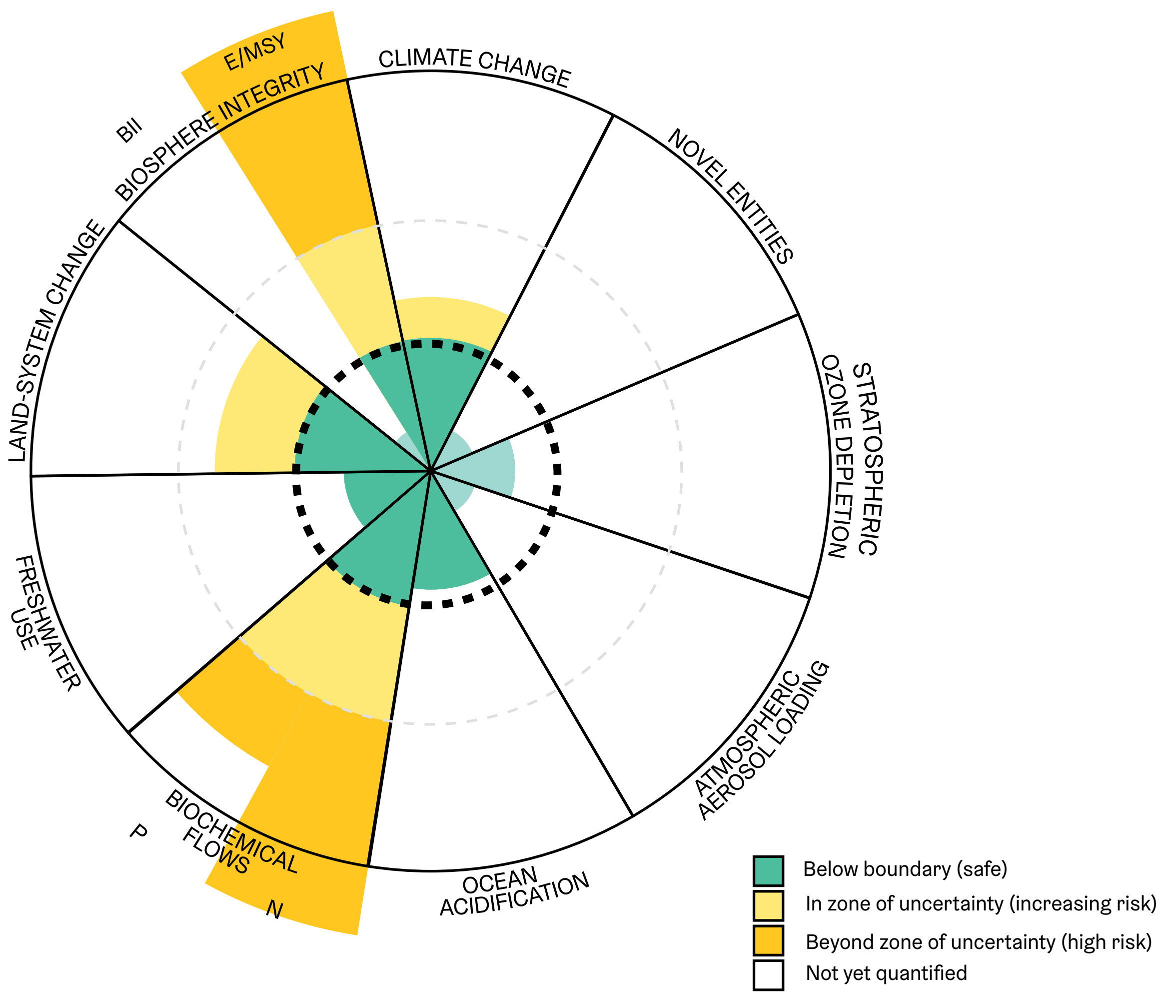
What are the primary critical functions to be protected when risks are realised? How should citizens be instructed? What else must be taken into account?

Several boundary conditions (Image 9) were identified based on research literature and expert interviews (Appendix 1), such as the emissions reduction need caused by global climate change and climate-driven migration, global material limitations, global biodiversity loss, adaptation needs caused by global climate change, minimum standard of living, cities' growth targets and the finiteness of available space. Of these, the following were identified as critical, to be taken into account at city level and to be examined in this report:

- **BOUNDARY CONDITION 1:** The emissions reduction need, which limits the possibilities for using emission-intensive solutions.
- **BOUNDARY CONDITION 2:** Material limitations, which in particular limit the possibilities for relying on heavily material-intensive and technological solutions.
- **BOUNDARY CONDITION 3:** Biodiversity loss, which must be taken into account particularly as part of climate change adaptation, carbon sink and carbon sequestration solutions.

Cities have a high population density and plenty of built environment, so the risks caused by climate change and the increasing extreme weather phenomena caused by it are significant to cities as well [94]. Because of this, it is important to form an understanding of the direction, magnitude and rate of changes as part of planning. When assessing climate

Figure 7. Planetary boundaries depicting the carrying capacity and state of different areas [89].



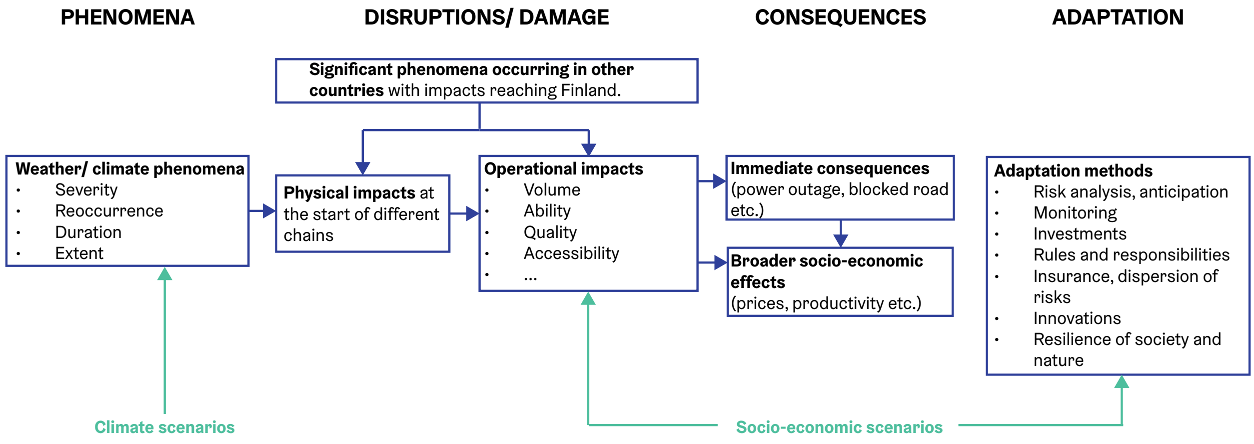


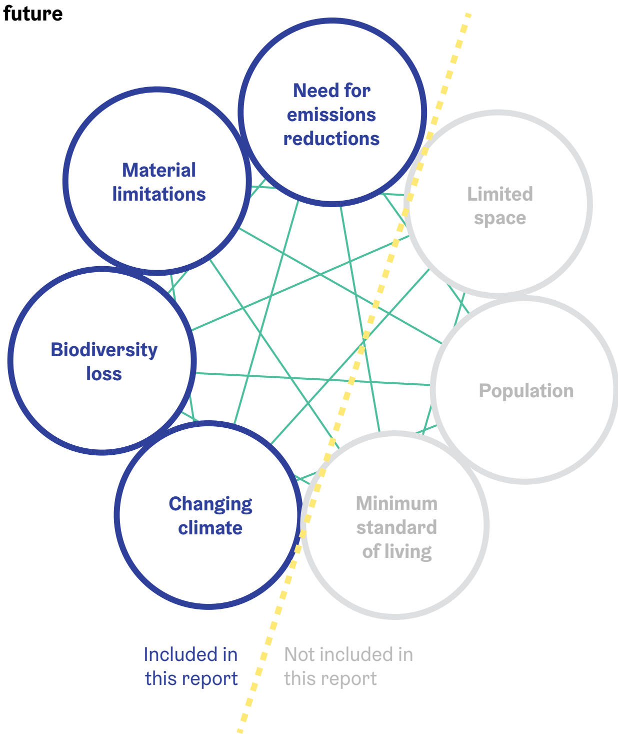
Figure 8. Structure of the climate change risk chain [93].

change, several alternative emission scenarios are taken into account [94]. The method of examining past statistics is losing its relevance as the rapidity of changes and fluctuations thereof increase [83]. The greatest uncertainties when modelling changes have to do with how greenhouse gas emission concentrations will develop over the next decades [95, 93]. From the perspective of the climate, the year 2050 is already drawing near, and the potential climates modelled by different scenarios do not differ greatly from one another. However, it must be noted that climate change has been more rapid than expected as it is. We are already seeing changes that were not expected to occur until decades later. The climate of Helsinki will also clearly change by the end of the century [96]. The most likely future situation lies somewhere between the target level of the Paris Agreement and the most pessimistic scenario [95]. Because of this, this examination focuses primarily on climate change scenario RCP4.5, which relies on partially successful climate policies and reductions in emissions around 2040. When talking about changes, it is important to bear in mind that major annual fluctuations are a natural part of the Finnish climate. Fluctuations from year to year will be typical in the future as well, but the key boundary conditions brought about by climate change should be taken into account in planning in the present:

- **BOUNDARY CONDITION 4:** warming.
- **BOUNDARY CONDITION 5:** increasing precipitation.
- **BOUNDARY CONDITION 6:** windiness.
- **BOUNDARY CONDITION 7:** rise in sea levels.

These boundary conditions set limits for the envisioning and planning of a carbon-negative city. Unless stated otherwise, this report examines changes with regard to the end of the century. In order to avoid sub-optimisation, this work aims to examine several boundary conditions identified as critical by experts simultaneously as part of the examination of methods. For example, where could cities find enough space for adaptation measures that require absorbant surfaces and are also subjected to pressures brought about by other functions? Or how should cities approach reducing emissions from transport fuel sources when the space available for transport is limited in any case? However, it must be noted that many boundary conditions and methods are also excluded from this examination.

Figure 9. Boundary conditions impacting a carbon-negative future



BOUNDARY CONDITION 1: The emissions reduction need

As the temperature of the climate increases, so does the probability of reserves of methane – which is stronger than carbon dioxide – releasing into the atmosphere, further strengthening the current development [83]. Many of these changes are irreversible. For example, glaciers have already started to melt, raising the sea level, and this development can no longer be reversed [72]. Based on emission scenarios, the change in the climate at the level of Helsinki – or even all of Finland – will not be dramatic from the perspective of viability. However, changes elsewhere will impact aspects such as increasing resource disputes and climate-driven migration, global supply chains, the availability of food and raw materials and the security of supply as living conditions become non-viable in places [97, 50, 95]. Global warming will cause additional problems particularly in areas that are already vulnerable to begin with [95], and in the future, climate change will be a significant reason for migration to cities if emissions are not reduced effectively at global level as well (Figure 10) [98]. As climate change progresses, cities must also prepare for climate-driven migration. In addition to actual hazard factors, the formation of climate risks is affected by vulnerability and exposure.

In order to concretise the emissions reduction need, it is important to understand which emissions classes should be affected primarily. The emissions classes that are highlighted in the achievement of the carbon neutrality objective will not necessarily be relatively the most significant later on in the future. So, what will be highlighted in the future in terms of the emissions reduction need? When faced with something new, we are often affected by a scale fallacy. It is difficult to grasp whether we are talking about abundance or scarcity in the future. Which actions or inactions have significance in terms of scale? When time and resources are limited, it is imperative to ensure that they are enough at least for the most impactful actions that can lead to the achievement of the objectives set.

Like other cities, Helsinki is currently systematically and comparably monitoring only the development of its Scope 1 and 2 emissions [100], as consumption-based calculation methods are yet to be established and thus incomparable with the aforementioned [101, 102, 103, 104]. Several overlapping and partially deficient calculation and assessment methods are in use, but the comparability regarding the relative importance of the different emissions

Figure 10. Climate change will continue to be a significant reason for migration as climate-driven migration will increase [99].

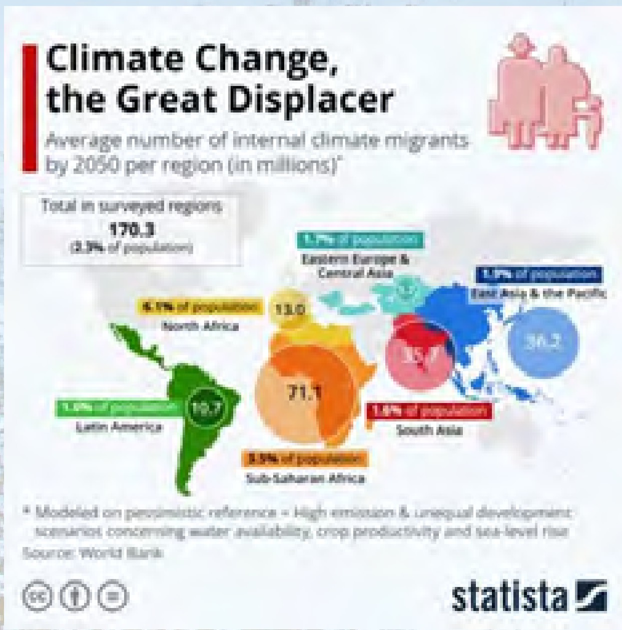


Photo: Yiping Feng and Ling Ouyang

At European level alone, public health, wildfire, food production and energy production related risks brought about by the reoccurrence and duration of heat waves will be highlighted in particular [97]. These risks also have reflective effects on Finland. As such, achieving emissions reductions and slowing down climate change are critical from the local perspective as well.

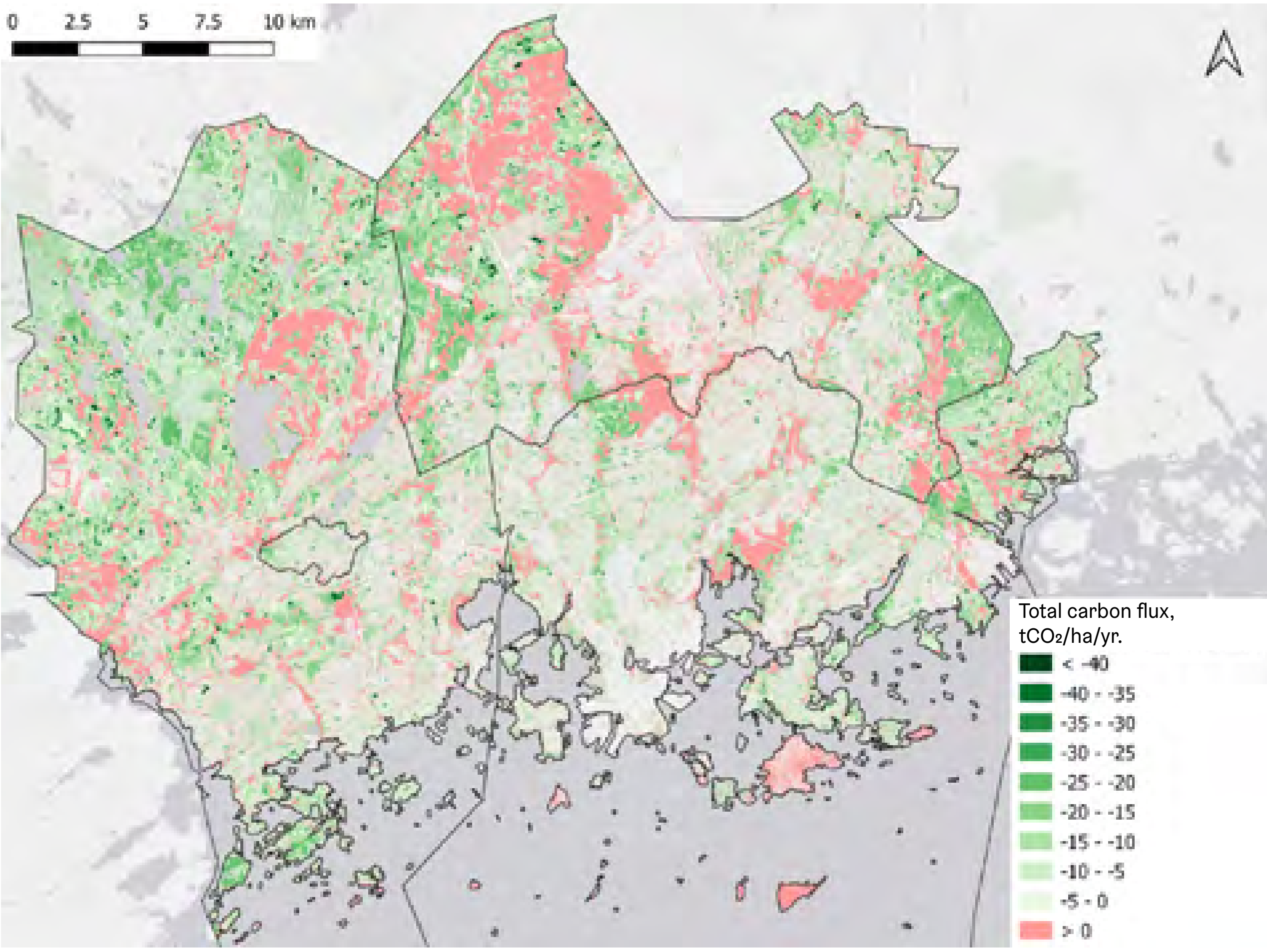
BOUNDARY CONDITION 1: The emissions reduction need is critical and emission-intensive solutions where the caused emissions exceed the reduction/ sequestration potential must be avoided.

classes that is required to support effective climate work has not yet been available [105, 106]. However, striving towards carbon negativity requires an indicative understanding of the current situation regarding Scope 1, 2 and 3 emissions, as well as an assessment of what emissions level can be achieved through BAU development by 2030, 2040 and 2050. As part of its background survey work regarding the carbon negativity objective, Helsinki has commissioned a comparable assessment of its Scope 1, 2 and 3 emissions for these comparison years in order to focus its measures [107].

In addition to actual emissions, the notion of carbon sinks and sequestration is often brought up. For example, plants sequester roughly one quarter of the world's carbon dioxide emissions [83]. In addition to nature, construction can also sequester carbon [e.g. 108]. The utilisation of materials (e.g. wood) for as long-term use as possible is highlighted in carbon sequestration in construction. In Finland, forests and their soil have sequestered approximately 1,000 teragrams of carbon each, while swamps have sequestered 5,500 teragrams [83]. However, carbon-sequestering nature has been modified heavily over the years [83] and the land use sector has turned from a carbon sequesterer to a carbon source [109].

In 2018, the carbon footprint of the average Finn was roughly 10 tCO_2-e [110]. It has been estimated that sequestering that amount requires roughly two hectares of new bare land to be afforested per person. As a biotope, a Finnish forest sequesters carbon at a rate of roughly 4.13 tCO_2-e/ha/yr. [111]. Only a growing forest sequesters carbon from the atmosphere. A young forest in a strong growth phase is the most effective as a carbon sink, but the carbon reservoir accumulated is at its greatest at the last stage of the forest [83]. In 2019, the calculated combined carbon sink of green areas located within the city borders of Helsinki was 8.58 tCO_2-e/resident (5,610,600 tCO_2-e), of which 35% (1,970,784 tCO_2-e) was sequestered by vegetation and 65% (3,639,800 tCO_2-e) by the soil [112] (Figure 11). However, is it possible to

Figure 11. Siting of the total carbon flux in the Helsinki metropolitan area [113].



increase the amount of forested surfaces and soil that serve as carbon reservoirs sufficiently within the city borders in relation to the current level of emissions (Example 3)? Or is it possible to use global carbon sinks to compensate for emissions (Example 4)?

- **Example 3:** With the population of 2019, the calculated carbon sequestration need of all Helsinki residents [114] was approximately 1,392,670 ha/yr., i.e. 13,926 km²/yr. In 2014, the total amount of forest-covered area in Helsinki was approximately 47 km² [115]. As such, the area needed for covering the sequestration need of all Helsinki residents is roughly 1.5 times the area of the entire Uusimaa region.
- **Example 4:** In 2021, global carbon sinks were only 0.76 tCO_2-e per resident at the calculated level. Of this, 0.40 tCO_2-e/resident (total 3,100,000,000 tCO_2-e) was sequestered by soil and 0.36 tCO_2-e/resident (2,800,000,000 tCO_2-e) by oceans [116]. How large, then, is the scale of compensating for total emissions generated from construction.

As regards green areas, studies have not determined the smallest significant size for a green area in terms of carbon sink or sequestration potential [71]. The greatest carbon sequestration potential of an urban living environment has been found to lie in vegetation, the soil and wood construction [118]. When assessing urban carbon sinks, it must be noted that in urban conditions, the potential is different from that of forest ecosystems, on which the estimates are largely based [119]. It must also be noted that, for example, street trees take up to 14 years to turn from a carbon source to a carbon sink at the annual level [119]. Cumulatively, becoming a carbon sink can take up to 30 years [120]. As such, with regard to carbon sinks, it is important to take the impact of the soil into account in addition to trees and other vegetation.

For example, the carbon sequestration potential of biochar has been found to be greater than that of elements such as trees [121]. In boreal forest areas, the greatest carbon sequestration potential lies in the soil. By contrast, elements such as green roofs, which are often mentioned as a partial solution, have been found to have a carbon sequestration potential comparable to that of yards and gardens [122, 123], yet their carbon storage ability is considerably lower due to their more limited and shorter-growing range of species, as well as the need to regularly renew the vegetation [118]. The sequestration impact of green roofs is not necessarily always enough to compensate even for the increasing emissions caused by their structural solutions [71]. How large, then, is the scale of compensating for total emissions generated from construction?

> ”In terms of compensation, people think that there is another planet on which it can be done; we are compensating somewhere else.”

As regards technical carbon sequestration and sink solutions, the efficiency of the world's largest current CCS (operational large-scale carbon capture and storage facility) is 7,000,000 tCO_2-e/yr. (Shute Creek Gas Processing Plant, USA), while the combined efficiency of all of the worlds CCSs is 38,220,000 tCO_2-e/yr. [124]. As the global annual CO_2-e emissions are approximately 34,900,000,000 tCO_2/yr. [125], the sequestration potential of even the world's largest CCS solutions remains quite low and significant emissions reductions are needed at global level as well.

As carbon sequestration opportunities in a delimited geographical area are limited, the significance of the emissions reduction need increases. In order to be realised, the emissions reductions required by carbon negativity demand from the urban structure that the existing infrastructure and structures are utilised to their fullest extent and urban structure relying on car-dependence is reduced. Density is one factor here, but it alone is not enough and may also lead to undesirable solutions. In addition to the urban structure, the amount of new construction needed must be moderated due to the emission load of construction, with attention paid to aspects such as the total amount, modifiability and space efficiency of construction. Emissions generated from necessary excavation and earthmoving work can be reduced by decreasing the amount of change work needed through taking aspects such as the terrain and ready-made infrastructure into account early on in the placement of construction [50]. In addition to energy needs, planning solutions affect aspects such as service life, future repair and change needs and the amount of materials needed [50].

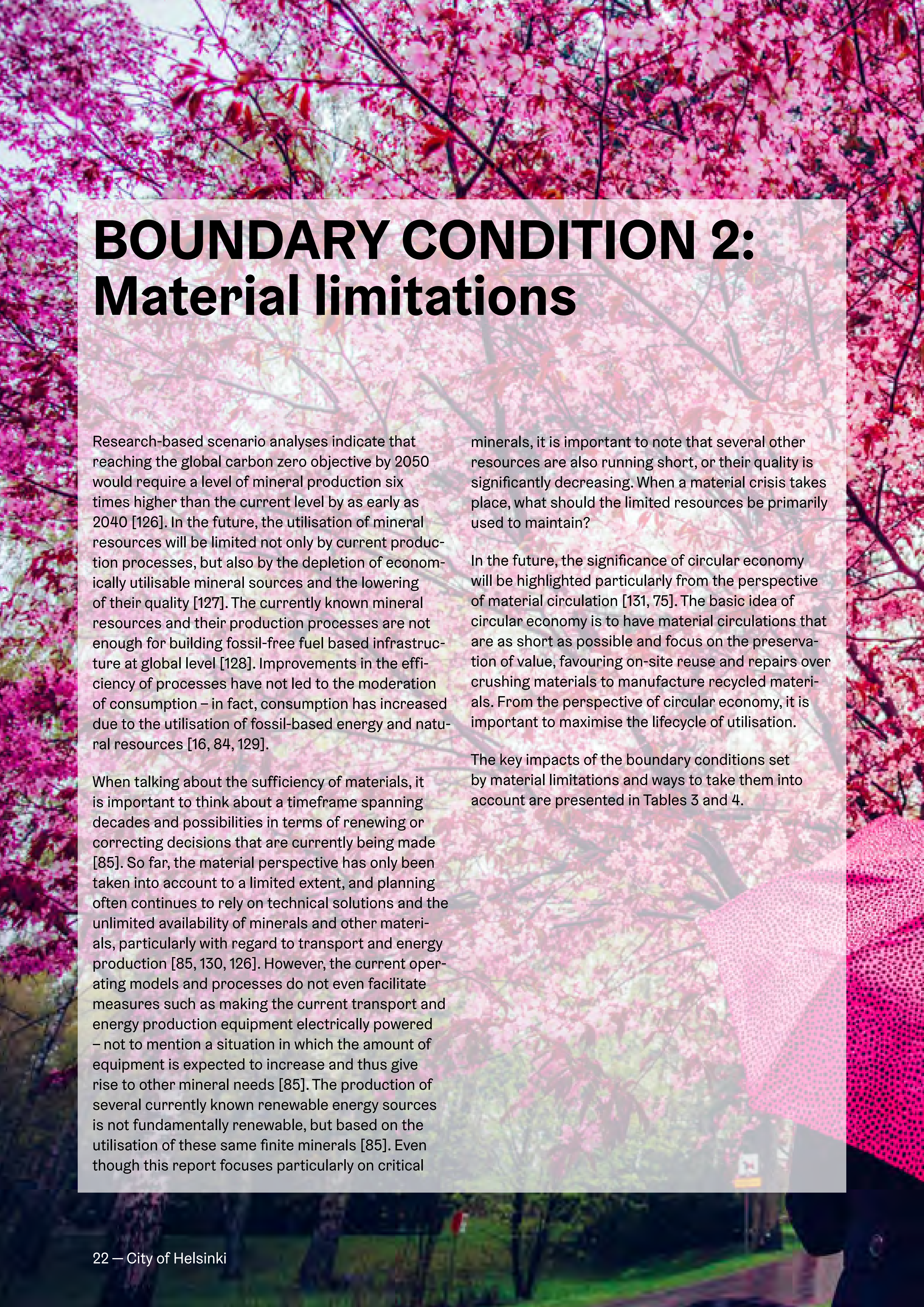
The key impacts of the boundary conditions set by the emissions reduction need and ways to take them into account are presented in Tables 1 and 2.

Table 1. Identified impacts and their significance for the boundary condition 1.

		1: CO_2	2: Materials	3: Biodiversity	4: Warming	5: Precipitation	6: Wind	7: Sea level
Urban structure	The emissions reduction need is critical for carbon negativity. The possibilities for carbon sinks and sequestration are not enough to achieve the objective.	+++						

Table 2. Identified means and their effectiveness for the boundary condition 1.

		1: CO_2	2: Materials	3: Biodiversity	4: Warming	5: Precipitation	6: Wind	7: Sea level
Urban structure	Minimising transport needs based on private driving by diversifying the urban structure and building new structures along the existing infrastructure.	+++		--	---	--		
	Densification of the urban structure.	+++		--	---	--		
	Building a walkable and cyclable city. In addition to the network, a walkable and cyclable city is sensitive to the quality and details of the urban space.	+++						
	Taking the terrain and ready-made infrastructure into account in location choices in order to minimise the amount of excavation and earthmoving work.	++	++					
	Moderation in construction (total amount, dwelling density, modifiability, space efficiency).	++	++					
	Strengthening the carbon sequestration potential of the marine ecosystem.	+		++				
Neighborhood blocks	Utilising the usable sunshine angle in order to maximise the potential of solar energy.	+	-					
	Providing non-consumption-based public space. A network of green and recreational areas is key to this.	+		++				
Buildings	Designing buildings to be multi-purpose, flexible and easy to modify.	++						
	Increasing the lifecycle of buildings: relaxing their functional and aesthetic requirements.	++	++					
	Utilising wasted spaces.	++	++					
	Increasing the lifecycle of buildings: streamlining maintenance and renovation projects.	++	++					
	Utilising low-carbon construction materials.	++						
	Improving the energy efficiency of buildings.	++	-					
	The long-term durability, maintainability and reparability of construction material and system choices.	+						
	Orienting the building in relation to the sun.	+			+			



BOUNDARY CONDITION 2: Material limitations

Research-based scenario analyses indicate that reaching the global carbon zero objective by 2050 would require a level of mineral production six times higher than the current level by as early as 2040 [126]. In the future, the utilisation of mineral resources will be limited not only by current production processes, but also by the depletion of economically utilisable mineral sources and the lowering of their quality [127]. The currently known mineral resources and their production processes are not enough for building fossil-free fuel based infrastructure at global level [128]. Improvements in the efficiency of processes have not led to the moderation of consumption – in fact, consumption has increased due to the utilisation of fossil-based energy and natural resources [16, 84, 129].

When talking about the sufficiency of materials, it is important to think about a timeframe spanning decades and possibilities in terms of renewing or correcting decisions that are currently being made [85]. So far, the material perspective has only been taken into account to a limited extent, and planning often continues to rely on technical solutions and the unlimited availability of minerals and other materials, particularly with regard to transport and energy production [85, 130, 126]. However, the current operating models and processes do not even facilitate measures such as making the current transport and energy production equipment electrically powered – not to mention a situation in which the amount of equipment is expected to increase and thus give rise to other mineral needs [85]. The production of several currently known renewable energy sources is not fundamentally renewable, but based on the utilisation of these same finite minerals [85]. Even though this report focuses particularly on critical minerals, it is important to note that several other resources are also running short, or their quality is significantly decreasing. When a material crisis takes place, what should the limited resources be primarily used to maintain?

In the future, the significance of circular economy will be highlighted particularly from the perspective of material circulation [131, 75]. The basic idea of circular economy is to have material circulations that are as short as possible and focus on the preservation of value, favouring on-site reuse and repairs over crushing materials to manufacture recycled materials. From the perspective of circular economy, it is important to maximise the lifecycle of utilisation.

The key impacts of the boundary conditions set by material limitations and ways to take them into account are presented in Tables 3 and 4.

Photo: Jussi Hellsten

We are living on a finite planet, and in the future, its material boundary conditions can no longer secure a societal model that is based on overconsumption. It is unlikely that securing our current lifestyle by switching to greener technology is possible [34]. It is important to prepare for changes in planning work and be ready to imagine futures other than ones based on critical resources [85]. Based on studies, the use of minerals and other materials in particular needs to be moderated and prioritised.

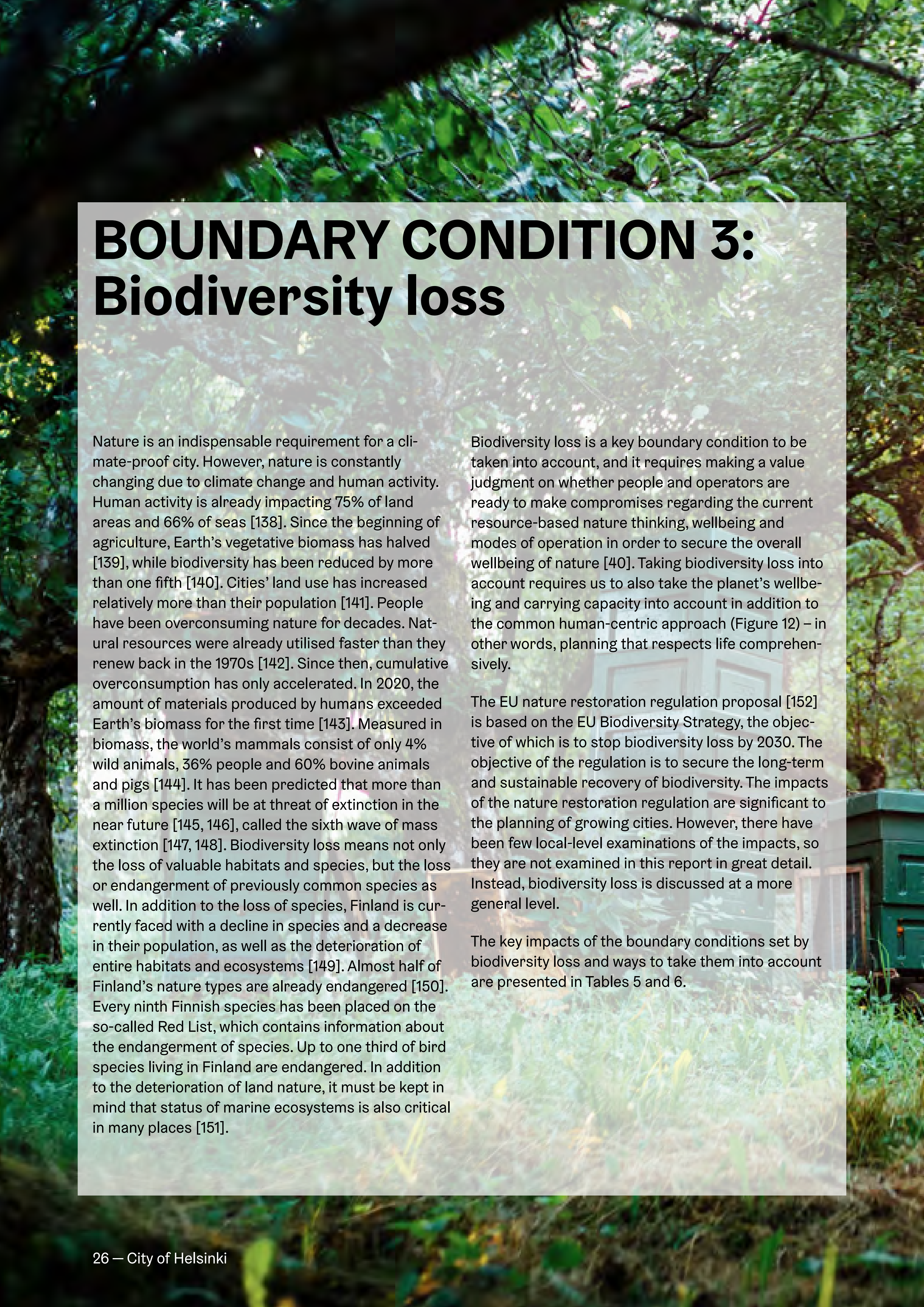
BOUNDARY CONDITION 2: Solutions cannot be based only on new technology that has not yet been invented but must instead also work in a world with scarce resources and rely strongly on existing infrastructure.

Table 3. Identified impacts and their significance for the boundary condition 2.

		1: CO_2	2: Materials	3: Biodiversity	4: Warming	5: Precipitation	6: Wind	7: Sea level
Urban structure	Favouring non-material-intensive solutions. The current processes and known mineral resources are not enough to fulfil the need for materials and critical minerals.	+	+++					

Table 4. Identified means and their effectiveness for the boundary condition 2.

		1: CO_2	2: Materials	3: Biodiversity	4: Warming	5: Precipitation	6: Wind	7: Sea level
Urban structure	Utilising the existing infrastructure and other structures.	++	+++					
	Assessing material and mineral intensive solutions and examining risks from the perspective of global availability.		+					
Buildings	Favouring on-site reuse of materials and repair.	+	++					
	Maximising the lifecycle of building use.	+	+					
	Increasing lifecycle. Whatever is done is done properly and durably.	+	+					



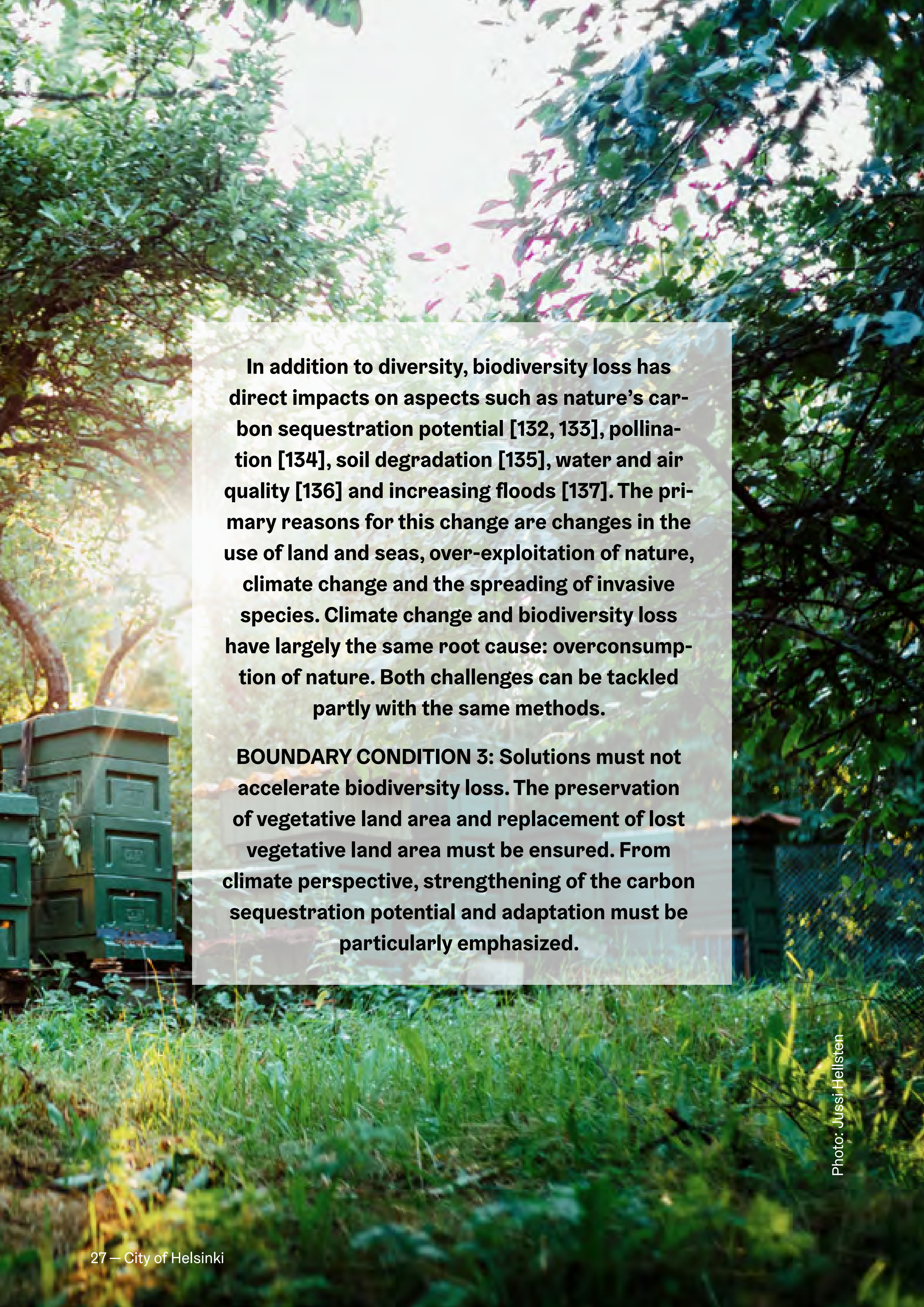
BOUNDARY CONDITION 3: Biodiversity loss

Nature is an indispensable requirement for a climate-proof city. However, nature is constantly changing due to climate change and human activity. Human activity is already impacting 75% of land areas and 66% of seas [138]. Since the beginning of agriculture, Earth's vegetative biomass has halved [139], while biodiversity has been reduced by more than one fifth [140]. Cities' land use has increased relatively more than their population [141]. People have been overconsuming nature for decades. Natural resources were already utilised faster than they renew back in the 1970s [142]. Since then, cumulative overconsumption has only accelerated. In 2020, the amount of materials produced by humans exceeded Earth's biomass for the first time [143]. Measured in biomass, the world's mammals consist of only 4% wild animals, 36% people and 60% bovine animals and pigs [144]. It has been predicted that more than a million species will be at threat of extinction in the near future [145, 146], called the sixth wave of mass extinction [147, 148]. Biodiversity loss means not only the loss of valuable habitats and species, but the loss or endangerment of previously common species as well. In addition to the loss of species, Finland is currently faced with a decline in species and a decrease in their population, as well as the deterioration of entire habitats and ecosystems [149]. Almost half of Finland's nature types are already endangered [150]. Every ninth Finnish species has been placed on the so-called Red List, which contains information about the endangerment of species. Up to one third of bird species living in Finland are endangered. In addition to the deterioration of land nature, it must be kept in mind that status of marine ecosystems is also critical in many places [151].

Biodiversity loss is a key boundary condition to be taken into account, and it requires making a value judgment on whether people and operators are ready to make compromises regarding the current resource-based nature thinking, wellbeing and modes of operation in order to secure the overall wellbeing of nature [40]. Taking biodiversity loss into account requires us to also take the planet's wellbeing and carrying capacity into account in addition to the common human-centric approach (Figure 12) – in other words, planning that respects life comprehensively.

The EU nature restoration regulation proposal [152] is based on the EU Biodiversity Strategy, the objective of which is to stop biodiversity loss by 2030. The objective of the regulation is to secure the long-term and sustainable recovery of biodiversity. The impacts of the nature restoration regulation are significant to the planning of growing cities. However, there have been few local-level examinations of the impacts, so they are not examined in this report in great detail. Instead, biodiversity loss is discussed at a more general level.

The key impacts of the boundary conditions set by biodiversity loss and ways to take them into account are presented in Tables 5 and 6.



In addition to diversity, biodiversity loss has direct impacts on aspects such as nature's carbon sequestration potential [132, 133], pollination [134], soil degradation [135], water and air quality [136] and increasing floods [137]. The primary reasons for this change are changes in the use of land and seas, over-exploitation of nature, climate change and the spreading of invasive species. Climate change and biodiversity loss have largely the same root cause: overconsumption of nature. Both challenges can be tackled partly with the same methods.

BOUNDARY CONDITION 3: Solutions must not accelerate biodiversity loss. The preservation of vegetative land area and replacement of lost vegetative land area must be ensured. From climate perspective, strengthening of the carbon sequestration potential and adaptation must be particularly emphasized.

Photo: Jussi Hellsten

Figure 12. Perspectives of a planning approach that takes different spheres into account [153].

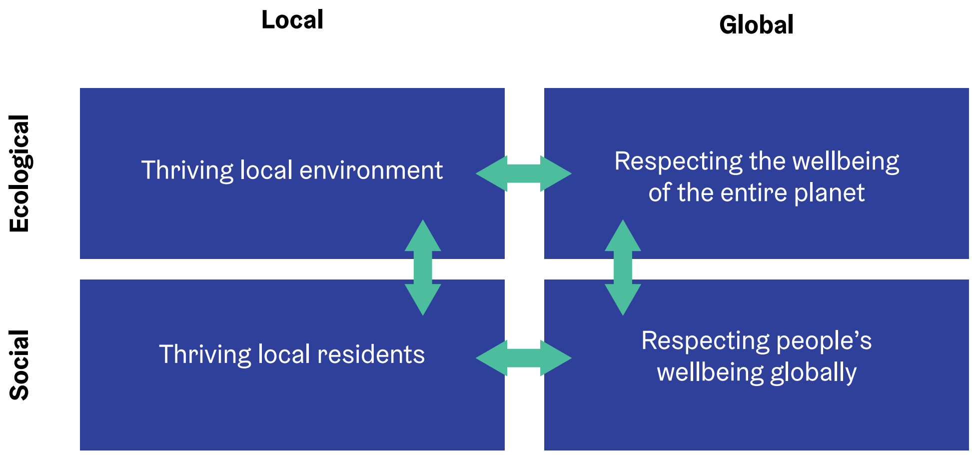
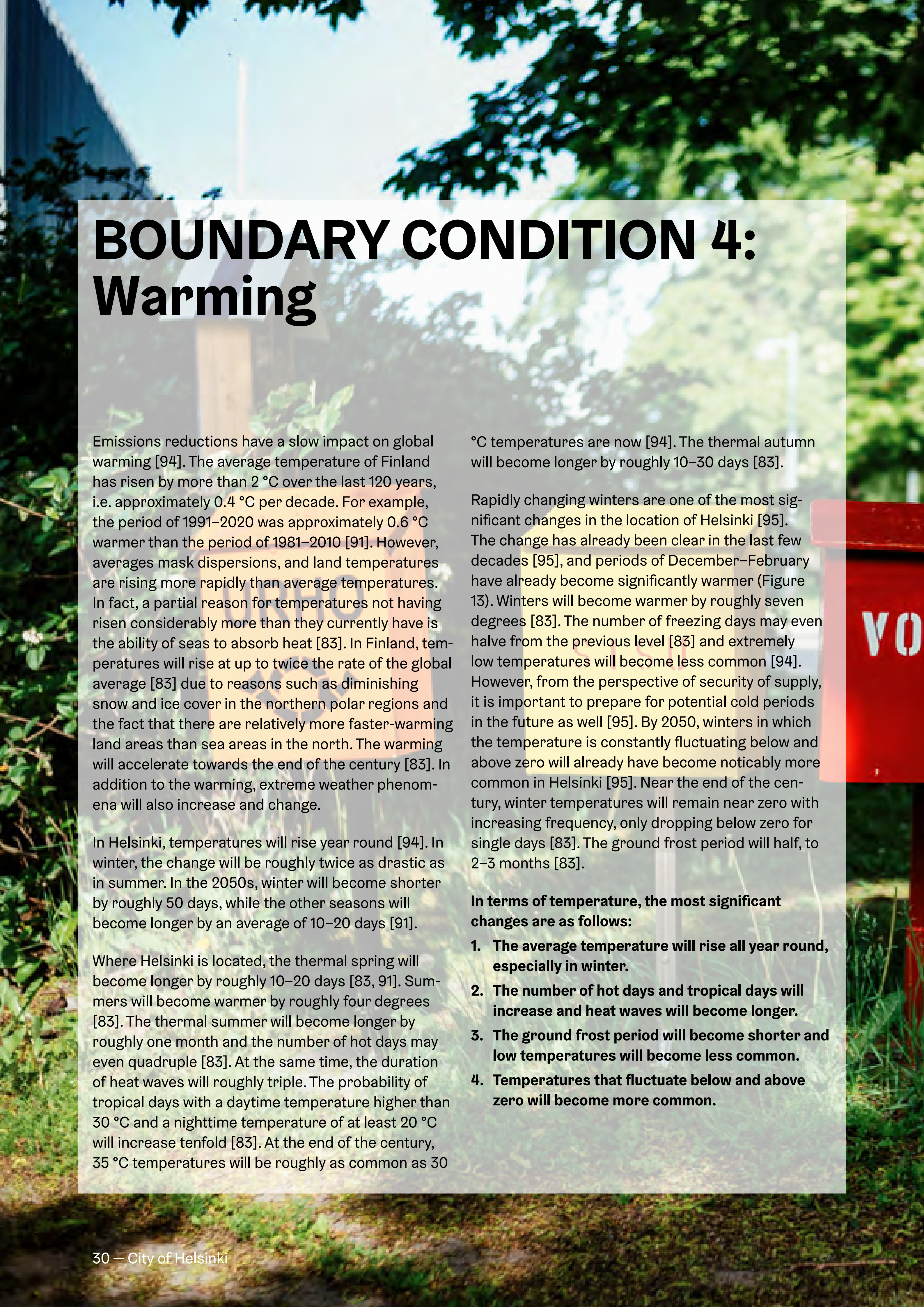


Table 5. Identified impacts and their significance for the boundary condition 3.

		1: CO_2	2: Materials	3: Biodiversity	4: Warming	5: Precipitation	6: Wind	7: Sea level
Urban structure	In addition to loss, species are facing a decline and a decrease in population, as well as the deterioration of entire habitats and ecosystems.	--		---				

Table 6. Identified means and their effectiveness for the boundary condition 3.

		1: CO_2	2: Materials	3: Biodiversity	4: Warming	5: Precipitation	6: Wind	7: Sea level
Urban structure	Identifying and securing ecological networks and the most valuable nature areas.			+++				+
	Maximising the preservation of vegetative land area.	++		++	++	++		
	Taking the soil, microclimate and existing nature into account in the placement of construction.	+		++				
	Renewing lost vegetation.			+	+	+		



BOUNDARY CONDITION 4: Warming

Emissions reductions have a slow impact on global warming [94]. The average temperature of Finland has risen by more than 2 °C over the last 120 years, i.e. approximately 0.4 °C per decade. For example, the period of 1991–2020 was approximately 0.6 °C warmer than the period of 1981–2010 [91]. However, averages mask dispersions, and land temperatures are rising more rapidly than average temperatures. In fact, a partial reason for temperatures not having risen considerably more than they currently have is the ability of seas to absorb heat [83]. In Finland, temperatures will rise at up to twice the rate of the global average [83] due to reasons such as diminishing snow and ice cover in the northern polar regions and the fact that there are relatively more faster-warming land areas than sea areas in the north. The warming will accelerate towards the end of the century [83]. In addition to the warming, extreme weather phenomena will also increase and change.

In Helsinki, temperatures will rise year round [94]. In winter, the change will be roughly twice as drastic as in summer. In the 2050s, winter will become shorter by roughly 50 days, while the other seasons will become longer by an average of 10–20 days [91].

Where Helsinki is located, the thermal spring will become longer by roughly 10–20 days [83, 91]. Summers will become warmer by roughly four degrees [83]. The thermal summer will become longer by roughly one month and the number of hot days may even quadruple [83]. At the same time, the duration of heat waves will roughly triple. The probability of tropical days with a daytime temperature higher than 30 °C and a nighttime temperature of at least 20 °C will increase tenfold [83]. At the end of the century, 35 °C temperatures will be roughly as common as 30 °C temperatures are now [94]. The thermal autumn will become longer by roughly 10–30 days [83].

Rapidly changing winters are one of the most significant changes in the location of Helsinki [95]. The change has already been clear in the last few decades [95], and periods of December–February have already become significantly warmer (Figure 13). Winters will become warmer by roughly seven degrees [83]. The number of freezing days may even halve from the previous level [83] and extremely low temperatures will become less common [94]. However, from the perspective of security of supply, it is important to prepare for potential cold periods in the future as well [95]. By 2050, winters in which the temperature is constantly fluctuating below and above zero will already have become noticably more common in Helsinki [95]. Near the end of the century, winter temperatures will remain near zero with increasing frequency, only dropping below zero for single days [83]. The ground frost period will half, to 2–3 months [83].

In terms of temperature, the most significant changes are as follows:

1. **The average temperature will rise all year round, especially in winter.**
2. **The number of hot days and tropical days will increase and heat waves will become longer.**
3. **The ground frost period will become shorter and low temperatures will become less common.**
4. **Temperatures that fluctuate below and above zero will become more common.**

Photo: Jussi Hellsten

In the future, temperatures will rise in Helsinki and Finland in general at a rate higher than the global average [154, 155, 83]. The change will be greater in winter [155] and low temperatures will become less common [156]. Snow cover and ground frost will become less common [157], affecting the moisture and carrying capacity of the soil particularly in the winter season [158]. At the same time, summer temperatures will become more extreme as the highest temperatures increase from their current level [157]. As temperatures rise, the growth season becomes longer [155] as plant and animal species migrate northwards [83].

BOUNDARY CONDITION 4: Solutions that accelerate the urban heat island phenomenon must be avoided. The passive resilience of the habitat must be ensured.

Boundary conditions set by changes in warming and taking them into account

The key impacts of the boundary conditions set by changes in warming and ways to take them into account are presented in Tables 7 and 8.

We are still constantly designing buildings for an urban climate that will no longer exist in the future [74]. In the urban heat island phenomenon, solar radiation is absorbed by city structures, which then release heat into their surroundings [94]. In addition to the urban structure, the urban heat island phenomenon is affected by factors such as the denseness of the building stock. In dense areas, temperatures often become higher than in the rest of the environment [160]. Due to the increasing density of the urban structure accelerating the urban heat phenomenon, the temperatures of urban areas can be up to 10 °C higher than in the surrounding areas [83]. The urban heat island phenomenon will have impacts such as the amount of severe heat stress experienced in different areas in Helsinki increasing considerably by the middle of the century (Figure 14). The urban heat island phenomenon and rising temperatures will reduce heating needs in construction by several tenths but also increase cooling needs nearly fivefold [83].

At the level of buildings, increasing heat waves will increase risks such as the overheating of apartments [162]. The temperature conditions of buildings are impacted by factors such as the location and orientation of the building and its windows, shading, the locations of apartments within the building and the building's ventilation and cooling systems [160]. Increased heat insulation necessitated by energy efficiency regulations will also increase buildings' cooling needs in spring and summer in the future [52]. The Decree of the Ministry of the Environment on the Energy Performance of New Buildings (1010/2017) stipulates that the calculated summertime room temperature must not exceed 150 degree hours between

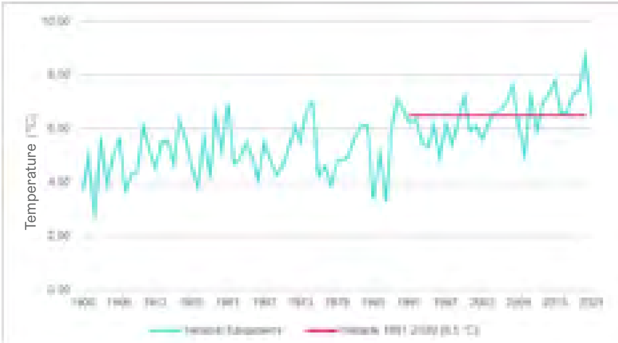


Figure 13. Annual average temperatures in Helsinki since 1900 [159].

Table 7. Identified impacts and their significance for the boundary condition 4.

		1: CO_2	2: Materials	3: Biodiversity	4: Warming	5: Precipitation	6: Wind	7: Sea level
Urban structure	The growth season will start earlier and last longer.				++			
	The range of species will change and new species will be introduced.			––	++			
	The amount of pests and parasites (number of species, populations) will increase.			––	++			
	Due to a lack of ground frost, the wear resistance of natural green areas will diminish as the city grows and usage pressure increases.				++	++		
Buildings	The need for heating will decrease, while the need for cooling will increase.				+++			
	The need for mechanical cooling will increase in spring and summer.	–	–		++			
	Structures will continue to need to be protected against ground frost.	–	–		+			
Individuals	Health risks caused by heat will increase.				+++			
	Health risks caused by cold will decrease.				++			
	Health risks caused by slippery conditions will increase.				++			

1 June and 31 August [163]. The cooling limit value set is 27 °C for apartment buildings and 25 °C for other buildings. However, the Decree does not take into account climate change during the lifecycle of the building [160]. In the future, there will be a need to protect the western and southern sides of buildings in particular against increasing heat radiation [52]. High indoor temperatures will increase, especially in spring and summer, leading to an increasing need for mechanical cooling [52]. The cooling of apartments often increases energy consumption and the generation of waste heat, warming the city further [94].

At the level of the city and the block structure, a denser urban structure increases heat stress, but it can be decreased through means such as building orientation and green construction [164]. The heat load and cooling can be affected in the built environment through active (e.g. mechanical solutions) and passive means (e.g. structural solutions, affecting the amount and placement of functions producing waste heat, green structure solutions). In terms of the

Table 8. Identified means and their effectiveness for the boundary condition 4.

		1: CO_2	2: Materials	3: Biodiversity	4: Warming	5: Precipitation	6: Wind	7: Sea level
Urban structure	Decreasing the amount of infrastructure that stores heat and produces waste heat and placing it so that its heat load decreases.	++	+		+++			
	Replacing lost vegetative land area.	+		+	++	++		
	Renewing the range of species to increase its climate-resistance. Incl. taking the diversity and varying ages of the flora into account.	+		++	++			
	Redistributing the street space so that space is transferred from emission-intensive infrastructure to green structure and other functions.	++	++	+	++	++		
	Preventing overheating and flood risks with green structure within the existing structure.			++	++	++		
	Taking the terrain into account in the placement of construction.	+		++	+	++	++	
	Taking the existing nature into account in placement decisions.	+		+	+	+		
	Community cooling spaces to protect the most vulnerable groups of people.				+			
	Varying field and forest patches and other green areas to prevent the spread of diseases.			++	+			
	Compensating for carbon sinks outside the city borders.	--		--	--	--		
	Infill building and densification at public transport hubs.		++		---	---		
Neighborhood blocks	Sufficient shady outdoor facilities with opportunities for cooling down.	+		++	+++			
	Utilising the shading effect of trees.	+			++			
Buildings	The cooling of facilities with active methods.	-	-		+++			
	Protecting and cooling facilities with passive methods (e.g. green roofs, lattices, nighttime ventilation, reflective surface materials). Increasing the passive resilience of buildings.	+		+	++			
	Increasing the presence of green walls alongside green roofs in the range of methods + underwater green walls.	-		+	+	+	+	

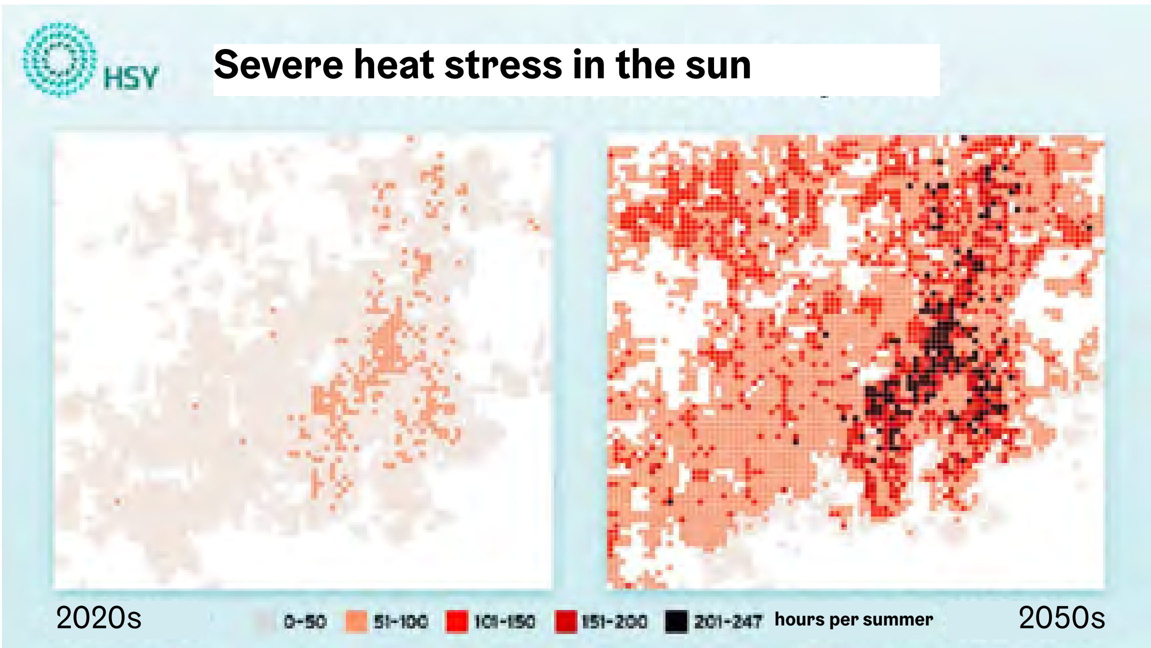
boundary conditions set by the emissions reduction need, the emission impact of structural solutions [71], mechanical cooling [52] and active solutions and building service systems [52] must be taken into account in particular, as well as the carbon footprint of more energy-efficient construction [52]. In turn, cooling solutions related to the increase in green structures can sequester carbon [71], increasing comfort at the same time. The tree stock and the moisture evaporating from it provide shading and cool the local climate [83]. In addition to providing shade, trees also sequester carbon from the air.

At building level, the passive resilience of construction will be highlighted increasingly [74], and it will be important to utilise more passive methods alongside active solutions in the heat regulation of buildings [24]. For example, passive cooling methods will increase and maintain the ability to adapt to climate change at individual level as well [74]. However, passive methods alone are often not enough to meet the requirements of the changing climate, but they do contribute to aspects such as decreasing the need for cooling energy [52]. Even though it will be difficult to achieve sufficient structural cooling and other impacts in the future through passive means alone, it is important that buildings are also habitable in situations in which active systems are not in use for one reason or another [74]. There are already examples in the world of how actors must show that they have utilised all passive methods before installing active systems (Example 5). In addition to mechanical cooling solutions, the cooling of facilities can be helped through means such as sun protection on windows and intensified nighttime ventilation [52]. As a means to mitigate the urban heat island phenomenon and the heating of buildings, trees and green roofs also provide shade, evening out the impact of the urban heat island phenomenon at building level [74, 71].

- **Example 5:** The London Plan requires that it has been shown in planning subjects how overheating and cooling needs are responded to. Cooling must utilise a hierarchy that prioritises passive solutions:
  - reduce the amount of heat entering a building through orientation, shading, high albedo materials, fenestration, insulation and the provision of green infrastructure;
  - minimise internal heat generation through energy efficient design;
  - manage the heat within the building through exposed internal thermal mass and high ceilings;
  - provide passive ventilation;
  - provide mechanical ventilation; active cooling systems [165].

At individual level, increasing heat waves are already causing significant health hazards in the current situation [160], and in the future, health risks caused by heat will increase considerably [96]. It has been estimated that in the future, the mortality risk related to heat waves may be more than six times higher in Helsinki than in the surrounding region [166, 167]. Conversely, health risks caused by cold will decrease [96]. Temperatures fluctuating below and above zero will increase the risk of slipping in the future [168].

Figure 14. The amount of severe heat stress will change considerably even when going from the 2020s to the 2050s [161].



The risk will be the highest in major cities, in which it is contributed to by aspects such as the higher amount of traffic and pedestrians [169]. Health risks caused by slippery conditions increase when there is no layer of snow covering the ground [96]. In addition to people's personal characteristics, health hazards are affected to a high degree by what kind of a building and built environment they live in [71]. One key risk is the overheating of buildings, which increases health risks especially among risk groups who spend the majority of their time indoors [170], such as the elderly and people with long-term illnesses [171]. The risk of overheating is highlighted during heat waves in which nighttime temperatures are also high, preventing the body from recovering from heat stress at night [160]. As such, in addition to the warming of individual facilities, attention must also be paid to the cumulative heat load to which people are exposed during the day [74]. It is particularly important to prevent heat hazards in sensitive locations, such as care institutions, nursing homes, daycare centres and schools [160].

The urban heat island phenomenon and the overheating of buildings are the most detrimental to the most vulnerable groups of people who cannot afford or have no opportunities to install cooling systems and who often live in buildings that are more prone to overheating [74]. The hazards caused by the overheating of buildings are highlighted if the occupants have no opportunities to go to nearby shady outdoor facilities to cool down [74, 75]. As such, it may be necessary to also provide public facilities for cooling down, particularly to the most vulnerable groups of people (Example 6). One example of facilities suitable for this purpose is public civil defence shelters, as they are naturally cool [74]. Modelling can be utilised to establish which buildings are the most prone to overheating. Affecting factors include the time of construction (regulations in force at the time) and factors contributing to the formation of the urban heat island phenomenon in the surroundings [74]. Apartments opening in one direction are particularly prone to overheating [74]. This effect is highlighted if the facade is highly perforated and the kitchen is located against the back wall of the apartment, heating the space from the other side as well [74].

Northern ecosystems are particularly vulnerable to the impacts of climate change [173]. The range of species will change to make way for species migrating from the south, as each animal and plant species is adapted to a certain kind of environment and the living conditions it provides [83]. The warming of the climate will prolong the growth period [83]. However, there will not be two growth seasons in Finland even in the future due to the fact that the amount of light will not increase [71]. Where Helsinki is located, the crop season will start as early as February–May in the future [83]. Even though the conditions for food production will improve in terms of the climate, the change will not necessary lead directly to increased production volumes due to annual temperature and humidity balance fluctuations [95].

The amount of carbon dioxide released from the ground will increase as the heat and moisture in the soil increase, negating the increased carbon sequestration effect in places [83]. In street areas, the conditions will grow extreme more than in forests and parks. The currently dominant tree species in the forests of Helsinki are the pine, the spruce and the birch. However, warming will cause deciduous trees to take over current conifer areas in the future [83]. For example, the spruce will be in a challenging situation in the future as its living conditions become more difficult [174, 175]. In the future, warming will cause new species to thrive in Southern Finland. Such species include the knotweed, the flax, the sunflower, the caraway, the hemp, the maize, the common pear, the European plum and the watermelon [83]. Examples of new animal species migrating to Southern Finland include new cervids, jackals and raccoons, many of which also thrive in urban conditions [83]. Warming will also cause the range of harmful pests and parasites to increase [83]. Conversely, the number of bird species and their populations will decrease [83].

Renewing the range of species to make it climate-resistant will provide protection against sudden broad destruction. It is important to respond to the changing conditions through means related to the diversity and varying ages of the flora. Variation in field and forest patches, bush plantations, gardens and other green areas can help prevent the spread of diseases and pests [83]. Ground-supported yard areas can be used to grow full-length trees and manage stormwater in a more natural manner.

- **Example 6:** Vancouver provides public 'Community cooling centre' facilities and other public services for cooling down during hot periods [172].

BOUNDARY CONDITION 5: High precipitation

The modelling of precipitation is subject to greater uncertainties than temperature modelling, but all models indicate that precipitation will increase [94]. For example, the probability of torrential rain floods will increase, but predicting how frequent they will be in the Helsinki area in particular in the future is challenging [95]. Warm air can hold more humidity, contributing to increasing precipitation [83]. High precipitation will be more frequent as weather types change more slowly than before and depressions increase in Northern Europe [83]. Annual precipitation levels are expected to increase by roughly 10–20% and even more in winter and spring [94]. The risk of floods will triple [83] and the risk of stormwater floods in particular will increase [91] as the capacity of stormwater drains and other water guidance routes is exceeded [177]. On the other hand, warming will also increase evaporation, increasing the period of dry soil from one month to roughly two [83].

In spring, precipitation will increase, as will the intensity of torrential rains [91]. However, springtime floods will decrease roughly by one quarter as wintertime precipitation will come increasingly often as rain instead of snow [83]. Springtime drought periods will grow worse and severe droughts will occur more frequently [83]. In summer, the mean precipitation will remain at roughly the current level, while torrential rains will intensify by approximately 10% [94]. The number of rainy summer days will decrease [91], but the highest level of precipitation within one day will increase roughly by one quarter [83]. Along with torrential rains, thunderstorms, hailstorms and downbursts are expected to increase [83]. However, changes in the occurrence of storms cannot be predicted with certainty, as they require several other factors to coincide with the temperature [95]. As temperatures rise, there will be occasional challenges related to the sufficiency of precipitation [83]. The terrain will dry faster than before and the moisture of the soil will decrease in summer as the number of very dry days almost doubles [83]. Summertime drought periods will also increase the risk of the quality of groundwater declining [173].

Precipitation will increase in autumn [83]. It has been estimated that autumn floods will increase by roughly one third due to the amount of runoff multiplying as a result of the increasing precipitation [83]. In autumn, the risk of stormwater floods will increase [91]. In winter, an increasing proportion of precipitation will come as water [95, 91, 94, 83]. The number of snowy days will decrease roughly by half, while the amount of snowfall will decrease by one quarter [83]. In turn, the highest single snowfall amounts may increase [83]. However, the amount of snow remaining on the ground will decrease, as the snow will melt quickly due to the warmth of the ground [83]. Runoff levels will multiply as precipitation increases [83]. As precipitation increases, winter floods will increase by one third and lead to significant damage more frequently [83]. In particular, the risk of river floods [177] and stormwater floods will increase due to an increase in torrential rains [91].

The most significant changes in terms of precipitation are as follows:

1. **Annual precipitation will increase, the occurrence of heavy rains will increase and torrential rains will intensify.**
2. **The amount of snowfall will decrease while the highest amounts of snowfall will increase.**
3. **The risk of floods will increase.**

Photo: Jussi Hellsten

Changes in precipitation will be greater in winter than in summer [176, 157]. Snowfall will become less common [157]. As precipitation and cloudiness increase, autumns and winters will become darker than before [155].

BOUNDARY CONDITION 5: The increase in permeable surfaces must be ensured. The city must prepare for an increasing stormwater flood risk especially with regard to critical infrastructure.

4. **Drought periods will increase and severe droughts will occur more frequently.**

Boundary conditions set by changes in precipitation and taking them into account

The key impacts of the boundary conditions set by changes in precipitation and ways to take them into account are presented in Tables 9 and 10.

Increased humidity and soil moisture, as well as floods, increase stress on structures. Due to previous cold winters, buildings have not been designed for conditions in which the outer surface of the building is constantly exposed to water [95, 74]. The RIL 250-2020 instructions for moisture control and mould damage prevention in construction have already been updated with climate change taken into account. The RIL 107 instructions for water and moisture insulation were updated for release in 2022 with the climate change perspective taken into account more than before [52].

The moisture technology performance of many structural solutions will decline and the risk of moisture damage will increase, particularly in unheated facilities [52]. The need to renew, repair and demolish structures may increase as the conditions change, and the need to protect structures and materials against external moisture will increase starting from the worksite stage [52]. Rain stress on buildings will increase by up to half in places due to increasing moisture levels and precipitation [83]. Wind-driven rain will increase by roughly one third and rain will affect walls other than those facing south and west more than before, keeping the wall surfaces wet for a long time [83]. Increasing precipitation and torrential rains will cause more and more damage to buildings and infrastructure [83]. In addition to moisture levels, temperatures fluctuating below and above zero will expose concrete, brick and plaster surfaces to wear and deterioration [83]. Wood structures will struggle with the wetter and warmer climate, as well as new pests [83]. Due to increasing moisture levels and the moistening of structures, mould will also have better growth conditions, and the risk of steel elements corroding will increase in the external parts of buildings as drying slows down [52].

In addition to stress on structures, decreasing ground frost and increasing soil moisture will also decrease the firmness of the soil [83, 173]. On the other hand, increasing drought periods will also cause a significant risk to built infrastructure, particularly on clay soil, which subsides as the groundwater level lowers [83]. Decreasing amounts of snow will also accelerate the drying of the terrain in spring, causing a significant increase to risks such as wildfires [83]. As such, preventing the risk of forest fires will be increasingly important in the future [72].

Increasing moisture levels and precipitation will also increase wear and rutting on road infrastructure [83]. In terms of infrastructure, the impact of stress will be highlighted particularly if there is already an accumulation of repair debt [95]. On the other hand, decreasing amounts of snow and shorter periods of ice coverage will reduce the need for ploughing and intermediate snow storage [83, 173, 72], facilitating active mobility year round better than before [83, 173]. However, as the amount of snow staying on the ground decreases, it will be important to define a sufficient level of preparedness for individual snow loads in the rare occasions of heavy one-off snowfalls [72]. The damage caused by heavy individual snow loads will increase, as the infrastructure has not been designed with them in mind [83].

Increasing precipitation and intensifying torrential rains will also increase the load peaks of stormwater systems, leading to an increased risk of urban floods [178]. Stormwater peaks caused by torrential rains will increase and must be taken into account in the planning and design of infrastructure [94]. As the moisture level of the ground increases, the absorption of rainwater slows down, increasing the overloading of sewer networks and contributing to the occurrence of floods [173]. Increasing floods will pose a risk to the built environment, particularly to cities' underground and low-altitude structures [173, 177] and other infrastructure, as well as occasional detrimental effects for traffic and structures located in street areas, for example [173, 177]. When water enters structures and underground facilities, it may lead to not only structural damage, but potential disruptions and hazardous situations as well [177].

Examples of ways to prepare for increasing precipitation and floods include increasing the amount of permeable surfaces and natural and local water absorption and delaying solutions [83, 74], subsurface drainage and directing surface water away from the vicinity of buildings [177] (Example 7). From the perspective of the emissions reduction need, aspects such as constant vegetation coverage on the ground and the circulation of cultivars bind the soil, decreasing the release of carbon and the flushing of nutrients [83]. Carbon farming fields are more flood-resistant and prevent the flushing of nutrients [71]. Green roofs have also often been suggested as a solution for retaining increasing amounts of water and delaying rainwater [72]. However, the carbon footprint of building green roofs must be taken into account from the perspective of the boundary conditions set by the emissions reduction need [52]. In order to protect the most critical infrastructure, one potential solution to be considered is to direct water to underground carparks, for example [95].

- **Example 7:** There are examples in the world of actors developing a so-called 'Sponge City' concept for managing increasing precipitation and flood risks. The concept involves utilising local natural absorption and delaying solutions that absorb water during torrential rains [e.g. 179, 180].

The sufficiency of structures related to directing water away is important in terms of individual-level impacts as well, as stagnant water is quicker to generate various contagious diseases in a warmer climate [71]. Individual-level risks caused by increasing precipitation floods are often not related to drowning during floods, but to aspects such as psychological stress caused by floods, equipment faults and impurities spread by flood water [74]. As stormwater stress increases, various contagious diseases may occur in stagnant water, such as mosquito and tick borne diseases [71]. The need to direct water away is highlighted in order to avoid stagnant water. The risk of floods in combined sewage systems will also increase in terms of water-borne epidemics [71].

From the perspective of individual level, increasing darkness particularly in the autumn and winter period must also be taken into account in addition to flood risks and water-borne diseases. As the amount of snow staying on the ground decreases, winters will be cloudier than before and there will be more sleet [98, 71, 83, 94]. Due to darkening winters, problems such as seasonal affective disorder (SAD) have been predicted to increase [98, 96, 72]. The increase of darkness and shade will be highlighted particularly in a dense and tall urban structure in which apartments receive less and less natural light [98]. As such, taking care of sufficient outdoor lighting will be important in terms of comfort and safety.

Table 9. Identified impacts and their significance for the boundary condition 5.

		1: CO_2	2: Materials	3: Biodiversity	4: Warming	5: Precipitation	6: Wind	7: Sea level
Urban structure	The occurrence of significant flood damage will increase, incl. roads being blocked; damage to the electricity, telephone and telecommunication networks; disruptions at wastewater treatment plants.		+			+++		
	Load peaks in stormwater systems will increase. Stormwater peaks caused by torrential rains will increase.					+++		
	The risk of wildfires will increase.	–				++		
	Drought will limit the increase of vegetativeness (+ risks to animals).	–		––		++		
	The amount of carbon dioxide released from forest soil will increase.	–				++		
	Due to a lack of ground frost, the wear resistance of natural green areas will diminish as their usage pressure increases.			–	++	++		
	Drought periods will increase the risk of the quality of groundwater declining.		––			++		
	The need for snowploughing and snow storage will decrease.				+	+		
Neighbourhood blocks	The risk of stormwater floods will increase.					++		
Buildings	The moisture technology performance of structural solutions will decline. Moisture stress, wear and moisture damage on structures will increase.					+++		
	The moisture load of structures will increase. Precipitation stress will increase, affecting wall surfaces more evenly.					++		
	Renewal, repair and demolition needs will increase.	––	–			++		
	The need to protect structures against moisture will increase at construction sites.					++		
	The risk of moisture damage in unheated facilities will increase.					+		
	The risk of individual snow loads will increase.					+		
Individuals	Vector-borne diseases spread through ticks, water etc. will increase.				++	+		
	Increasing cloudiness and precipitation will make autumns and winters even darker than before. Decreasing light levels may exacerbate winter depression symptoms.					+		
	Increases in moisture and mould damage will increase building health risks.					+		
	Drought periods will increase the risk of the quality of groundwater declining.					+		

Table 10. Identified means and their effectiveness for the boundary condition 5.

		1: CO_2	2: Materials	3: Biodiversity	4: Warming	5: Precipitation	6: Wind	7: Sea level
Urban structure	Placing functions outside flood risk areas.					++		+++
	Runoff area oriented stormwater planning that involves identifying key sites to be turned into permeable surfaces.					++		
	Green areas must be preserved in infill building.	++		+		+		
	Directing individual snow loads to current on-street parking locations.	+				+		
	Taking flood risks into account in the planning of social services and health care sites and the service network.					+		
	Reducing overflows in combined sewage systems by separating stormwater.					+		
	Constant flora coverage of the ground and the circulation of cultivars bind the soil, decreasing the release of carbon and the flushing of nutrients.	+		+		+		
	Carbon farming fields are more flood-resistant and prevent the flushing of nutrients.	+				+		
Neighborhood blocks	Increasing the amount of permeable surfaces.	+		+		+++		
	Increasing the amount of natural and local water absorption and delaying solutions.	+				++		
	Taking care of water drainage.	–				++		
	Directing sudden flood spikes to underground carparks in order to protect more critical infrastructure.	–				++		
	Taking care of the quality of outdoor facilities during the polar night period as well (winter maintenance, lighting etc.).					+		
	Taking snow into account at local level, e.g. through clearing pockets.					+		
Buildings	Passive water retention and delaying solutions (e.g. green roofs).	+		+		+		

BOUNDARY CONDITION 6: Windiness

Climate change will cause windiness in Finland and its surrounding areas to change relatively little, but there are major uncertainties related to its modelling [95]. Windiness models differ from one another to a degree with regard to average wind speeds [155]. No equally clear long-term trends have been observed in terms of changes in windiness, but fluctuations from year to year will continue to be high. Changes in the occurrence of strong winds are uncertain due to the sporadic nature of the phenomena [182, 183].

It has been estimated that wind speeds will increase in spring [91]. No change in windiness has been reported for summers. In autumn, windiness will increase, as will the destructive power of individual storms [83]. In winter, windiness will increase by one fifth as southerly and south-westerly winds increase [83]. It has been predicted that a lack of ice on the Baltic Sea will increase windiness in the winter season [173]. Wind speeds will also increase in the winter season [91]. Wind damage risks will increase more than the actual windiness itself due to decreased ground frost [83].

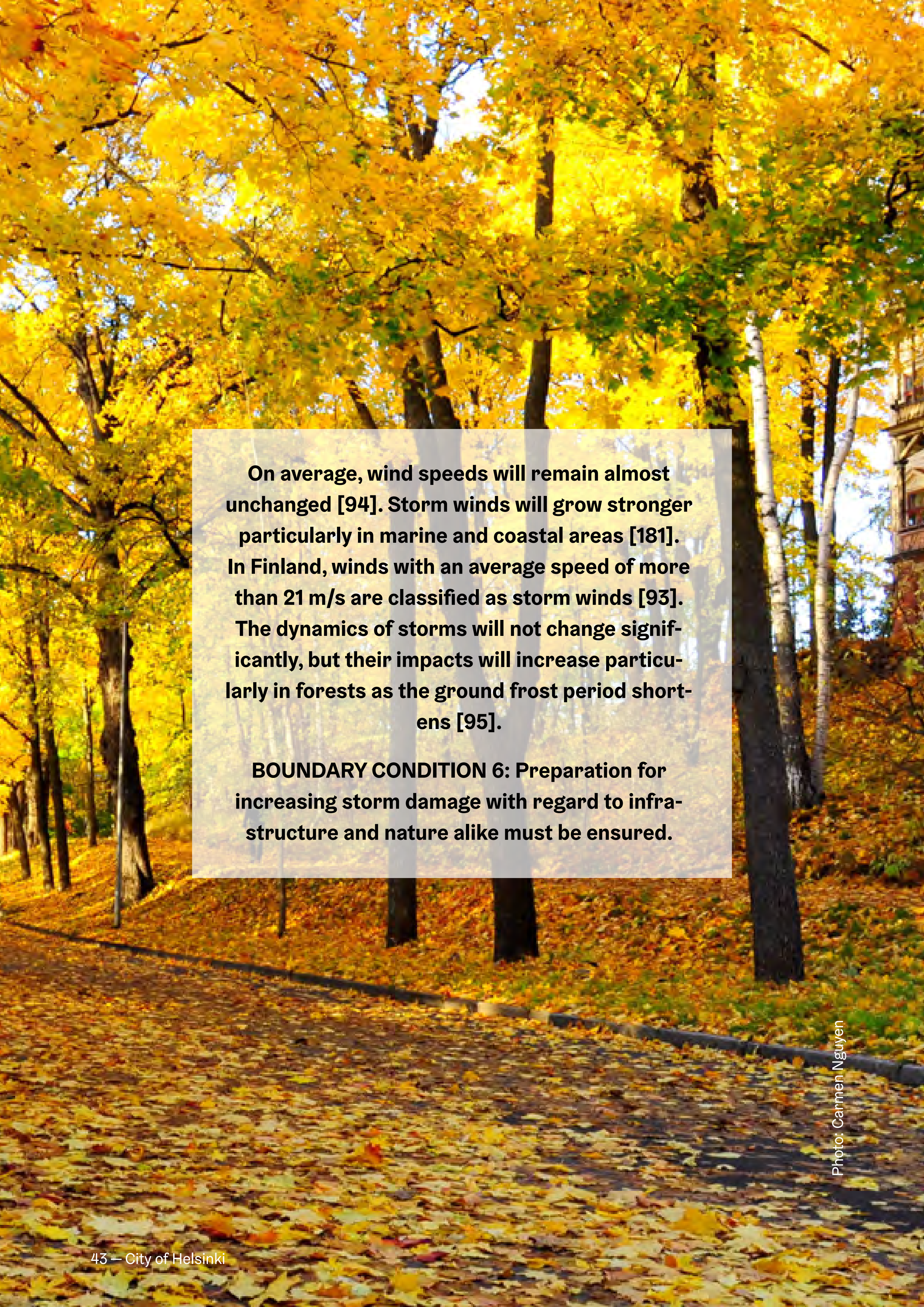
The most significant changes in terms of windiness are as follows:

1. **Wind speeds will increase at times, but their average speed will remain almost unchanged.**
2. **Southerly and south-westerly winds will increase.**
3. **The destructive power of individual storms will increase.**

Boundary conditions set by changes in windiness and taking them into account

The key impacts of the boundary conditions set by changes in windiness and ways to take them into account are presented in Tables 11 and 12.

Increasing windiness may decrease the comfort of outdoor facilities [173]. As regards storm damage, the key risk identified is local but often sizeable damage to the tree stock, as well as damage caused by falling trees to the electricity network, traffic, buildings and other infrastructure [93]. Decreasing ground frost will increase the amount of wind damage in nature [83], and even small changes may increase the risk of damage significantly [91].



On average, wind speeds will remain almost unchanged [94]. Storm winds will grow stronger particularly in marine and coastal areas [181]. In Finland, winds with an average speed of more than 21 m/s are classified as storm winds [93]. The dynamics of storms will not change significantly, but their impacts will increase particularly in forests as the ground frost period shortens [95].

BOUNDARY CONDITION 6: Preparation for increasing storm damage with regard to infrastructure and nature alike must be ensured.

Photo: Carmen Nguyen

Table 11. Identified impacts and their significance for the boundary condition 6.

		1: CO_2	2: Materials	3: Biodiversity	4: Warming	5: Precipitation	6: Wind	7:Sea level
Urban structure	Wind damage risks will increase as the ground frost period shortens. The amount of wind damage in forests and on the coast will increase.						+	
	Storm damage will increase susceptibility to insect and fungus invasions.			–			+	
	Damage caused by falling trees to the electricity network, traffic, buildings and other infrastructure.		–				+	
Neighborhood blocks	Increasing windiness may affect the comfort of outdoor facilities.						+	

Table 12. Identified means and their effectiveness for the boundary condition 6.

		1: CO_2	2: Materials	3: Biodiversity	4: Warming	5: Precipitation	6: Wind	7:Sea level
Neighborhood blocks	Taking the terrain into account in the placement of construction.	+		++	+	++	++	

BOUNDARY CONDITION 7: Rise in sea levels

Climate change will increase torrential rains and raise sea levels, increasing the probability of sea water floods in Helsinki as well [177]. However, there are uncertainties in sea water modelling with regard to the distribution of impacts in different parts of the globe. In the Gulf of Finland, post-glacial rebound will have only a slight impact on the rise in sea levels, and the level of the sea has already been rising for decades [83]. As such, the coastal area of Helsinki is a key sea water flood risk area at Uusimaa level due to the large population and traffic connections and other necessity services that will be disrupted in flood situationsi [91]. It has been estimated that the sea level will rise in Helsinki by an average of tens of centimetres (the best estimate mentioned in the sources being +33 cm) due to the melting of coastal glaciers, the thermal expansion of sea water and changes in wind conditions [94]. However, rises in sea levels are not the only change related to the Baltic Sea that will have an impact on the coast. For example, the salinity of the Baltic Sea is decreasing, while the phosphorus and nitrogen loads of the Gulf of Finland are increasing [83].

In addition to the rising sea level, Helsinki has several river flood risk areas, such as the areas in Savela and Oulunkylä that are susceptible to rises in the water level of the Vantaa River [177]. Examples of areas susceptible to flood risks include the Market Square area; the old Market Hall; the valuable plots of the city centre; Hakaniemenranta; Merihaka; Sörnäisten rantatie; the shore areas of Laajasalo; Marjaniemi and the areas of Vartiokylänlahti; the shore areas of Lauttasaari, Munkkiniemi, Viikki and Tammisalo; and Talinranta [177].

No changes have been reported with regard to spring, summer and autumn. In winter, the ice over the sea will become thinner with a smaller surface area [94]. When there is no protective layer of ice, storms and windiness will cause wear on the coast and its vegetation [83].

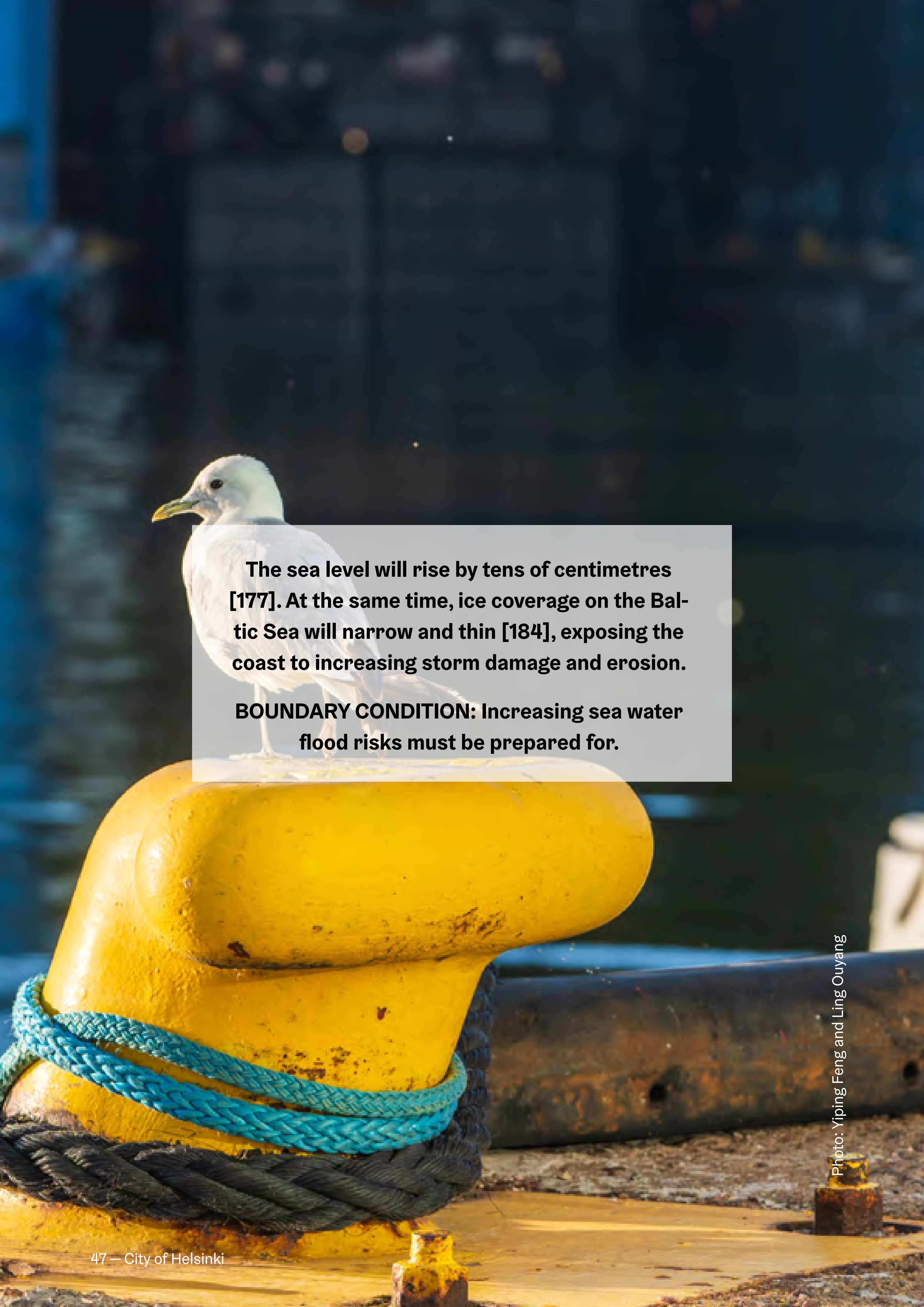
The most significant changes in terms of the sea and water bodies are as follows:

1. **The sea level will rise by tens of centimetres.**
2. **The coastal area of Helsinki will be a significant sea water flood risk area.**
3. **In winter, the ice over the sea will become thinner with a smaller surface area.**

Boundary conditions set by changes in the sea level and other water bodies and taking them into account

The key impacts of the boundary conditions set by changes in the sea level and water bodies and ways to take them into account are presented in Tables 13 and 14.

The level of sea water will rise, increasing the risk of sea water flood damage with regard to construction and infrastructure. At the same time, the ice conditions of the Baltic Sea will become more unpredictable from the perspective of transport and logistics [95]. Ice coverage on the Baltic Sea will become less common [96]. Rises in sea levels will cause floods and erosion on the coast [173]. As sea water warms, its ability to sequester carbon dioxide decreases [83]. Increasing run-off will decrease the salinity of the Baltic Sea, causing increased eutrophication [173, 71, 83].



The sea level will rise by tens of centimetres [177]. At the same time, ice coverage on the Baltic Sea will narrow and thin [184], exposing the coast to increasing storm damage and erosion.

BOUNDARY CONDITION: Increasing sea water flood risks must be prepared for.

Photo: Yiping Feng and Ling Ouyang

Structures can be protected against the rising sea water level through means such as flood barriers and embankments [83]. In Helsinki, embankments have already been planned to be built in seashore locations and along the Vantaa River [177]. In terms of flood damage, sea water is even more detrimental to structures due to the salt crystals it contains [74]. Some construction materials, such as wood and mineral wool, are particularly susceptible to flood damage [74]. Modelling can be utilised to survey how long it will take for buildings to dry after potential floods. In addition to building height, this is affected by factors such as the construction materials used [74].

Table 13. Identified impacts and their significance for the boundary condition 7.

		1: CO_2	2: Materials	3: Biodiversity	4: Warming	5: Precipitation	6: Wind	7: Sea level
Urban structure	The sea water level will rise and the risk of sea water floods will increase. Coastal floods and erosion will increase.					++		+++
	The salinity of the Baltic Sea will decrease and eutrophication will increase.			--				+++
	The oxygen deficit in the water near the bottom in coastal seas will increase.	-		--			++	++

Table 14. Identified methods and their effectiveness for the boundary condition 7.

		1: CO_2	2: Materials	3: Biodiversity	4: Warming	5: Precipitation	6: Wind	7: Sea level
Urban structure	Restoring coastal marine areas.	++		++				++
	Maximising the preservation of the vegetative coastal zone of the marine environment and the amount of seafloor.	+		+				++
	Gently sloping shores covered by vegetation instead of seashores built strongly with support walls.	+		+				+
	Utilising reeds as carbon reservoirs and entities that mitigate shoreline erosion.	+		+				+

4 Steps towards concretising the carbon negativity target

Expert interviews indicate that in addition to the actual boundary conditions, it must also be assessed whether current institutional structures and modes of operation facilitate operating within the critical boundary conditions identified, achieving the targets set and taking changes into account. Current practices and modes of operation often rely primarily on maintaining the current institutional systems and lifestyle – not so much on taking the planetary system and its different life forms into account and maintaining them [85]. The appropriateness of the current modes of operation must be reassessed, and resources must be directed at the structures and steering methods that have the greatest preventive or facilitating impact in terms of the objective.

4.1 Strategic steering and structures

The strategy is used to direct the organisation's operations from the perspective of the boundary conditions and objectives, and it also serves as a tool for relinquishing and excluding things. Many of these require a clear policy that spans the council period of office and city level – if not further. As such, it is important that any conflicting objectives and boundary conditions are clearly prioritised in terms of their significance starting from strategy level, not individual project level. When operating at the level of individual projects, coordinating and prioritising complex and conflicting objectives and boundary conditions is challenging and may easily lead to sub-optimisation and ignoring the most challenging objectives and boundary conditions. Major extensively defined objectives involve all operators, but the solutions are left in crisis when the process of concretising them begins, leaving too much room for partial optimisation. All this calls for a clearer policy regarding how partly conflicting objectives are to be coordinated. In order to avoid sub-optimisation, it is also essential to assess whether the choices made cause challenges from the perspective of fulfilling other boundary conditions or objectives. Currently, actors' understanding of the relations between objectives and boundary conditions is often lacking at system level. The participation practices currently in place also tend to highlight certain perspectives at the expense of others. If things are in conflict with people's perception of their own everyday life and wellbeing, acceptance of them decreases.

Wicked challenges require multidisciplinary cooperation and the participation of new professional fields in the processes. Adopting a sectoral, as well as value-based, silo mentality in thinking is a risk not only in terms of the boundary conditions identified, but the climate targets as well [185], and disruptions in guidance at strategic and operational level lead to the dispersion of operations and unattainability of targets. Despite sharing a objective, interpretation of it and commitment to it vary from silo to silo – or even within them. When tackling complex objectives, aspects such as information flow and the ensuring of responsibilities between key actors are highlighted in order for all involved to know the objectives steering their operations and their own role in achieving the said objectives. However, at individual level, it is also psychologically important for many that their duties and responsibilities can be delimited clearly enough.

What is decision-making like in a world of constant polycrises? How well does the current decision-making model meet the needs of the future? How can it be ensured that objectives are resilient and long-term enough in a constantly changing world?

Identified challenges:

- Discontinuity between strategic and operational level.
- Conflicts between objectives, and sub-optimisation.
- Emphasising of short-term thinking.
- Blurring of scales and effectiveness.
- Reliance on linear economic thinking and continuous growth.

Identified change needs:

- Prioritisation of objectives and boundary conditions starting from strategy level.
- Systems analysis in order to coordinate the objectives and boundary conditions to be prioritised and to identify any conflicts.
- Directing resource planning based on the prioritised objectives and boundary conditions.
- Specification of roles and responsibilities from the perspective of the objectives.

4.2 Instruments, steering and processes

The basis for taking the objectives and boundary conditions into account is created in city planning. It determines whether the objectives are achieved or not. The entire land use process from state level to regional, municipal and project level should work as a unified chain in order for the objectives set to be achieved. However, there are now significant discontinuity points in the overall process that undermine the operationalisation of the objectives, and individual municipalities' ways of promoting taking the objectives and boundary conditions into account remain limited. For example, the legislation currently in force provides few steering methods for taking carbon negativity and its boundary conditions into account. Planning is often based on modelling future developments and identifying change needs based on past developments [19]. However, this is no longer enough when the objective is to achieve a transformative change that requires identifying as of yet unidentified methods and systemic wholes, as well as planning that is atypical in comparison to established practices. To make it possible to steer the change, it is important that long-term legal steering instruments also facilitate the change and steer actors actively towards it, from strategic level to implementation planning.

Various methods for assessing impacts and performing carbon calculations are already in use. Impact assessments and calculations provide information about planned solutions, but they alone do not guarantee that objectives are met, and projects are not often left unimplemented even if their impact assessments are in conflict with aspects such as the climate objectives set. Reports and impact assessments continue to steer planning in a carbon-intensive direction even though the more demanding climate targets are already known. Improvements should continue to be made in how impacts are assessed, not only in relation to each other, but also in relation to the targets set.

It is important for competitions to also include taking the carbon negativity target and its boundary conditions into account in a binding manner during the implementation stage as well. It is still typical at the moment that ambitious solutions presented at competition stage are discarded during the implementation process. When developing new solutions, it is important to also monitor their functionality [75]. Even now, numerous different projects are up and running with the purpose of developing climate-wiser solutions, but after trials, the monitoring of their effectiveness and results continues to be somewhat lacking. At present, achieving low-carbon solutions is more expensive than promoting emission-intensive solutions.

What are zoning regulations that promote carbon negativity like? When financial resources are limited, how can low-carbon operations be promoted and the implementation of ideas presented ensured at the same time?

Identified challenges:

- Planning is not based on achieving a target, but incrementally improving current practices.
- Reports and impact assessments do not adequately steer actors towards the targets set.
- Ambitious climate solutions presented in the early stages of the processes are often not integrated into the solution that is ultimately implemented.
- The current planning and assessment methods renew already identified challenges.
- Discontinuity points between the different stages of the process.

- Current and past processes continue to promote solutions that are in conflict with the targets set.

Identified change needs:
- Transitioning from tried-and-true methods to planning and analysis methods that facilitate a transformative change.
- From declarative to target-oriented impact assessment practices to openly assess the effectiveness on the set targets.
- Examining existing and currently implemented plans from the perspective of the targets set.
- Steering cooperation between actors in a more target-oriented manner.
- Reforming statutes from the perspective of carbon negativity and its boundary conditions.
- Including the carbon negativity target and its boundary conditions in competition criteria and steering their implementation.
- Increasing the role of building regulation in taking the carbon negativity target and its boundary conditions into account.
- Including stress tests regarding the change in conditions in the planning process.
- Redefining realism and reducing self-censorship from the perspective of the targets set: what would achieving the targets set really require and are actors ready for it?

4.3 Steps towards concretising carbon negativity

Boundary conditions and sector-specific reductions are easier to define, but how is the systemic overall picture of a carbon-negative city understood? What does compensating emissions to zero and sequestering carbon mean in practice? What does the systemic whole we call a carbon-negative city actually mean in general? What does it mean in terms of living, lifestyles and many other aspects? Five key steps for concretising the carbon negativity target (Figure 15) were identified based on expert interviews.

STEP 1: Identifying the starting points

Climate targets concerning both emissions reductions and adaptation can only be achieved through actions. Even though the parallel development of various calculation, assessment and impact assessment methods is currently emphasised, the climate targets ultimately require actions that reduce emissions and improve the city's resilience in terms of preparing for and adjusting to changes that will occur in any case. So, let us take our envisioning forward a few decades, to the year 2050. Let us forget the limitations of the existing urban structure for a moment. We will take them into account later. Let us select an imaginary place in the same climate zone to which we have no existing emotional bond and in which letting go of old things and unlearning do not pose the kind of challenges they would in familiar places that already have a strong identity. The time to think about these will come in the later stages of the process. Let us focus on using the boundary conditions to create a vision that is also viable in conditions significantly worse than the current ones and with lower emissions. Let us ensure that our cities remain viable even if the worst climate scenarios were to come true. What should be different in the lifestyle and supporting urban structure in order for this to be possible?

At the moment, the general climate discourse continues to focus largely on the question of what things that are part of current cities and lifestyles we will have to relinquish in order to achieve the climate targets. However, there is less discussion about what good things worth waiting for that are not yet possible at the moment and with current modes of operation carbon negativity would facilitate. As such, it is important that the discussion regarding a carbon-negative future focuses also on the positive side facilitated by the change [19]. What is the valuable aspect that will replace the old when transitioning to carbon negativity?

1. Let us create a vision for 2050 that is also viable in conditions significantly worse than the current ones.
2. The realisation of carbon negativity requires emissions to be reduced as much as possible. The significance of carbon sequestration and compensation is important, but secondary.

Figure 15. Steps towards concretising carbon negativity.

STEP 2: Setting boundary conditions

None of us have been to the future and seen what it is like. Thus, imagining an unknown future is often found to be very challenging, which is why it is important to create discussion conditions that support settling into the future [19, 186] (Figure 16, for an enlarged version see Appendix 4). It is also important to bring up future changes that are already known with relatively high certainty as clear baseline information and boundary conditions: for example, what will the climate be like at the mid-point of the century, how will it change and how should it be taken into account as part of planning, which emissions classes will be emphasised in the future, etc.?

3. What will change in any case? What aspects can still be impacted?
4. What are the obstacles to a carbon-negative city? What in the current operating environment prevents the achievement of carbon negativity?

STEP 3: Starting from the future

The aim of envisioning is to momentarily detach from the current situation and think about what the ideal situation of a carbon-negative city would look like. It is important to emphasise in further preparations that carbon negativity is a long-term objective and there is no need to limit the envisioning to things are possible or achievable in the near future [19]. There are many different possibilities in terms of a carbon-negative future, and the path towards carbon negativity can also form in different ways [19]. However, that path does not have to be identified in the envisioning phase, but it can instead be worked on later with backcasting methods after an understanding of the desired future has been formed.

5. What are the possibilities of a carbon-negative city?
6. What will be preserved, what will change, what new things will be introduced? What positive aspects will carbon negativity facilitate?
7. What are the structure of a carbon-negative city and its diversity like?
8. Will individualism be emphasised more in the future, or will the future mark a transition towards communality and aspects such as increased sharing of facilities and means of transport?
9. Making transport sustainable in the future requires long-term infrastructure investments in the present, increasing emissions particularly in the short term. How are emissions generated at different times and for different reasons valuated in relation to each other?
10. What are the requirements set by carbon negativity for what buildings must be like or how the cityscape appears?
11. What do people need in their everyday living environment to thrive?

STEP 4: Visualisation

A carbon-negative city does not only operate in a lower-carbon manner, but it also looks and feels different [75]. As such, in terms of generating discussion, it will be important going forward to also be able to illustrate ideas of what the new city could look, feel and sound like [75, 19]. This will make the change and the need for change easier to understand.

STEP 5: Backcasting

In addition to describing what the future that the targets set will lead to is and what realising said targets requires, it is important to also understand and describe what the world to which our current operating models are leading us to is. Only this way is it possible to examine what we need to and even can change in order for the target set to be achieved:

12. What is the future that we are moving towards with our current operating models?
13. All in all, what needs to change in order for the objectives set to be possible to achieve?

Once the vision and change needs have been established, actions can be outlined through means such as backcasting. Backcasting is particularly well-suited for examining things that are complex, multifaceted and in need of a transformative change [187, 188, 189]. It provides a holistic and systematic way to identify the needs of the change process from starting points of the future [190]. The backasting process involves identifying possibilities and challenges related to the realisation of the vision defined, as well as interim targets required based on them in order to facilitate the change [191]. Backcasting can be utilised to approach potential futures through three different questions [192]:

14. What can change (target-oriented as an approach; often focuses in particular on technical and material factors and boundary conditions that directly affect the fulfilment of a target)?
15. How can the change take place (path-oriented as an approach; often focuses on examining the difference between the current situation and the target situation, identifying necessary principal

and behaviour-related change needs)?

16. Who can make the change happen (action-oriented as an approach; aims to form a comprehensive understanding of the transformative change required and related learning needs)?

Figure 16. Identified boundary conditions for envisioning a carbon-negative city.

BOUNDARY CONDITION 1:

1. Emissions have not been reduced sufficiently and at a sufficient rate. Currently used methods are constantly renewing challenges related to emission-intensive solutions.
2. In a delimited geographical area, carbon sinks and sequestration are not enough to compensate for the current level of emissions.

- The emissions reduction need is critical and emission-intensive solutions where the caused emissions exceed the reduction/sequestration potential must be avoided.

BOUNDARY CONDITION 2:

1. Currently known critical mineral and material reserves and production processes are unable to meet the increasing need.
2. There are not enough critical minerals even for electrifying the current vehicle stock and energy production needs.

- Solutions cannot be based only on new technology that has not yet been invented but must instead also work in a world with scarce resources and rely strongly on existing infrastructure.

BOUNDARY CONDITION 3:

1. In addition to loss, species are facing a decline and a decrease in population, as well as the deterioration of entire habitats and ecosystems.
2. In addition to diversity, there are impacts on aspects such as nature's carbon sequestration potential and soil degradation.

- Solutions must not accelerate biodiversity loss. The preservation of vegetative land area and renewal of lost vegetative land area must be ensured. From climate perspective, strengthening of the carbon sequestration potential and adaptation must be particularly emphasized.

BOUNDARY CONDITION 4:

1. The average temperature will rise all year round, especially in winter.
2. The number of hot days will increase and heat waves will grow longer.
3. The ground frost period will become shorter and low temperatures will become less common.
4. Temperatures that fluctuate below and above zero will become more common.

- Solutions that accelerate the urban heat island phenomenon must be avoided. The passive resilience of the habitat must be ensured with regard to aspects such as overheating.

BOUNDARY CONDITION 5:

1. Annual precipitation will increase, and the amount of heavy rains and flood risks will increase.
2. The amount of snowfall will decrease while the highest amounts of snowfall will increase.
3. Drought periods will increase and severe droughts will occur more frequently.

- The increase in permeable surfaces must be ensured. The city must prepare for an increasing stormwater flood risk especially with regard to critical infrastructure.

BOUNDARY CONDITION 6:

1. Wind speeds will increase at times, but their average speed will remain almost unchanged.
2. The destructive power of individual storms will increase.

- Preparation for increasing storm damage with regard to infrastructure and nature alike must be ensured.

BOUNDARY CONDITION 7:

1. The sea level will rise by tens of centimetres.
2. In winter, the ice over the sea will become thinner with a smaller surface area.

- Increasing sea water flood risks must be prepared for.

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APPENDIX 3: Identified methods for taking boundary conditions into account

		1: CO_2	2: Materials	3: Biodiversity	4: Warming	5: Precipitation	6: Wind	7: Sea level
Urban structure	Building a walkable and cyclable city. In addition to the network, a walkable and cyclable city is sensitive to the quality and details of the urban space.	+++						
	Minimising transport needs based on private driving by diversifying the urban structure and building new structures along the existing infrastructure.	+++		--	---	--		
	Densification of the urban structure.	+++		--	---	--		
	Taking the terrain and ready-made infrastructure into account in location choices in order to minimise the amount of excavation and earthmoving work.	++	++					
	Moderation in construction (total amount, dwelling density, modifiability, space efficiency).	++	++					
	Strengthening the carbon sequestration potential of the marine ecosystem.	+		++				
	Utilising the existing infrastructure and other structures.	++	+++					
	Assessing material and mineral intensive solutions and examining risks from the perspective of global availability.		+					
	Identifying and securing ecological networks and the most valuable nature areas.			+++				+
	Maximising the preservation of vegetative land area.	++		++	++	++		
	Taking the soil, microclimate and existing nature into account in the placement of construction.	+		++				
	Renewing lost vegetation.			+	+	+		
	Decreasing the amount of infrastructure that stores heat and produces waste heat and placing it so that its heat load decreases.	++	+		+++			
	Replacing lost vegetative land area.	+		+	++	++		

		1: CO_2	2: Materials	3: Biodiversity	4: Warming	5: Precipitation	6: Wind	7: Sea level
Urban structure	Renewing the range of species to increase its climate-resistance. Incl. taking the diversity and varying ages of the flora into account.	+		++	++			
	Redistributing the street space so that space is transferred from emission-intensive infrastructure to green structure and other functions.	++	++	+	++	++		
	Preventing overheating and flood risks with green structure within the existing structure.			++	++	++		
	Taking the terrain into account in the placement of construction.	+		++	+	++	++	
	Taking the existing nature into account in placement decisions.	+		+	+	+		
	Community cooling spaces to protect the most vulnerable groups of people.				+			
	Varying field and forest patches and other green areas to prevent the spread of diseases.			++	+			
	Compensating for carbon sinks outside the city borders.	––		––	––	––		
	Infill building and densification at public transport hubs.		++		–––	–––		
	Placing functions outside flood risk areas.					++		+++
	Runoff area oriented stormwater planning that involves identifying key sites to be turned into permeable surfaces.					++		
	Green areas must be preserved in infill building.	+++		+		+		
	Directing individual snow loads to current on-street parking locations.	+				+		
	Taking flood risks into account in the planning of social services and health care sites and the service network.					+		
	Reducing overflows in combined sewage systems by separating stormwater.					+		
	Constant vegetation coverage of the ground and the circulation of cultivars bind the soil, decreasing the release of carbon and the flushing of nutrients.	+		+		+		
	Carbon farming fields are more flood-resistant and prevent the flushing of nutrients.	+				+		
	Restoring coastal marine areas.	++		++				++
	Maximising the preservation of the vegetative coastal zone of the marine environment and the amount of seafloor.	+		+				++
	Gently sloping shores covered by vegetation instead of seashores built strongly with support walls.	+		+				+
	Utilising reeds as carbon reservoirs and entities that mitigate shoreline erosion.	+		+				+
Neighborhood blocks	Utilising the usable sunshine angle in order to maximise the potential of solar energy.	+	–					
	Providing non-consumption-based public space. A network of green and recreational areas is key to this.	+		++				

		1: CO_2	2: Materials	3: Biodiversity	4: Warming	5: Precipitation	6: Wind	7: Sea level
Neigh-borhood blocks	Sufficient shady outdoor facilities with opportunities for cooling down.	+		++	+++			
	Utilising the shading effect of trees.	+			++			
	Increasing the amount of permeable surfaces.	+		+		+++		
	Increasing the amount of natural and local water absorption and delaying solutions.	+				++		
	Taking care of water drainage.	–				++		
	Directing sudden flood spikes to underground carparks in order to protect more critical infrastructure.	–				++		
	Taking care of the quality of outdoor facilities during the polar night period as well (winter maintenance, lighting etc.).					+		
	Taking snow into account at local level, e.g. through clearing pockets.					+		
	Taking the terrain into account in the placement of construction.	+		++	+	++	++	
Buildings	Designing buildings to be multi-purpose, flexible and easy to modify.	++						
	Increasing the lifecycle of buildings: relaxing their functional and aesthetic requirements.	++	++					
	Utilising wasted spaces.	++	++					
	Increasing the lifecycle of buildings: streamlining maintenance and renovation projects.	++	++					
	Utilising low-carbon construction materials.	++						
	Improving the energy efficiency of buildings.	++	–					
	The long-term durability, maintainability and reparability of construction material and system choices.	+						
	Orienting the building in relation to the sun.	+			+			
	Favouring on-site reuse of materials and repair.	+	++					
	Maximising the lifecycle of building use.	+	+					
	Increasing lifecycle. Whatever is done is done properly and durably.	+	+					
	The cooling of facilities with active methods.	–	–		+++			
	Protecting and cooling facilities with passive methods (e.g. green roofs, lattices, nighttime ventilation, reflective surface materials). Increasing the passive resilience of buildings.	+		+	++			
	Increasing the presence of green walls alongside green roofs in the range of methods + underwater green walls.	–		+	+	+	+	
	Passive water retention and delaying solutions (e.g. green roofs).	+		+		+		

APPENDIX 4: Identified boundary conditions and their stress test

BOUNDARY CONDITION 1: The emissions reduction need

- Emissions have not been reduced sufficiently and at a sufficient rate. Currently used methods are constantly renewing challenges related to emission-intensive solutions.
- In a delimited geographical area, carbon sinks and sequestration are not enough to compensate for the current level of emissions.
- The emissions reduction need is critical and emission-intensive solutions where the caused emissions exceed the reduction/ sequestration potential must be avoided.
  - What is the estimated emission load caused by the project? What is the timeframe for its realisation?
  - What is the project's expected amount of carbon sequestration? What is the timeframe for its realisation?
  - Is it possible to sequester the potential emission load with solutions implemented within the city boundaries so that the emission load is lower than the amount of emissions sequestered?

BOUNDARY CONDITION 2: Material limitations

- Currently known critical mineral and material reserves and production processes are unable to meet the increasing need.

- There are not enough critical minerals even for electrifying the current vehicle stock and energy production needs.
- Solutions cannot be based only on new technology that has not yet been invented but must instead also work in a world with scarce resources and rely strongly on existing infrastructure.
  - Is the project based on solutions that rely on materials the availability of which can be secure with sufficient certainty?

BOUNDARY CONDITION 3: Biodiversity loss

- In addition to loss, species are facing a decline and a decrease in population, as well as the deterioration of entire habitats and ecosystems.
- In addition to diversity, there are impacts on aspects such as nature's carbon sequestration potential and soil degradation.
- Solutions must not accelerate biodiversity loss. The preservation of vegetative land area and renewal of lost vegetative land area must be ensured. From climate perspective, strengthening of the carbon sequestration potential and adaptation must be particularly emphasized.
  - Will the solution preserve or increase the amount of vegetative land area, species and ecosystems within the city boundaries?

BOUNDARY CONDITION 4: Warming

- The average temperature will rise all year round, especially in winter.
- The number of hot days will increase and heat waves will grow longer.
- The ground frost period will become shorter and low temperatures will become less common.
- Temperatures that fluctuate below and above zero will become more common.
- Solutions that accelerate the urban heat island phenomenon must be avoided. The passive resilience of the habitat must be ensured with regard to aspects such as overheating.
  - Is the project resilient in terms of the increasing urban heat island phenomenon and overheating?
  - Will the project ensure that the solutions have sufficient passive resilience in terms of overheating?
  - Will the project prevent the strengthening of the urban heat island phenomenon, e.g. with placement-related and structural solutions?

BOUNDARY CONDITION 5: High precipitation

- Annual precipitation will increase, and the amount of heavy rains and flood risks will increase.
- The amount of snowfall will decrease while the highest amounts of snowfall will increase.
- Drought periods will increase and severe droughts will occur more frequently.
- The increase in permeable surfaces must be ensured. The city must prepare for an increasing stormwater flood risk especially with regard to critical infrastructure.
  - Is the project resilient in terms of increasing precipitation and structural moisture stress? Will the solution prevent structural moisture stress and flood risks caused by increasing precipitation through natural, structural or construction engineering means?

BOUNDARY CONDITION 6: Windiness

- Wind speeds will increase at times, but their average speed will remain almost unchanged.
- The destructive power of individual storms will increase.
- Preparation for increasing storm damage with regard to infrastructure and nature alike must be ensured.
  - Is the project resilient in terms of increasing windiness? Will the solution prevent the probability, risks and impacts of increasing windiness and storm damage in the planning area?

BOUNDARY CONDITION 7: Rises in sea levels

- The sea level will rise by tens of centimetres.
- In winter, the ice over the sea will become thinner with a smaller surface area.
- Increasing sea water flood risks must be prepared for.
  - Is the project resilient in terms of rises in sea levels? Will the solution be located outside sea water flood risk areas or significantly decrease the probability of risks through natural, structural or construction engineering solutions?

Figures

Tables