The Fire Susceptibility of Future Climate-Smart Forests

A Foresight Study

VELP

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Preface

Before you is the thesis 'The Fire Susceptibility of Future Climate-Smart Forests'. This thesis was written to fulfil the graduation requirements of the Forest and Nature management course at Van Hall Larenstein University of Applied Sciences in Velp. I have been researching and writing my thesis from September 2023 to January 2024.

Throughout my studies, I noticed that I avoided stepping outside my comfort zone. This time, I decided to take a different approach by choosing a subject that demanded skills I did not already have. I developed my proprietary method for determining the fire susceptibility of forests. I also gained greater experience with programmes I was already familiar with, such as Excel. Therefore, this thesis taught me valuable lessons both personally and professionally.

I would like to thank my supervisors, Juriaan Zandvliet and Marcel van der Heide, for their excellent guidance and assistance during the process. I deliberately chose you as supervisors because I knew you would challenge me to take my research to a higher level. This maximised my learning opportunities, for which I thank you. With sincere appreciation, I express my thanks to the ecology consultancy Eelerwoude, which contributed significantly to the realisation of my thesis. I also want to thank the brainstorming session participants and survey respondents for their contribution to the data collection of this study. Without them, this research would not have been possible.

Finally, I wish to thank my relatives and friends for being there during my research process.

I hope you enjoy your reading.

Rowan Karssen

Velp, 7 January 2024

Abstract

Contemporary European forests are devastated by severe forest fires. The probability of forest fires is only growing due to climate change. Forest managers are therefore transforming the forests into species-rich forests resilient to the impacts of climate change. These forests are also referred to as climate-smart forests. It will take at least another century before a fully fledged climate-smart forest is established. However, it is unknown what tree species a climate-smart forest will consist of and how susceptible it is to forest fires. The objective of this research is to define what a climate-smart forest in the Netherlands in the year 2100 looks like and to determine its susceptibility to forest fires. A combination of literature, qualitative, and quantitative research was conducted to answer this question. A total of eight climate-smart forests were conceived based on four scenarios (I-IV), four of them through a brainstorming session (BS) and four through artificial intelligence (AI). Fire sensitivity scores were calculated for these climate-smart forests and the average Dutch forest. The fire sensitivity score of the average Dutch forest was considered as a baseline to calculate the percentage increase or decrease in fire susceptibility of the climate-smart forests. The percentage increases and decreases are, respectively: I BS = +375%, II BS = +139%, III BS = +371%, IV BS = -95%, I AI = +137%, II AI = -36%, III AI = +139% and IV AI = -97%. This study has found that the fire susceptibility of a climate-smart forest in the Netherlands in 2100 increases on average by 117% relative to the average Dutch forest in 2023. It was expected that the climate-smart forests would decrease in fire susceptibility, except for the forests of scenario IV.

Keywords: Climate-smart forest, fire susceptibility, forest fires, the Netherlands, 2100

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List of Abbreviations

Abbreviation	**Definition**
BS	Brainstorming session
CO_2	Carbon dioxide
cm	Centimetre
m^3	Cubic metre
DBH	Diameter at breast height
ha	Hectare
kg	Kilogramme
CH_4	Methane
mm	Millimetre
m	Million
N_2O	Nitrous oxide
s	Second
SD	Standard deviation

Chapter I

Introduction

1 Introduction

Climate change, a phenomenon that has been shaping our planet for centuries (Maslin, 2021, pp. 12–25), is currently the focus of global attention for nearly everyone. Many news items, scientific articles and reports on the subject are published every day. It is a process that is occurring gradually and noticeably, but which now calls for an urgent sense of responsibility and action by humanity. It affects our ecosystems, impacts the availability of natural resources, and poses immense challenges in the coming decades. This introduction explores the complexity of climate change by briefly explaining its underlying causal factors and specific impacts. It is a story of constant changes in meteorological patterns and frequent extremes, which provokes one to think collectively and critically about the future of this world and people its role in it.

What is climate change?

Climate change is interpreted differently by several scientists. According to Brown and McLeman (2013), it is defined as a persistent, identifiable change in the state of the climate in terms of average conditions and/or variability, which may be stimulated by natural processes or through alteration of the composition of the atmosphere due to human activities such as energy use and forest clearance. Whereas Regoto et al. (2022, p. 1) describe climate as the average state of the atmosphere resulting from the composition and interactions between natural elements (air, oceans, plants, animals, ice, snow, and rocks), and climate change as the consequence of changes in these elements. Mimura (2013, pp. 46–57) argues that climate change is a fundamental change in Earth its physical systems that has a range of impacts on many climate-dependent systems and sectors, including water resources, terrestrial and marine ecosystems, food production, natural disasters, coastal areas, industries, and human health. The aforementioned definitions of climate change diverge, however all of them refer to shifts in the Earth its climate.

The causes of climate change

Climate change is caused by a complex interplay of factors, yet the scientific consensus that human activities are the main driver of recent climate change is strong (Myers et al., 2021, p. 8). The burning of fossil fuels such as coal, oil and gas have led to an increase in greenhouse gases in the atmosphere. These emitted gases, including CO_2, CH_4 and N_2O, amplify the natural greenhouse effect by trapping heat in the atmosphere. Greenhouse gases act like a blanket. The thicker the blanket, the warmer the planet becomes (Reddy, 2014, pp. 17–26). Deforestation, particularly in tropical regions, contributes to climate change by releasing stored carbon and reducing the ability of forests to absorb CO_2 from the atmosphere (WWF, n.d.). In addition to deforestation, urbanisation and land-use shifts lead to alterations in local climate patterns and can affect the albedo (light reflectivity) of the Earth its surface. Although anthropogenic activities are considered the main cause of recent climate change, natural factors as volcanic eruptions and variations in solar activity can also temporarily affect climate (Harrington, 1987, pp. 1313–1339).

The implications of climate change

Climate change has a wide range of impacts on the environment, society, and the economy. One is that global average temperatures are rising, causing ice sheets and glaciers to melt, oceans to warm, and sea levels to rise (Rounce et al., 2023, pp. 78–83). This process is rapidly disappearing the habitat of many species. A recent study showed that some 10,000 chicks of emperor penguins drowned due to melting ice sheets (Fretwell et al., 2023). The melting of ice sheets and glaciers, along with the thermal expansion of warming oceans, also leads to rising sea levels (Lindsey, 2022). This affects coastal communities around the world and increases the risk of flooding, which could make many areas uninhabitable and create environmental refugees (Tickell, 1990). In addition, climate change induces differences in precipitation patterns and can lead to longer periods of drought in some regions and increasing precipitation intensity in others (Hansen & Hoffman, 2011, pp. 6–23). This has consequences for freshwater resource availability and agricultural productivity. Beyond that, it also magnifies the frequency of extreme weather events, such as hurricanes, floods, droughts, and forest fires (Field et al., 2012). The combination of prolonged periods of drought and the global rise in temperatures contribute to an increased risk of forest fires occurring. Higher atmospheric temperatures lead to an increase in evaporation of moisture from vegetation and soil. The evaporation dehydrates the ligneous material present in the forest, facilitating its ignition (Masson-Delmotte et al., 2023, p. 1157). A study by Parks and Abatzoglou (2020) confirmed that warmer and drier periods triggered by climate change are increasing the extent of severe fires in forests of the western United States. Furthermore, elevated temperatures are often associated with strong winds and changing wind patterns. Strong winds can rapidly disperse a fire by transporting burning particles over long distances (Nelson Jr. & Adkins, 1988, pp. 391–397). This study focuses on the increased risk of forest fires as a consequence of climate change and forest transformation described in the following heading.

Forest transformation

Europe was mostly covered with untouched forests 8,000 years ago, but over time, forest cover has been progressively fragmented due to human activities such as agriculture and deforestation (Roberts et al., 2018). Also in the Netherlands, genuine primeval forests have not existed for a considerable time. Research by Groenewoudt et al. (2007, pp. 17–33) has revealed that the landscape in the eastern Netherlands in the Iron Age and Roman period was almost as open as in the Middle Ages indicating that the primeval forests had largely disappeared by that time. Forests have been cleared for various reasons over the past thousands of years, including for cooking, keeping warm, growing crops, providing planks for ships, construction materials for houses, and raw materials for paper production (Victor & Ausubel, 2000, p. 127). However, the main driver of deforestation throughout this entire period has remained the expansion of agriculture (Pimentel et al., 1986, p. 404). This development can be attributed to continued population growth, which resulted in a greater demand for food (Ghazoul, 2013, pp. 447–456). Over the past few centuries, farmers have enhanced their efficiency by acquiring knowledge on how to grow crops more intensively on less agricultural land. Meanwhile, the increased use of metals, plastics and electricity has eased the need for timber. In addition, recycling has cut the amount of virgin wood processed into paper (Victor & Ausubel, 2000, p. 127). Nevertheless, with continued population growth and sustained demand for timber, reforestation started since roughly the second half of the 19th century (Vadell Guiral et al., 2019, p. 108). To facilitate silvicultural treatments and maximise timber yields, these forests were primarily planted in monocultures (Ribeiro Paula et al., 2020, pp. 1–13). A monoculture is a forestry practice where only a single tree species is planted on a large scale in a certain area (Wageningen University & Research, n.d.). This implies that all individuals in that area belong to the same species and are often genetically similar. In these man-made managed forests, both structural diversity and compositional heterogeneity are drastically altered (Bauhus & Pyttel, 2015). Monocultures are hence more susceptible to natural disturbances such as forest fires or diseases as compared to species-rich forests (Gayer, 1886; Möller, 1922). As indicated, the whole forest in monocultures consists of the same species, meaning that if a disease or pest spreads or a fire occurs, all trees are equally vulnerable because of their similar genetic composition. In contrast, in species-rich forests, different tree species may have distinct levels of resistance to diseases, pests or fires (Jactel et al., 2017, pp. 223–243). The variety of species in such a forest therefore partially protects it from natural outbreaks. In recent years, efforts have been made to transform Europe its existing forest from predominantly monocultures to a species-rich forest that can withstand the effects of climate change, has the ability to adapt and is less vulnerable to change (Delforterie, 2020, p. 5; FOREST EUROPE, 2020, p. 9). This species-rich forest is not called a primeval forest but a climate-smart forest (Bowditch et al., 2020, p. 1; Weatherall et al., 2021, p. 35). Since the transition of these forests is still in progress and a first example of a climate-smart forest is probably not present until the year 2100, limited information is available. There is not yet a detailed understanding of the composition of such a forest in terms of tree species and their interactions, nor the degree of vulnerability to natural disturbances such as forest fires. To acquire knowledge and a deeper comprehension on how resilient these forests are, this report focuses only on the fire susceptibility of climate-smart forests. An illustration of the forest transition in Europe is shown in figure 1 on the next page.

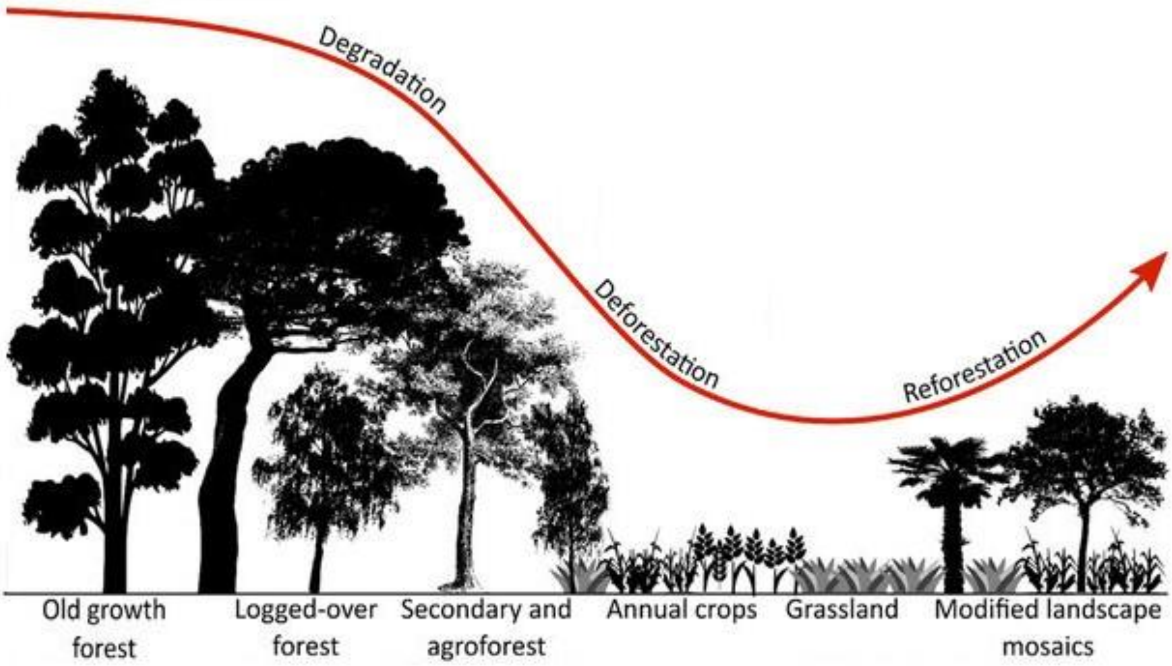


Figure 1. A picture illustrating the conversion of European forests with primary forests on the left, agricultural land in the middle and monocultures currently changing to climate-smart forests on the right (Reed et al., 2017, p. 65).

1.1 Problem definition

Nowadays, many news articles are appearing about forest fires which are caused by climate change. Fierce forest fires raged in France, Portugal, and Spain during the summer of 2023 (Hanegreefs, 2023; NOS Nieuws, 2023; RTL Nieuws, 2023). These fires resulted not only in the annihilation of nature, but unfortunately also in the loss of human lives. According to research by Khabarov et al. (2014, p. 21), the potential increase in forest fires in Europe without any forest modifications is about 200% by 2090 compared to 2000-2008. A major part of Europe its forests consists of monocultures that are less tolerant to abiotic factors such as fire (Knoke et al., 2007, p. 89). Forest managers are thus concerned with transforming monocultures into forests resistant to a changing climate, also known as climate-smart forests. The transition is taking place, but it requires at least a century until a fully fledged climate-smart forest has formed (Trees for All, 2023). However, the problem is that it is unknown which tree species a climate-smart forest will be composed of and how sensitive this forest is to forest fires.

1.2 Research objective

The aim of this study is to describe what a climate-smart forest in the Netherlands in the year 2100 looks like and to understand its susceptibility to forest fires. Based on the information and knowledge gathered from this research, forest managers can amend their management measures against forest fires for these forest types. This will allow forest managers to avoid the tremendous havoc wreaked by forest fires.

1.3 Research questions

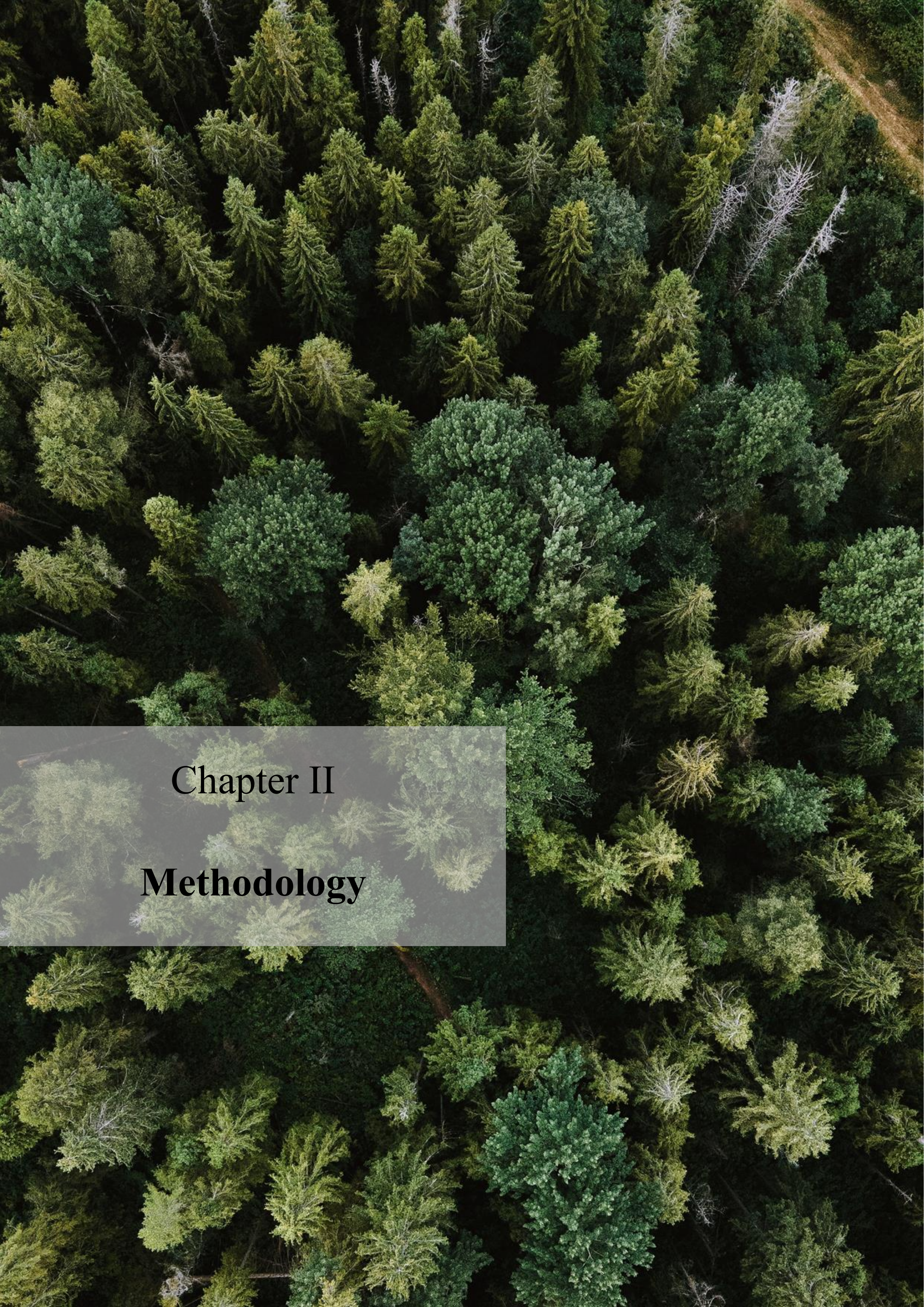
The preceding information led to the formulation of the following main question:

'How susceptible is a climate-smart forest in the Netherlands in the year 2100 to forest fires?'

To support the main question, the following sub-questions are formulated:

1. What characteristics determine the fire susceptibility of a tree?
2. What factors determine the fire susceptibility of a forest?
3. What does a climate-smart forest in the Netherlands in the year 2100 look like?
4. What is the difference in fire susceptibility between a climate-smart forest in the Netherlands in the year 2100 and the average forest in the Netherlands in the year 2023?

Fire susceptibility refers to the risk of a fire starting and the horizontal and vertical propagation of the fire. The fire susceptibility is expressed in a fire sensitivity score. Throughout the remainder of this report, the terms 'future' and 'prospective' are used to refer 'in the year 2100'.



Chapter II

Methodology

2 Methodology

This chapter provides a detailed description of the methodology applied in conducting the study. The chapter starts by outlining the design of the research. The manner in which the data was collected is detailed in the second paragraph. Finally, the approach for analysing the research data is introduced in the third paragraph.

2.1 Research design

The research design entails a mixed methods approach referred to as triangulation. This approach involves the use of multiple data collection methods to obtain a comprehensive understanding of the research problem and to enhance the credibility of the research findings (Hussein, 2009, p. 107). Initially, a literature review was conducted to collate additional information. One of the reasons for employing this literature review is to establish a solid theoretical basis for the study (Giles et al., 2013; Linda et al., 2014, p. 502). The literature research was primarily used to gather information on the characteristics and factors that define the fire susceptibility of a tree and a forest, but also to retrieve information on the Dutch forest.

It was important to ascertain what a climate-smart forest might resemble. To this end, a brainstorming session with experts was arranged with the objective of forming perceptions of a climate-smart forest based on their creativity, experience, and knowledge. To strengthen the research, visions of a climate-smart forest were also created using AI technology. In the brainstorming session, the outcomes derived from the literature review served as the conversation topics. These findings were also used as inputs to the AI model.

The brainstorming session takes a hybrid approach, combining both creativity and interaction-based methodologies. Creative methods require an interplay of original and inventive thinking, whereas interaction-based methods rely on the exchange of ideas and thoughts (Popper, 2008). This method was chosen because the brainstorming session aims at sketching a future image of a climate-smart forest based on the joint knowledge of the attendees. Appendix I presents the foresight diamond containing the possible research methods according to Popper (2008). The knowledge of AI is based on a diverse set of sources available on the internet, such as websites, books, articles, and other texts. It should be noted that AI does not have real-time access to the internet and the information is up-to-date until its last training date in January 2022. Also, there are no active moderators behind AI who specifically review sources for veracity.

Both the brainstorming session and the AI model clarified which tree species are expected to constitute future climate-smart forests in the Netherlands. Additionally, the factors from the second sub-question were also identified for these forests. Based on this amassed knowledge, two multi-criteria analyses were conducted for each conceived climate-smart forest type to quantify the fire sensitivity score. One for the characteristics that determine the fire susceptibility of a tree and the other for the factors that determine the fire susceptibility of a forest. These two multi-criteria analyses were also carried out for the average Dutch forest. This enabled the comparison of fire susceptibility between the conceived climate-smart forests and the average Dutch forest.

2.2 Data collection

The data of this research was collected in three different ways: through literature research on characteristics and factors influencing the fire susceptibility of a tree and a forest, qualitative research with a brainstorming session and an AI model on what a future climate-smart forest looks like and quantitative research by determining the fire sensitivity scores for the climate-smart forests and the average Dutch forest. The three different methods are described in detail below.

Literature research

The information provided within the literature review have been gathered by consulting various platforms, including Elicit, Google Scholar, and GreenI. The accessibility provided by these platforms assisted in the compiled sources that show important relevance for the content of this research. Further information was collected through internal sources within Eelerwoude. The data acquired from the literature review was used to answer sub-questions one, two, and partly four.

Qualitative research – *brainstorming session and AI model*

A brainstorming session was organised to discover what a climate-smart forest might look like in the Netherlands in the year 2100. The brainstorming session took place on Wednesday 8 November 2023 in room D207 at Van Hall Larenstein University of Applied Sciences in Velp from ten o'clock in the morning until noon. A total of five participants attended this talk, two of whom work as ecologists at Eelerwoude, two as lecturers at Van Hall Larenstein University of Applied Sciences and the last one is a Forest and Nature management student at the same educational institution. A note-taker was present during the brainstorming session to ensure the reliability and validity of this study. Out of consideration for the privacy concerns of the contestants, their personal details remain anonymous. The method conceived by Osborn (1953) was applied during the brainstorming session. This method is guided by two principles: defer judgement and reach for quantity. From these two principles follow four rules: go for quantity, withhold criticism, welcome wild ideas, and combine and improve ideas. The rules are established with the intention of reducing social inhibitions among group members, stimulating idea generation, and increasing the overall creativity of the group. The brainstorming session started with a practice round as the participants were inexperienced. The purpose of this exercise was to acquaint the participants with the method used. After this round, the objective of the brainstorming session was explained and the aforementioned rules were presented. The complete flowchart followed during the brainstorming session is attached in appendix II. Subsequently, invitees were asked to describe how they envision a climate-smart forest in the Netherlands in the year 2100 using four scenarios. The four scenarios are:

- Equal weights
- Avoid risks
- Strengthen ecosystem services
- Generate high yields

These scenarios are rated on four attributes. The four attributes are:

- Proceeds
- Wood properties and use
- Ecosystem services
- Risks

The four scenarios and attributes are adopted from a report by De Avila et al. (2021, p. 226) on the use of alternative tree species against climate change impacts in Germany. This scenario-based approach was selected because a forest generally fulfils multiple roles. For more on the scenarios and the scores assigned to the attributes, see paragraph 3.3. The attendees conceived a climate-smart forest for each scenario. This involved identifying the following aspects:

- Tree species including percentages
- Standing wood stock in m^3/ha
- Percentage undergrowth of the entire forest
- Stand density in number of trees per hectare
- Standing dead wood in m^3/ha
- Lying dead wood in m^3/ha

In total, four distinct concepts of a future climate-smart forest emerged from the brainstorming session. It was decided beforehand not to raise the subject of forest fires to encourage an unbiased response from the participants. If this had been done, there was a chance that different tree species would have been chosen than the current ones. The aspects listed above come from paragraphs 3.1 and 3.2 and determine the fire susceptibility of a tree and a forest. To support the research, four more climate-smart forests were developed through ChatGPT 4.0. This AI model was posed the same questions as those present at the brainstorming session, see appendix III for the prompts. The information obtained from the brainstorming session and AI was used to address sub-question three and provide the necessary data to conduct the multi-criteria analyses in sub-question four. The multi-criteria analyses are explained in the next heading.

Quantitative research – *multi-criteria analyses*

A total of eighteen multi-criteria analyses were carried out to determine the fire sensitivity scores of the conceived climate-smart forests and the average Dutch forest. Multi-criteria analyses were conducted for both the characteristics that determine the fire susceptibility of a tree and the factors that determine the fire susceptibility of a forest. Of the total, sixteen multi-criteria analyses were performed for the eight conceived climate-smart forests and two for the average Dutch forest. Two multi-criteria analyses were carried out for the average Dutch forest to enable comparison with all climate-smart forests. To conduct these multi-criteria analyses, the five most common tree species were selected from the 7th edition of the Dutch forest inventory. The rest of the required data was also retrieved from the Dutch forest inventory, only stand density comes from a different source. These sources are referenced in paragraph 3.4. Paragraph 3.2 showed that several factors are involved in terms of the fire susceptibility of a forest. However, there was uncertainty about which factor was more important than the others. To conduct the multi-criteria analyses, it was necessary to rank these factors according to their importance. The ranking was carried out by a survey based on the 7-point agreement Likert scale (Bhandari & Nikolopoulou, 2023). This survey required respondents to give a score from one to seven to the factors, where one represents strongly disagree and seven indicates strongly agree. For each factor, the number of scores given was multiplied by the score associated with it. As an example, the wood stock factor was rated two times as agree and five times as strongly agree. Agree corresponds to a score of six and strongly agree relates to a score of seven. The six for agree is then multiplied by two and the seven for strongly agree by five. The results are added together and divided by the total number of scores given, in this case seven, to obtain an average. The formula **(1)** used to calculate this average score is given below.

(1) $$A = \frac{\Sigma(Nl * s)}{Nt}$$

Where:

A = average score of a factor

Nl = number of scores given for the level (strongly disagree - strongly agree)

s = score from 1-7

Nt = total number of scores given for a factor

The results are shown in paragraph 3.2. The survey is presented in appendix IV. The survey was performed during the Nature Fire Symposium on Wednesday 22 November 2023 at the Nederlands Instituut Publieke Veiligheid at Kemperbergerweg 783 in Arnhem and was completed by six respondents. Respondents are employed by Bosgroep Zuid-Nederland, Brandweer, and Staatsbosbeheer, among others. Again, due to the privacy rights of the contestants, their personal data is kept anonymous. The Likert scale was not used for the characteristics that determine the fire susceptibility of a tree due to time restraints.

There are a total of three different fire sensitivity scores: the fire sensitivity score of a tree species, the average fire sensitivity score of the tree species composition of a forest and the final fire sensitivity score of a forest. The first two were calculated in the multi-criteria analyses of the characteristics that determine the fire susceptibility of a tree. The third was calculated in the multi-criteria analyses of the factors that determine the fire susceptibility of a forest. The calculations are explained in more detail below.

Calculation – *the fire sensitivity score of a tree species and the average fire sensitivity score of the tree species composition of a forest*

Of all forests, both the climate-smart forests that emerged from the brainstorming session and from AI as well as those of the average Dutch forest, the values for the characteristics that determine the fire susceptibility of a tree were searched. Only the values for bark thickness and moisture content of *Corylus avellana*, *Corylus colurna,* and *Sorbus aucuparia* were estimated by consulting AI and personal knowledge. The characteristics that determine the fire susceptibility of a tree are:

- The maximum bark thickness in cm
- The density of air-dried wood in kg/m^3 (moisture content: 12%)
- The average moisture content of the green wood in per cent
- Whether the tree species contains resin

These characteristics come from paragraph 3.1. In addition, percentages were allocated to all tree species of each climate-smart forest. This percentage represents the proportion of the tree species compared to the entire forest. The percentages of all tree species added together constitute the entire respective forest. The calculation starts by multiplying the maximum bark thickness in cm by the density of air-dried wood in kg/m^3 and the average moisture content of the green wood in per cent for each tree species. If the tree species does not contain resin, then the value one is divided by the result of the previous calculation. When it does contain resin then the value two is divided by the result. Subsequently, this figure is multiplied by the percentage listed at the left-hand side of the table for each tree species. The outcome constitutes the fire sensitivity score of the tree species in question.

The formula **(2)** used to calculate this fire sensitivity score is given below.

(2) $$f = \left(\frac{r}{b * d * m}\right) * Pt$$

Where:

f = fire sensitivity score of a tree species
r = does the tree species contain resin? Yes = 2 | No = 1
b = maximum bark thickness [cm]
d = density of air-dried wood [kg/m^3]
m = average moisture content of the green wood [%]
Pt = proportion of a tree species compared to an entire forest [%]

This process is repeated for each tree species within the respective forest. Finally, the fire sensitivity scores are summed and divided by the number of tree species within this forest. This results in the average fire sensitivity score of the tree species composition of the respective forest. The formula **(3)** used to calculate this fire sensitivity score is given below.

(3) $$Af = \frac{\Sigma f}{n}$$

Where:

Af = average fire sensitivity score of the tree species composition of a forest
Σf = sum of all fire sensitivity scores in a forest
n = number of tree species in a forest

This calculation was repeated for all forests. The average fire sensitivity scores were incorporated into the multi-criteria analyses of the factors that determine the fire susceptibility of a forest.

Calculation – *the final fire sensitivity score of a forest*

All eight conceived future climate-smart forests, both those resulting from the brainstorming session and those from AI, were assigned values for the factors that determine the fire susceptibility of a forest. The values for these factors of the average Dutch forest originate from the 7th edition of the Dutch forest inventory. The factors that determine the fire susceptibility of a forest are:

- Standing wood stock in m^3/ha
- Percentage undergrowth of the entire forest
- Stand density in number of trees per hectare
- Standing dead wood in m^3/ha
- Lying dead wood in m^3/ha

These factors come from paragraph 3.2. First, the values of each factor for every forest were multiplied by the average scores from the survey. The average scores from the survey are described in paragraph 3.2 and shown in tables 4 and 6 in paragraph 3.4. Thereafter, the outcomes of these calculations were multiplied by each other for each forest. Lastly, the value obtained is multiplied by the average fire sensitivity score of the tree species composition of the respective forest from the multi-criteria analysis on the characteristics that determine the fire susceptibility of a tree. This calculation produces the final fire sensitivity score of the respective forest. The formula **(4)** used to calculate this fire sensitivity score is given below.

$$Ff = \big((s * a) * (Pu * a) * (sd * a) * (st * a) * (ly * a)\big) * Af \tag{4}$$

Where:

Ff = final fire sensitivity score of a forest
s = standing wood stock [m^3/ha]
Pu = undergrowth of an entire forest [%]
sd = stand density in number of trees per ha
st = standing dead wood [m^3/ha]
ly = lying dead wood [m^3/ha]
a = average score from the survey for the respective factor
Af = average fire sensitivity score of the tree species composition of a forest

The higher the value of the final fire sensitivity score in tables 4 and 6 in paragraph 3.4, the higher the probability of a fire starting and the faster it propagates through the forest. Figure 5 in paragraph 3.4 compares the percentage increase or decrease in the final fire sensitivity scores of the climate-smart forests with the average Dutch forest. In this figure, the average Dutch forest is considered the baseline.

2.3 Data processing

The findings from the literature research were summarised for the report. The information gathered during the brainstorming session and obtained through AI was systematically processed using Excel. The results of the data processing in Excel are presented in bar and pie charts. The data from these bar and pie charts were in turn used to conduct the multi-criteria analyses.

Chapter III

Results

3 Results

This chapter presents and analyses the results of the study. The data acquired provide insight into the fire susceptibility of the eight conceived future climate-smart forests and the average Dutch forest. The chapter is divided into four paragraphs, with each paragraph addressing one sub-question. The first paragraph discusses the first sub-question, the second paragraph covers the second sub-question and so forth. The results presented form the basis of the conclusion in chapter V.

3.1 Characteristics determining the fire susceptibility of a tree

This section addresses the first sub-question and deals with the characteristics of trees that influence fire susceptibility. These characteristics are listed below and are used to calculate the fire sensitivity scores of the tree species of the future climate-smart forests and the average Dutch forest. The fire sensitivity scores of the tree species of the climate-smart forests and the average Dutch forest are calculated in paragraph 3.4.

Different forms of fuel are present in forests, such as litter, branches, dead wood, living wood, etc. These forms of fuel all consist of woody tissue that is combustible. However, not all types of woody tissue react to ignition and combustion in the same way. This can vary significantly depending on the tree species, as the morphology, density and chemical composition of the wood can affect its fire behaviour (Osvaldová et al., 2023, p. 195). Starting with the bark that preserves the vascular cambium of a tree from fire through the presence of polyphenol tannin. Trees are deemed fire-resistant if the temperature of the vascular cambium remains below the thermal cell death threshold of 60°C during a fire. The extent of protection depends on the thickness of the bark, which varies between species (Bauer et al., 2010, p. 5950; Odhiambo et al., 2014, p. 555). According to research by VanderWeide and Hartnett (2011, p. 1530), a minimum bark thickness of approximately 8.6 mm is necessary to maintain the vascular cambium temperature below 60°C. However, the bark samples in this study were subjected to fire of 400°C for a maximum of 120 seconds to mimic surface fires. These conditions naturally do not correlate with the intense heat of approximately 800°C and the prolonged duration of an actual forest fire (Lemmers, 2017). Consequently, the threshold value of minimum bark thickness is not applied when calculating the fire sensitivity score of a tree species. Research by Brando et al. (2011, p. 630) also demonstrated that tree mortality of thick-barked trees was lower than thin-barked trees when exposed to medium-intensity fires. Furthermore, it seems reasonable to assume that bark moisture content and density would also be involved in preventing the lethal cambium temperature from being reached. Yet the study by VanderWeide and Hartnett (2011, p. 1534) found that neither has a significant effect. Besides tree bark, several authors have investigated the effect of wood density on ignition and burning using various tree species and laboratory methods (Osvaldová et al., 2016; Osvaldová et al., 2021). Density has been proven to be among the greatest influences on the ignition and combustion of any wood. Other studies reported that denser wood provides a lower burning rate which means the fire resistance of wood improves by increasing the density (Adetayo & Dahunsi, 2020, p. 70; Haurie Ibarra et al., 2019, pp. 200–201; White, 2000, p. 9). These studies also indicate that the burnt wood transforms into a layer of charcoal that loses all strength, but continues to serve as an insulating layer to keep the core its temperature from rising too quickly. Moreover, the moisture content of a tree significantly affects its susceptibility to fire, with different species exhibiting varying levels of resistance (Daosheng et al., 2001). A study published by Hasburgh et al. (2019, p. 365) also highlighted the importance of wood moisture content in flame spread. Tree species with lower moisture levels are more vulnerable to fire (De Santis et al., 2006). Wood moisture content can range from about 30% to more than 200% (Glass & Zelinka, 2010). Lastly, whether the tree species contains resin or not is also pertinent to fire susceptibility. Resin is a non-volatile, insoluble, and stable plant product composed of a complex terpenoid mixture (Dell & McComb, 1979). It is produced, stored, and translocated in specialised surface glands or internal ducts and serves as a crucial defence mechanism against bark beetles and fungal pathogens (Trapp & Croteau, 2001; Vázquez-González et al., 2020, p. 1314). Deciduous trees do not contain resin, as resin is a characteristic of conifers. Resin can make a tree more flammable, because it contains organic metabolites that can increase the risk of ignition and energy release during combustion (Bolier, 2014; Guerrero et al., 2021).

Summary of characteristics

In summary, the following characteristics are used to calculate the fire sensitivity score of a tree species: the maximum bark thickness in cm, the density of air-dried wood in kg/m^3 (moisture content: 12%), the average moisture content of the green wood in per cent and whether the tree species contains resin. The maximum bark thickness of a tree species was taken instead of the bark thickness at a certain age of the tree or at a particular DBH to avoid erroneous comparisons. The likelihood of differences by growth location is too high. As an example, a *Quercus robur* with an age of thirty years at an optimal growth location may have a bark thickness of five cm while the same tree at an unfavourable growth location only achieves a bark thickness of two cm. In addition, due to a lack of available information on the green density of tree species, the density of air-dried wood has been applied. This density is widely used when calculating the strength of timber as a construction material. The moisture content of the air-dried wood is 12%. Besides, the average moisture content of the green wood is included, as it can vary greatly depending on the season and location. Regarding resin, deciduous species are assigned a value of one and coniferous species a value of two.

3.2 Factors determining the fire susceptibility of a forest

This paragraph answers the second sub-question and discusses the factors that determine the fire susceptibility of a forest. The section begins with the elements required to initiate a fire. Followed by an explanation of these particular elements in a forest environment. The paragraph ends by listing the factors that determine the fire susceptibility of a forest and the results of the survey for ranking the factors. These factors were discussed during the brainstorming session and incorporated into the AI model for conceiving future climate-smart forests. To make the text more readable, reference is made only to the brainstorming session.

Climate change has led to increased average temperatures and shifting weather patterns worldwide. Since the year 1880, the Earth its average temperature has risen steadily at an increment of 0.08 degrees Celsius per decade (Lindsey et al., 2023). This equates to a cumulative increase of about 1.12 degrees Celsius, a seemingly modest value. Nevertheless, it is important to note that for every degree Celsius temperature rise, the intensity of precipitation showers increases by 2% to 14% (Selten, 2022). Moreover, the annual number of months of heat waves also increases by 0.4 months for every half-degree rise in temperature (Milieudefensie, 2021). These heat waves result in a more frequent occurrence of severe droughts (Spinoni et al., 2017, p. 1732; Van Hateren et al., 2021, Chapter 1). The synergy between higher temperatures and protracted droughts significantly enhances the risk of forest fires (Mansoor et al., 2022). Although this increased probability is critical for forest managers in devising adequate management policies, it does not provide any insight into the fire susceptibility of forests. The fire susceptibility of forests depends on several intricate factors, which are explained in detail in this paragraph. Understanding these factors is essential for effective forest management, ecosystem conservation and minimising fire-related risks to both humanity and nature (Jinzhu et al., 2007; Luijks, 2020). These factors are used as guides by forest managers, scientists, and policy makers to develop targeted measures to reduce flammability and improve forest resilience.

Starting a fire

It is essential to succinctly explain what a fire is and how it generally starts. Every fire starts somewhere. Almost all fires begin as an initially modest and innocuous fire. A sizeable, rapidly disseminating house fire can originate in the same way as a minor flame in a rubbish bin (Chapman, 1999, p. 12). Fire is considered an unwanted combustion capable of spreading unimpeded and causing danger (Simon et al., 2006). The concept of fire is directly related to the process of combustion, which occurs in various ways and is crucial for human survival. Examples include the metabolism of the human body and the combustion process needed to heat a home or office (Boden, 1999, p. 231; Boudko, 2005, p. 797). Any combustion process initiates with a combustion reaction, a chemical reaction between a fuel and oxygen. However, the start of a fire does not depend only on the presence of fuel and oxygen; a sufficiently high temperature is also a requirement (Bosbrandweer Noord-Nederland, n.d., p. 12). Therefore, three fundamental elements are necessary for fire to start: fuel, heat or an ignition source and oxygen (Muchatuta & Sale, 2007, p. 457; Stauffer & Nic Daéid, 2013; Tearle, 1998). For each of these elements, an explanation of their specific role within a forest environment is given below.

Fuel

Different forms of fuels are present in a forest. These fuels originate from natural sources and can be classified into three categories:

- **Living biomass** covers all living trees and shrubs within a forest and is the primary component with respect to forest fires (Díaz García et al., 2013, p. 396). This group also includes both the needles of conifers and the leaves of deciduous trees that are still attached to the trees. Despite being flammable, a living tree or shrub will not simply catch fire. Polyphenol tannin present in tree bark acts as a protective agent that shields a tree its heartwood and sapwood from fire, damage, dehydration, and external pathogens (Ducatez-Boyer & Majourau, 2017, p. 4; Ghosh, 2013, p. 51; Tributsch & Fiechter, 2008, p. 43). The bark properties of several climate-smart and indigenous tree species are described in paragraph 3.4. Prior to the occurrence of an actual forest fire, the fire has to make its way from the soil vegetation through the understorey to the forest canopy. The term understorey or undergrowth denotes the vegetation located beneath the tree layer and consists of trees and shrubs with a diameter at breast height (DBH) less than five centimetres as well as the herb layer of e.g. *Pteridium aquilinum* or *Rubus plicatus*. The understorey is also known as a fuel ladder in this process (Smits et al., 2020, p. 22). The amount of undergrowth present in a forest is a decisive factor in the initiation of forest fires (Blauw et al., 2017, p. 483). Therefore, the percentage of undergrowth of the entire forest is a topic during the brainstorming session. The generation of a fire is impossible without fuel which makes the standing wood stock in m^3/ha also a determining factor in assessing the fire susceptibility of a forest. However, it should be noted that wood supply is only a partial determinant as it mainly relates to the duration of a forest fire (P. Schuur, personal communication, November 22, 2023). The more fuel present in a forest, the longer the fire will last. Another factor that drives the fire susceptibility of a forest is stand density. Stand density is the number of trees (DBH ≥ 5 cm) per unit area, with the unit area used in this study being hectares. In a forest with high stand density, fire can easily spread to surrounding trees via the interconnected branches and twigs of the canopies. Unlike a forest with low stand density where it is almost impossible for the tree crowns to be connected (Ihsan et al., 2023, p. 31). There are exceptions in low stand density forests where the stand density at specific locations in the forest is considerably higher than elsewhere in the same forest. In those places, tree crowns can be connected. The stand density does not distinguish between coniferous and deciduous trees because of the flammable resin in conifers, as this distinction is already made in sub-question one and would therefore be duplicative.

Besides undergrowth and wood stock, stand density in number of trees per hectare is another topic during the brainstorming session.

- **Dead biomass** constitutes a significant proportion among the combustible resources found in a forest (Gormley et al., 2020, p. 1). It comprises dry leaves and needles that have fallen from trees, along with decomposed branches, grass and other dead vegetative matter that accumulates on the forest floor (Varner et al., 2015, p. 91; Westaway, 2013). These materials desiccate and can easily ignite when exposed to enough heat. Although the litter layer is relevant in determining the fire susceptibility of a forest, it is not included in the brainstorming session. The litter layer is complicated to measure because it can consist of leaves and/or needles from multiple tree species which possess different properties. Not to be forgotten is the standing and lying dead wood that also belongs to this category. The presence of both is desirable for forest managers given the enormous biodiversity it preserves. Dying and dead trees, either standing or fallen and at different stages of decay, are valuable habitats by providing food, shelter, and breeding conditions for all kinds of species. Examples of species that utilise dead wood are: birds, bryophytes, invertebrates, lichens, mammals and saproxylic insects (Radu, 2006, p. 137; Tomescu et al., 2011, p. 12). The long-term target for a forest with a nature function is to achieve a quantity of 30-40 m^3 of dead wood per hectare, with an optimal ratio of 50-50% between standing and lying dead wood. By contrast, managed forests often have only 1-3 m^3 of dead wood per hectare (Jagers Op Akkerhuis et al., 2005, pp. 66–67). It is possible for forest managers to regulate the amount of standing and lying dead wood in a forest and hence it was chosen to address this subject during the brainstorming session. Standing and lying dead wood are discussed separately in the brainstorming session since standing dead trees have relatively lower moisture content compared to lying dead trees (Van Leeuwen, 2020). Standing dead trees are therefore also expected to be more vulnerable to fire than lying dead trees. Complete failure of forest stands consisting of *Larix kaempferi* or *Picea abies* as a result of infestations by the *Ips cembrae* and the *Ips typographus* are disregarded (Alblas, 2023; Willems, 2019).
- **Below-ground biomass**, consisting of roots and stumps of trees, plays a minor role in forest fires compared to the previous two categories. A stump refers to the part that remains after a tree has been cut down or fallen naturally. These are usually not plentiful in a forest as they decompose over time by fungi and insects. On the contrary, roots are always present in a forest but are unlikely to catch fire since they are in the ground. Nonetheless, this category is still a form of fuel and can combust under the right circumstances. Underground fires from roots and stumps are hard to detect and fight (Saulov et al., 2018). These fires can harm the roots of healthy trees, endangering their survival. Current technologies for extinguishing underground fires like nitrogen injection are either costly or do not produce satisfactory results (Sipilä et al., 2012). Forest managers have no bearing on the amount of roots present in a forest and are thus exempt from the brainstorming session.

Heat

Forest fires are caused either by humans or by nature itself. According to findings presented by Rowell and Moore (2000) and Weicheng (2005), approximately 90% of forest fires are attributed to human acts. This sometimes happens on purpose, for example by a pyromaniac, but more often unconsciously. Examples of fires started by humans include: people carelessly discarding a cigarette, imprudent barbecuing in nature or a glass that has been smashed on the ground and its shards acting as a magnifying glass (Stijkel, 2018). The majority of forest fires that arise from nature itself are caused by lightning strikes. Both forest fires caused by human activity and lightning are growing in number. Due to climate change, lightning strikes are becoming more frequent in some places (Harvey, 2017). A study by Romps et al. (2014, p. 851) expects the number of lightning strikes could increase by about 12% for every degree Celsius of warming. Unfortunately, forest managers have no influence on the number of lightning strikes, nor can they change people its behaviour. Nevertheless, they do attempt to make people aware of the consequences of these actions by spreading information campaigns and issuing fines (Beuker, 2023; Oldenbeuving, 2019). Since forest managers have no control over this part of the three components, it was decided to leave this topic out of the brainstorming session.

Oxygen

It deserves mention that forest management focuses solely on preventing fires and reducing fire risk rather than regulating oxygen supply. Oxygen is always abundant, even in densely forested areas. As a consequence, forest managers have no control over the amount of oxygen available during a forest fire (Van den Berg, 2023). The fire will consume the available oxygen to burn regardless of the efforts by forest managers and firefighters to manage it. This issue is thus excluded from the brainstorming session.

Summary of factors and survey results

In summary, the following factors are considered during the brainstorming session and in the AI model: standing wood stock in m^3/ha, percentage undergrowth of the entire forest, stand density in number of trees per hectare and standing and lying dead wood in m^3/ha. However, it was unclear which factor was more important than the other and hence a survey was conducted based on the 7-point agreement Likert scale. The explanation of this method is described in paragraph 2.2 and the survey itself is in appendix IV. Undergrowth was found to be the core factor with an average score of 6.67 (SD: 0.52). Wood stock ranked second with a score of 5 (SD: 1.67). In third place is lying dead wood to which a score of 4.83 (SD: 1.94) was assigned. Following that is standing dead wood in fourth place scoring 4.5 (SD: 1.22). Stand density is in last place and rated 4.17 (SD: 2.23). The abbreviation SD after the outcomes represents the standard deviation. The larger the number of the standard deviation the more dispersed the responses. The outcomes are also shown in tables 4 and 6 in paragraph 3.4.

3.3 Climate-smart forests in the Netherlands in the year 2100

This section covers the third sub-question and examines the possible appearances of climate-smart forests in the Netherlands in the year 2100. First, it explains the four scenarios used to identify the future climate-smart forest types. Second, the prospective climate-smart forests conceived by the attendees during the brainstorming session are described. Last, the future climate-smart forests concocted by AI technology are presented.

In all, there are four scenarios and each one is rated on four attributes. The four attributes are proceeds, wood properties and use, ecosystem services, and risks. Proceeds is about all the earnings that can be gained from a forest. An example is the merits a forest manager receives after selling the harvested timber to a timber merchant. Wood properties looks at the quality of the timber by considering the amount of knots, damage to the log caused by machinery and the width of annual rings. Based on these characteristics and the tree species, the wood can be applied for various purposes such as sawn wood, fibre wood, veneer wood, and so forth (Sikkema, 1996). Ecosystem services are the contributions provided by an ecosystem to people and animals. These services are divided into four categories: provisioning services, regulating services, cultural services, and supporting services. Forests offer numerous ecosystem services such as producing oxygen and biomass through photosynthesis, hosting several animal species and sequestering carbon dioxide. Also, leisure activities like hiking or mountain biking are among the ecosystem services of a forest (Hendriks & Melman, 2012). A risk is the probability of an undesirable event occurring with an adverse consequence and affects the attainment of objectives (Durlinger, n.d.). Examples include the impacts of climate change and the total collapse of forest stands consisting of *Larix kaempferi* as a result of attacks by the *Ips cembrae* (Zwart, 2019). The **first** scenario represents an even distribution of scores across all traits. The **second** scenario prioritises risk aversion and therefore a species-rich forest with *Acer pseudoplatanus*, *Carpinus betulus*, *Fagus sylvatica*, *Ulmus laevis* etc. fits this scenario as it is more resilient to complete mortality from drought, rainfall extremes or pests (Van den Berg et al., 2022, p. 99). Scenario **three** is concerned with enhancing ecosystem services. Not every forest delivers the same ecosystem services, leading to possible variations in forest type by location. The **last** scenario seeks to maximise yield and focuses mainly on timber quality. A representative example of a forest for this scenario is a production forest of *Castanea sativa*, *Fagus sylvatica*, *Pseudotsuga menziesii* or *Quercus rubra*. All scenarios and the traits on which the scenarios were evaluated are shown in table 1 on the next page. The four scenarios and attributes in table 1 are adopted from a report by De Avila et al. (2021, p. 226) on the use of alternative tree species against climate change impacts in Germany. In the report, these were also used to predict what a forest might look like in the future. However, it has not been reproduced completely, as the original table mentions another feature. This concerns the attribute ‘Anbau’, and it has not been incorporated because a clear description is missing in the report. The values allocated to this property were divided equally between the remaining properties.

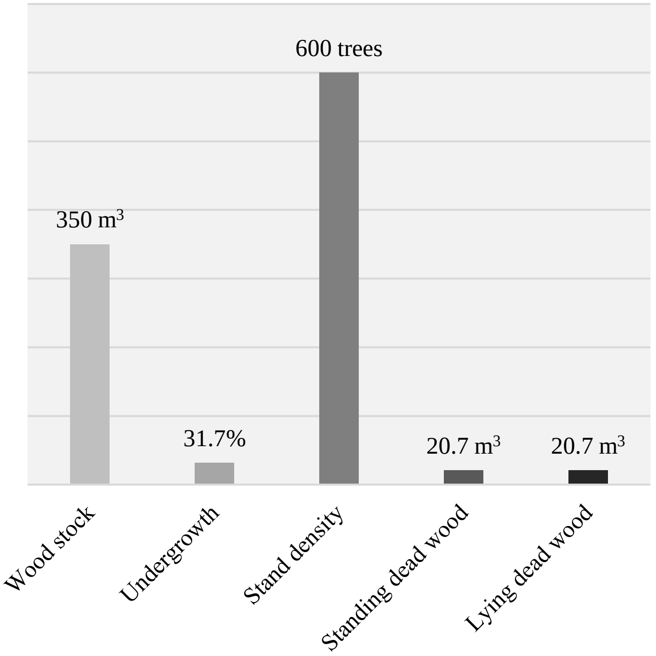
Table 1. The four different scenarios along with the properties on which the scenarios were assessed, retrieved from the research by De Avila et al. (2021, p. 226).

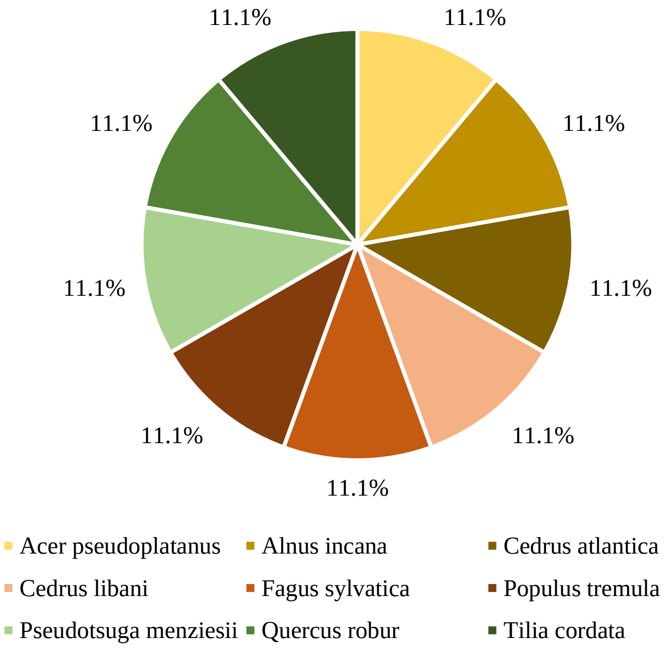
Target system	**Scenario I** *Equal weights*	**Scenario II** *Avoid risks*	**Scenario III** *Strengthen ecosystem services*	**Scenario IV** *Generate high yields*
Proceeds	0.2500	0.1875	0.1875	0.3325
Wood properties and use	0.2500	0.1875	0.1875	0.3325
Ecosystem services	0.2500	0.1875	0.4375	0.1625
Risks	0.2500	0.4375	0.1875	0.1625

By means of the approach explained in paragraph 2.2, four distinct concepts of climate-smart forests in the Netherlands in the year 2100 were constituted during the brainstorming session. For each scenario from table 1 a particular climate-smart forest type was conceived. Also, four climate-smart forests were coined by AI for each scenario from table 1. In the following pages, eight prospective climate-smart forest types are outlined. The initial four forest types were collectively formulated by the attendees during the brainstorming session and the final four were generated with AI technology. The descriptions at the climate-smart forests from the brainstorming session are based on the information obtained and the narratives on AI its climate-smart forests were concocted by AI itself. The pie charts illustrate the different tree species, with the percentage indicating the proportion of each tree species in the entire forest. The factors that determine the fire susceptibility of a forest from paragraph 3.2 are included in bar charts. The values shown in the bar charts are expressed per hectare, except for the percentage of undergrowth pertaining to the whole forest. All images displayed in the descriptions were created by AI. The acronym BS mentioned on the next pages denotes the brainstorming session.

Scenario I *Equal weights - BS*

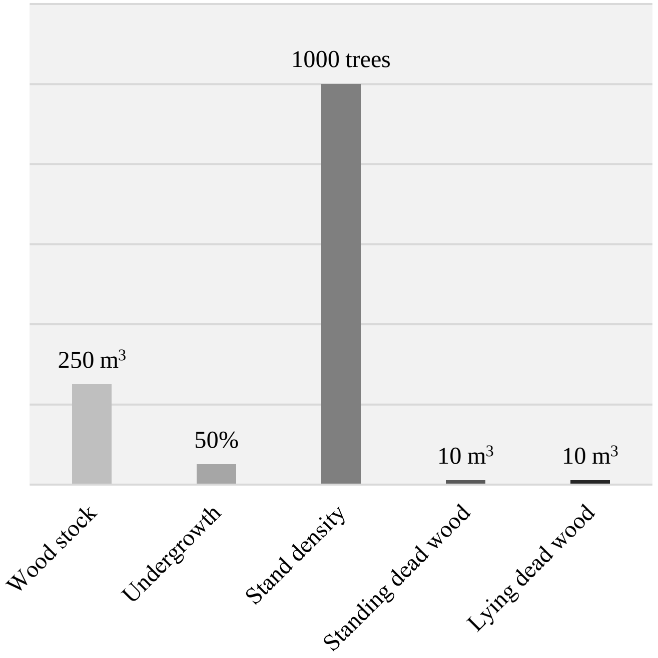
This forest aims to fulfil all its functions to the best of its ability. The proportions of tree species are equal. The most frequently mentioned tree species in the other climate-smart forests of the brainstorming session represent the tree species of this forest. Also, the values of wood stock, undergrowth etc. are the average of the other climate-smart forests from the brainstorming session.

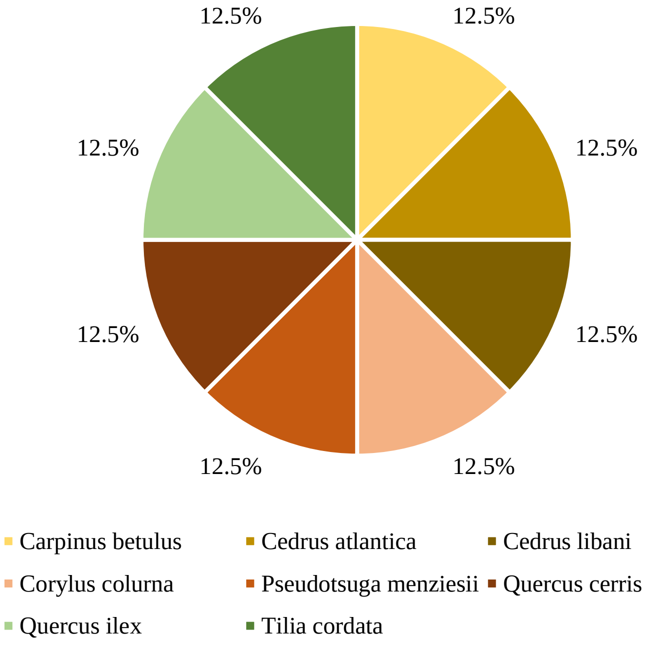




Scenario II *Avoid risks - BS*

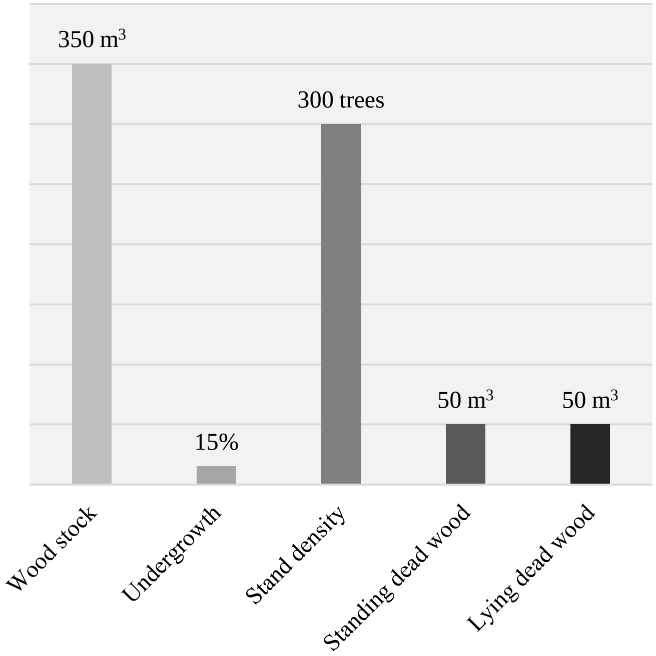
This is a stratified forest where sufficient rejuvenation is always present in case something happens to the large mixture of species. Again, the proportions of tree species are similar. There are alternative species from Mediterranean areas in this forest that thrive in dry weather conditions. Undergrowth is sparse where the forest grows well and plenty in the bare patches. Besides, the wildlife population is intentionally maintained low to give the undergrowth enough chance to survive. There is little dead wood to prevent disease and reduce fire risk.

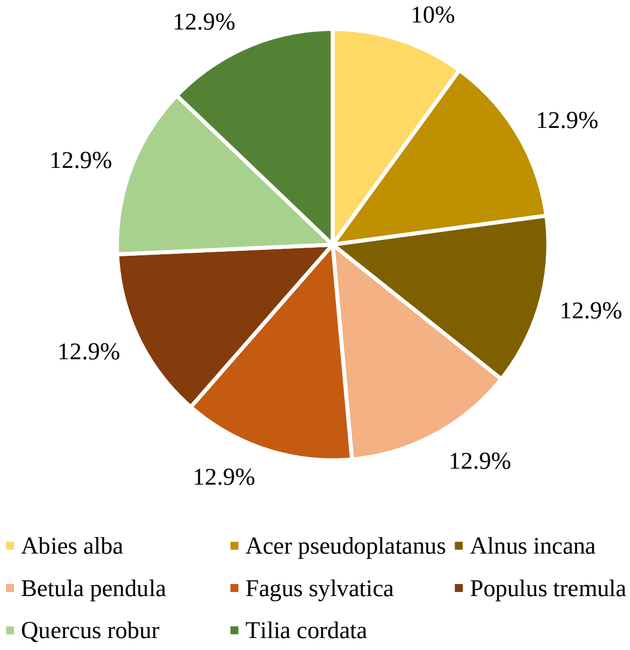




Scenario III *Strengthen ecosystem services - BS*

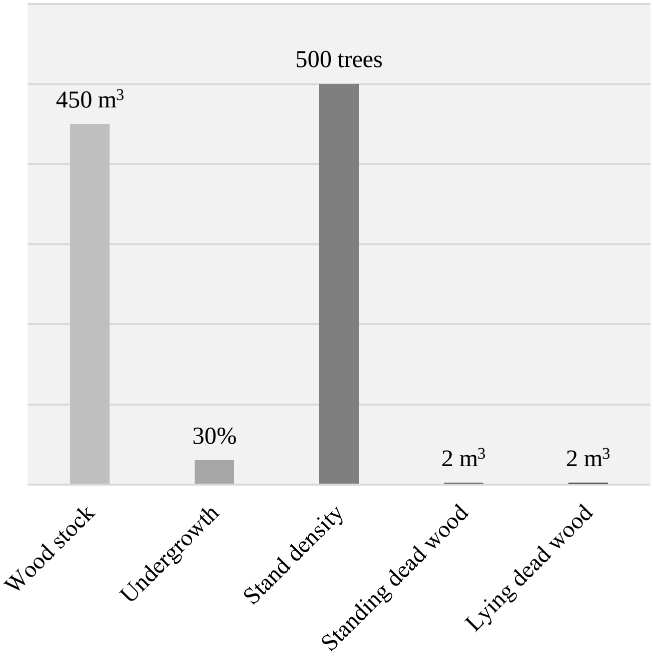
This is a structured forest with abundant dead wood and continuous cover. The ratio consists of 90% deciduous and 10% coniferous species, both of native provenance. *Fagus sylvatica* and *Quercus robur* will disappear over time in the arid parts, to be replaced by *Betula pendula* and *Tilia cordata*. The percentage of undergrowth is low relative to the other climate-smart forests, with rejuvenation only in the canopy gaps. In this forest, there is minimal felling and room for timber production only where it is most beneficial. In addition, there is ample space for leisure pursuits such as mountain biking and hiking.

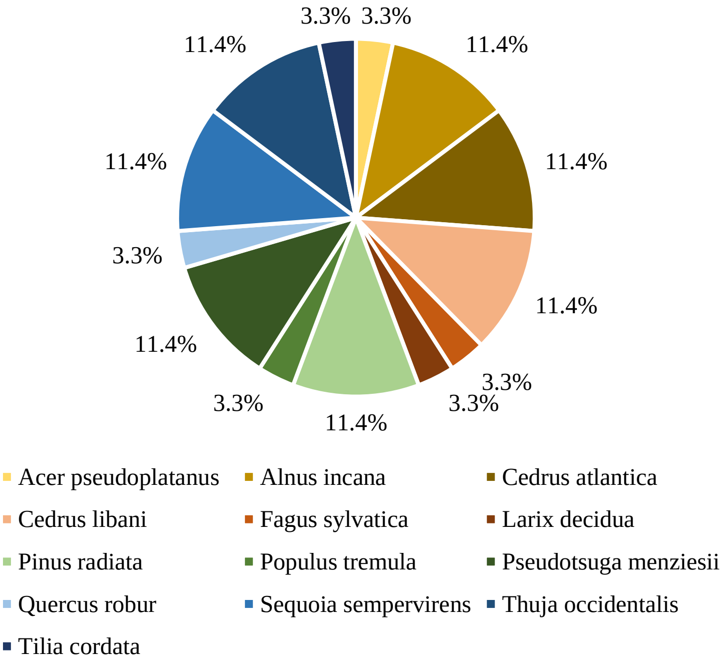


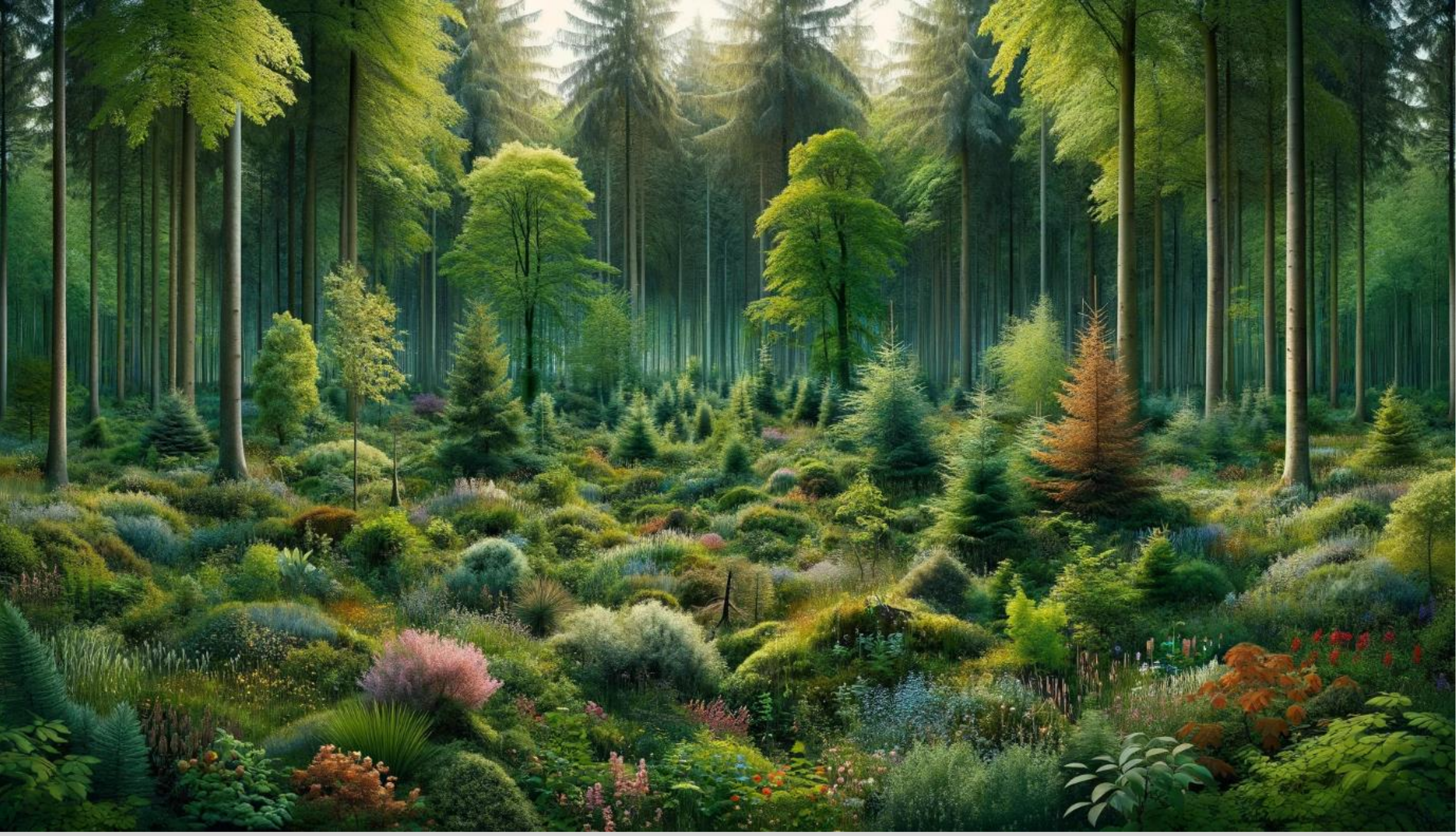


Scenario IV *Generate high yields - BS*

This is an even-aged forest with a mixture of as many deciduous and fast-growing coniferous species as possible to limit risks such as pests. The ratio comprises 20% indigenous tree species and 80% exotic tree species capable of withstanding high temperatures and drought. The goal is to efficiently produce local low-quality, high-production timber. The timber is harvested according to the clearcut method to achieve rapid turnover. Natural rejuvenation consists largely of coniferous wood and is not removed as it does not compete with the prevailing stand. New saplings are planted where the forest fails to rejuvenate naturally. Dead wood in this forest serves no purpose and is hence cleared.

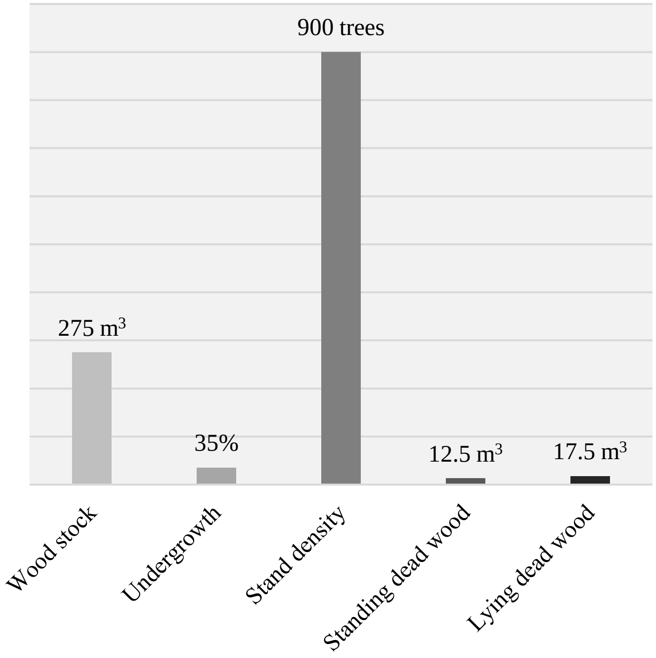


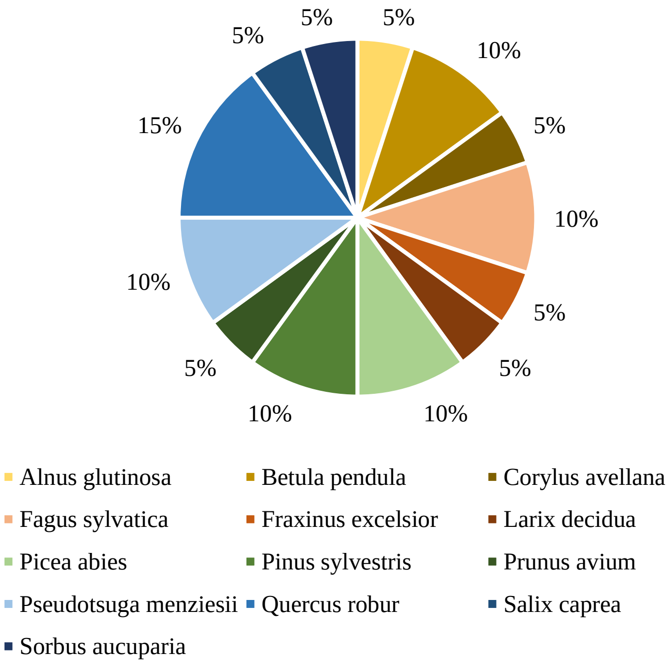




Scenario I *Equal weights - AI*

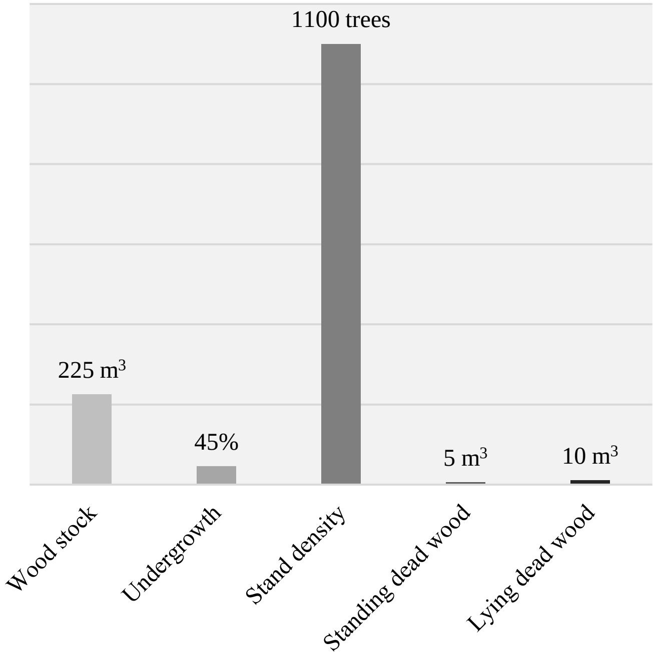
A multifunctional forest ecosystem, reflecting a diverse mix of tree species and rich understorey vegetation defines this forest. The objective of this forest is to balance timber production with ecological considerations. Some tree species support wildlife by producing berries and providing shelter while others contribute to the production of quality timber.

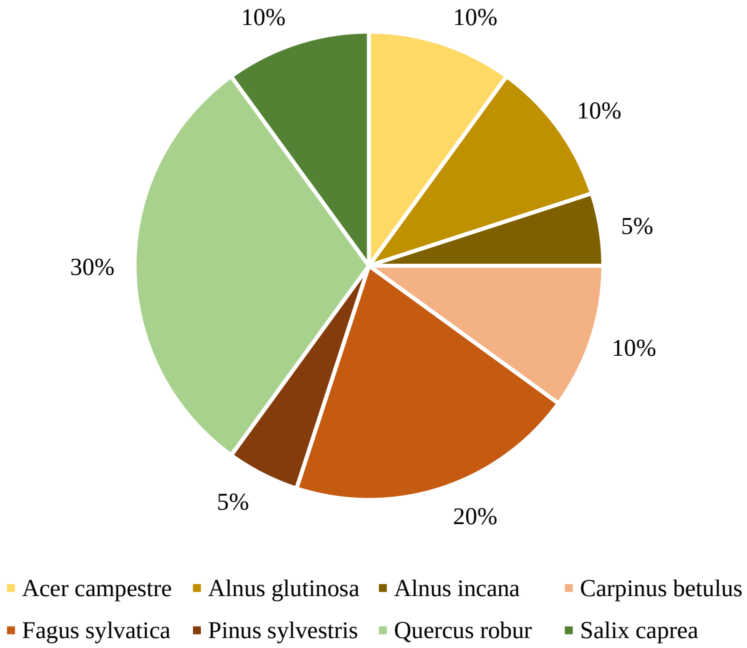


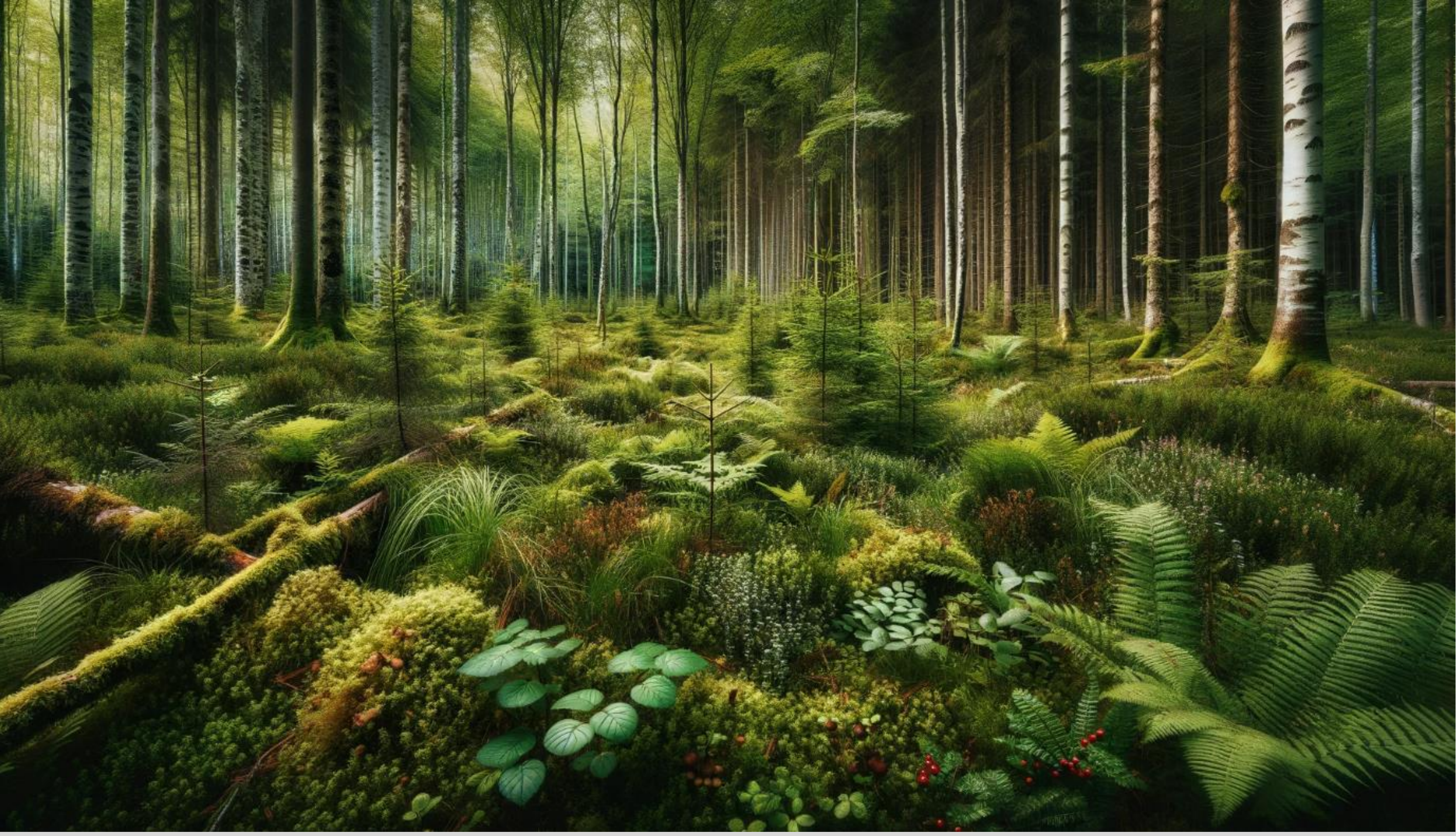


Scenario II *Avoid risks - AI*

This forest is conceived to reduce risks, with a variety of resilient tree species and a diverse understorey. The forest is adapted to a changing climate, emphasising resilience and ecosystem health.

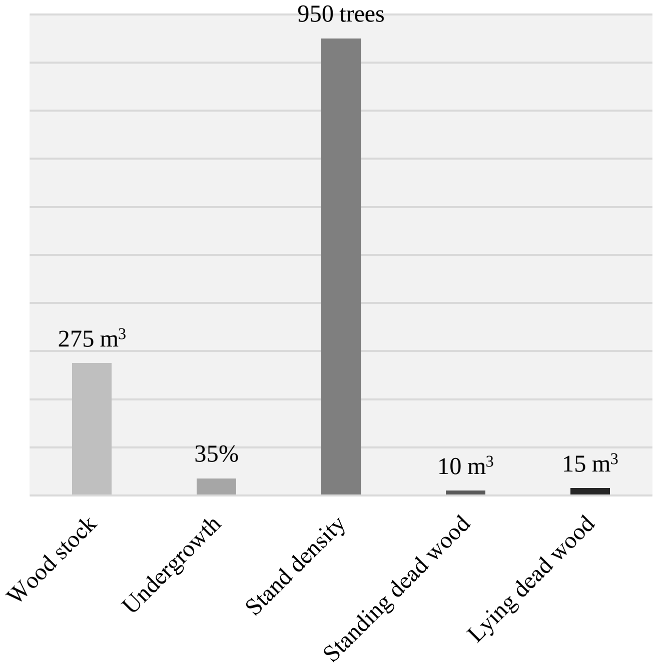


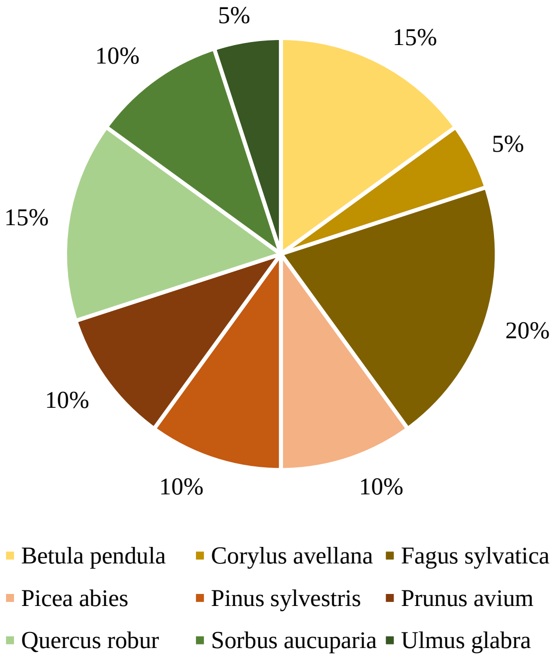




Scenario III *Strengthen ecosystem services - AI*

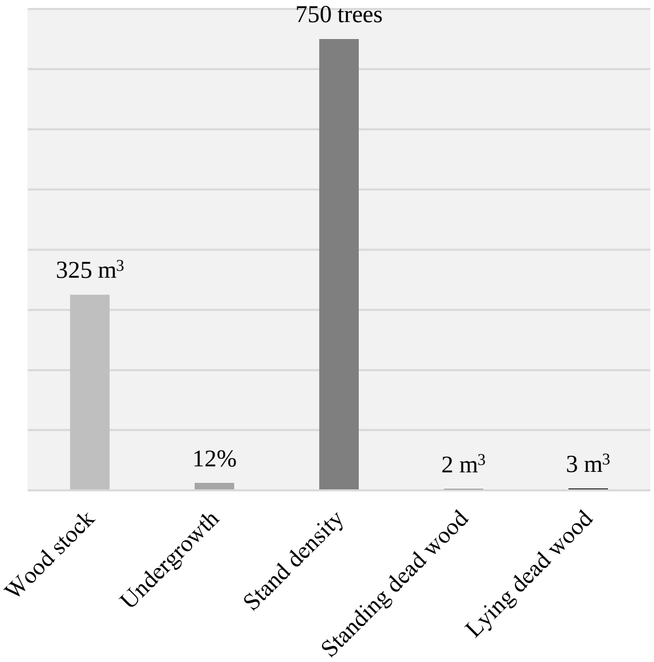
This forest focuses on ecosystem services and is rich in biodiversity. It features a diverse mix of tree species and a lush understorey teeming with life. The stand density reflects a more diverse and less densely planted forest.

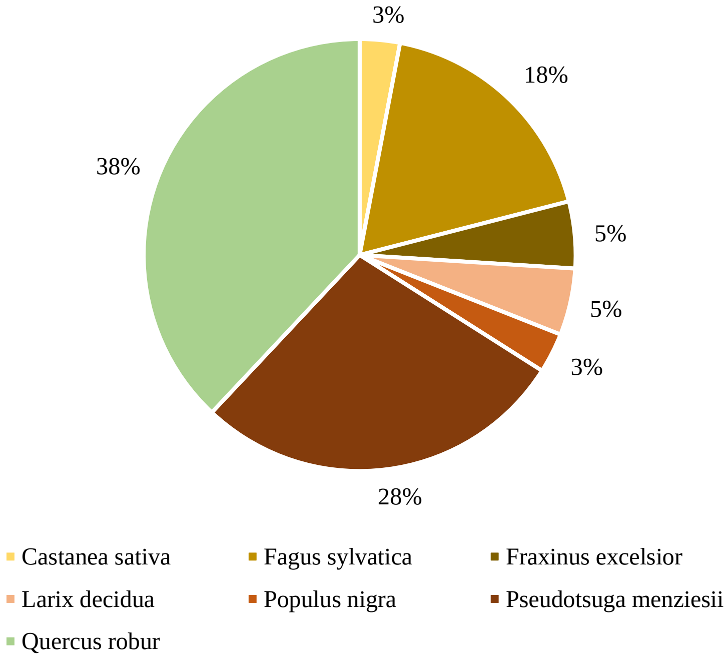




Scenario IV *Generate high yields - AI*

Designed for the production of quality timber, this forest consists mainly of high-value timber species. Undergrowth is minimal, emphasising the tall, straight trunks of the timber trees.





In order to highlight the distinguishing characteristics of all climate-smart forests, figures 2, 3 and 4 are presented below. The chart in figure 2 illustrates the variations among the climate-smart forests resulting from the brainstorming session. Figure 3 shows the contrast between the climate-smart forests derived from the AI model. Finally, figure 4 provides insight into the differences between all climate-smart forests.

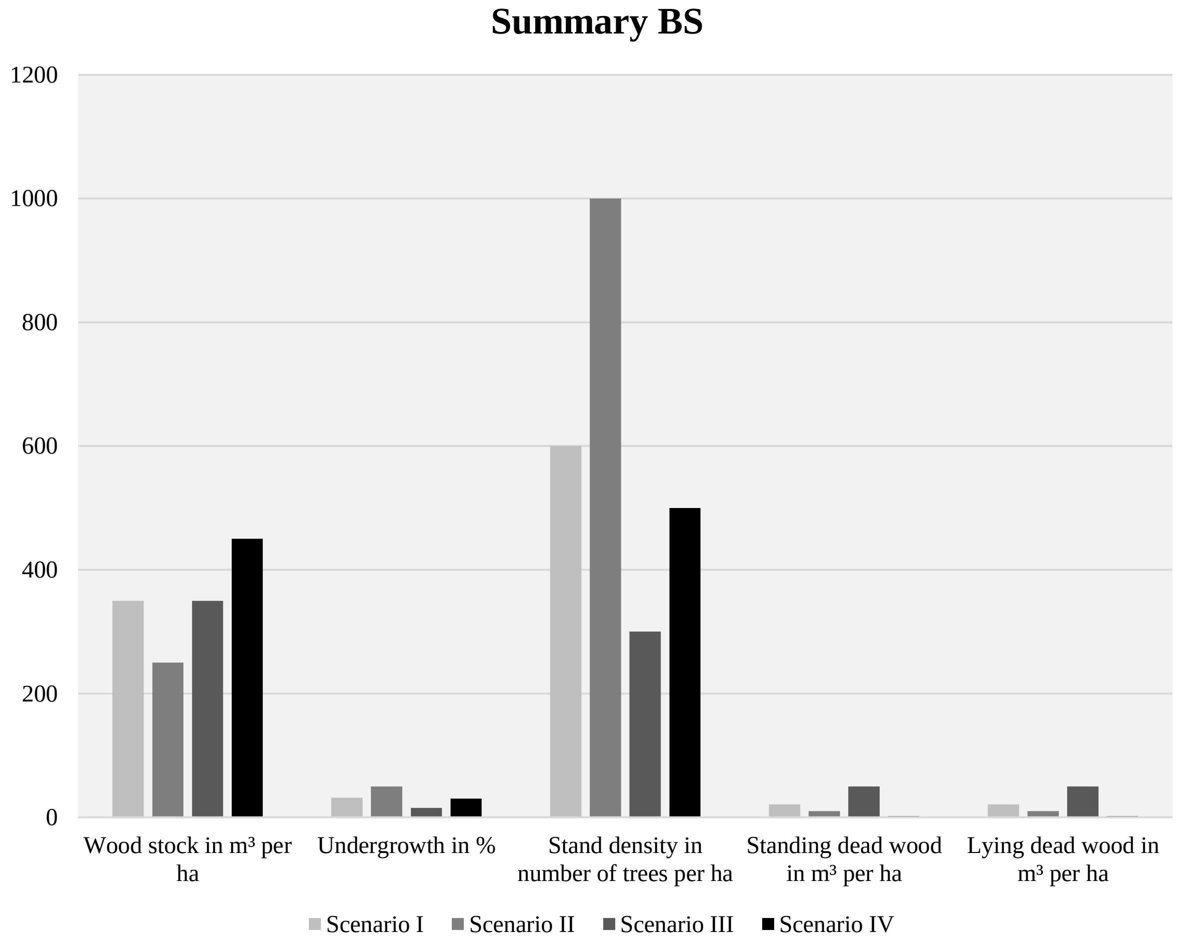


Figure 2. The values for the factors determining the fire susceptibility of a forest of all climate-smart forests resulting from the brainstorming session.

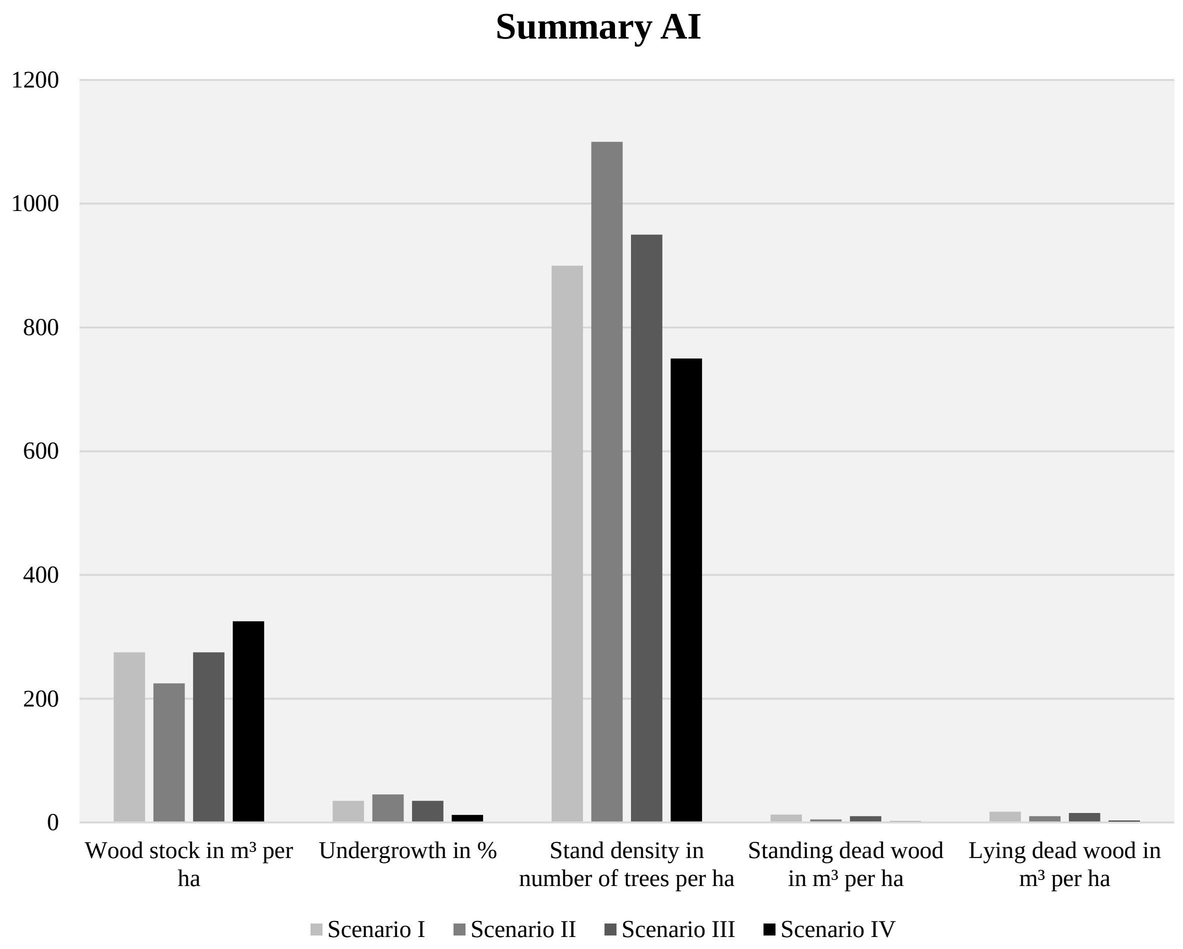


Figure 3. The values for the factors determining the fire susceptibility of a forest of all climate-smart forests resulting from AI.

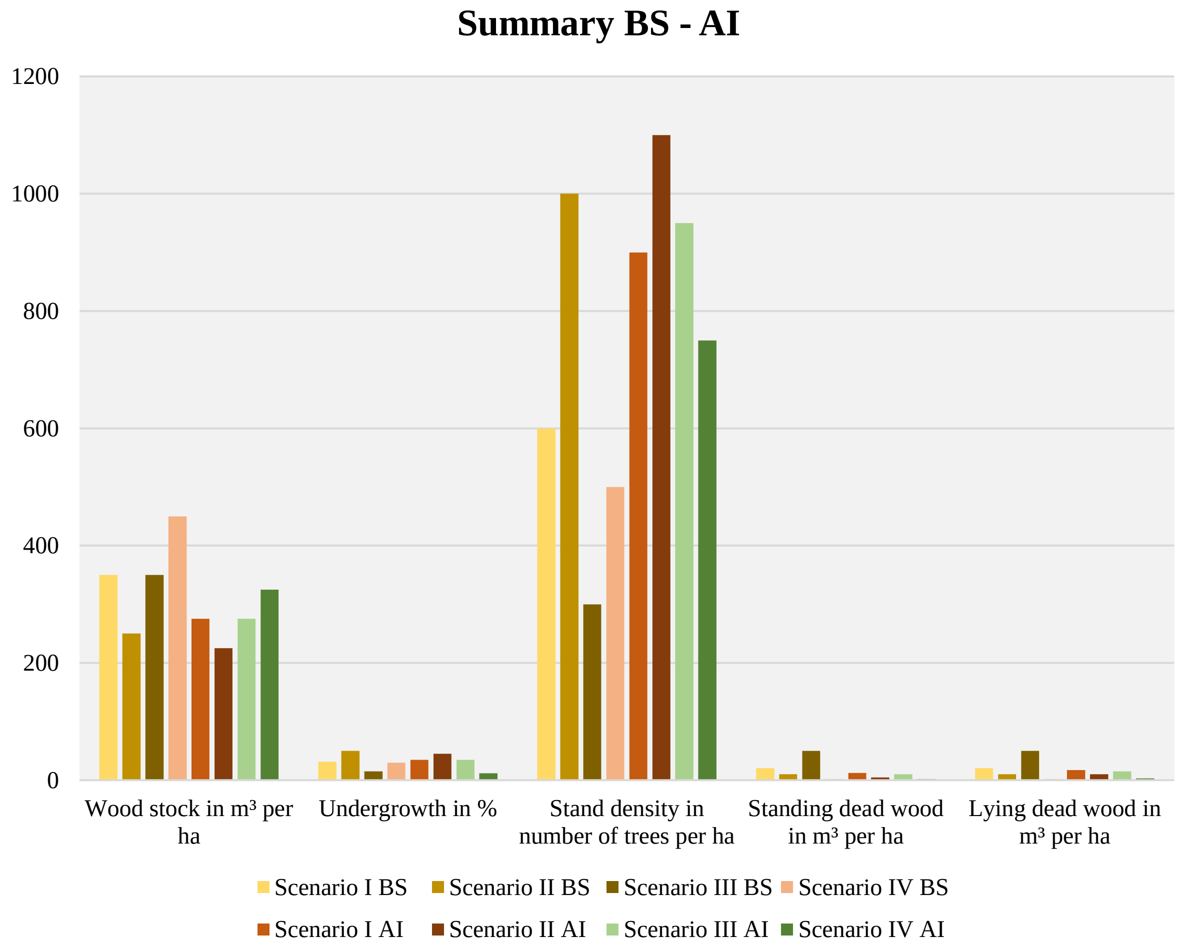


Figure 4. The values for the factors determining the fire susceptibility of a forest of all climate-smart forests.

3.4 Difference in fire susceptibility

This paragraph deliberates the fourth sub-question and discusses the difference in fire susceptibility between the eight conceived future climate-smart forests and the average Dutch forest. First, a brief explanation is given necessary for understanding the multi-criteria analyses in the tables. Second, two tables are presented containing the multi-criteria analyses for determining the fire sensitivity scores of the tree species and the average fire sensitivity scores of the tree species compositions of the future climate-smart forests. Third, another table is presented showing the final fire sensitivity scores of the climate-smart forests. Fourth, a description of the average Dutch forest is given. Fifth, the three fire sensitivity scores for the average Dutch forest are calculated to allow comparison with the climate-smart forests. The paragraph ends with a bar chart illustrating the percentage increase or decrease in the final fire sensitivity scores of the climate-smart forests relative to the average Dutch forest.

Table 2 shows the multi-criteria analyses for determining the fire sensitivity scores of the tree species and the average fire sensitivity scores of the tree species compositions of the future climate-smart forests resulting from the brainstorming session. The scores are also given in table 3 but these refer to the climate-smart forests coined by AI. The multi-criteria analyses for determining the final fire sensitivity scores of all eight prospective climate-smart forests are reported in table 4. The sources of tables 2 and 3 are referenced only below table 2 with footnotes to ensure clarity and readability. The explanations and formulae for calculating the three different fire sensitivity scores are given in paragraph 2.2.

Multi-criteria analyses

Table 2. The multi-criteria analyses for determining the fire sensitivity scores of the tree species and the average fire sensitivity scores of the tree species compositions of the climate-smart forests derived from the brainstorming session.

Climate-smart forests | brainstorming session							
Characteristics / **Tree species incl. %**		Maximum bark thickness[I] in cm	Density of air-dried wood[II] in kg/m^3 (moisture content: 12%)	Average moisture content of the green wood[III] in %	Contains resin? Yes = 2 No = 1	Fire sensitivity score of the tree species	**Average fire sensitivity score of the tree species composition of the forest**
Scenario I *Equal weights*							
Acer pseudoplatanus	11.1%	3	652	57	1	9.95587E-05	1.2776E-04
Alnus incana	11.1%	6	553	99	1	3.37918E-05	
Cedrus atlantica	11.1%	5	530	35	2	2.39353E-04	
Cedrus libani	11.1%	5	530	35	2	2.39353E-04	
Fagus sylvatica	11.1%	2	717	54	1	1.43344E-04	
Populus tremula	11.1%	5	450	56	1	8.80952E-05	
Pseudotsuga menziesii	11.1%	5	542	35	2	2.34054E-04	
Quercus robur	11.1%	8	722	58	1	3.31335E-05	
Tilia cordata	11.1%	5	540	105	1	3.91534E-05	
Scenario II *Avoid risks*							
Carpinus betulus	12.5%	3	717	46	1	1.26332E-04	1.4675E-04
Cedrus atlantica	12.5%	5	530	35	2	2.69542E-04	
Cedrus libani	12.5%	5	530	35	2	2.69542E-04	
Corylus colurna	12.5%	3	544	66	1	1.1605E-04	
Pseudotsuga menziesii	12.5%	5	542	35	2	2.63574E-04	
Quercus cerris	12.5%	7	722	58	1	4.26429E-05	
Quercus ilex	12.5%	5	800	74	1	4.22297E-05	
Tilia cordata	12.5%	5	540	105	1	4.40917E-05	
Scenario III *Strengthen ecosystem services*							
Abies alba	10%	4	450	70	2	1.5873E-04	9.17408E-05
Acer pseudoplatanus	12.9%	3	652	57	1	1.15703E-04	
Alnus incana	12.9%	6	553	99	1	3.92716E-05	
Betula pendula	12.9%	4	657	73	1	6.72421E-05	
Fagus sylvatica	12.9%	2	717	54	1	1.66589E-04	
Populus tremula	12.9%	5	450	56	1	1.02381E-04	
Quercus robur	12.9%	8	722	58	1	3.85065E-05	
Tilia cordata	12.9%	5	540	105	1	4.55026E-05	
Scenario IV *Generate high yields*							
Acer pseudoplatanus	3.3%	3	652	57	1	2.95985E-05	1.32136E-04
Alnus incana	11.4%	6	553	99	1	3.47051E-05	
Cedrus atlantica	11.4%	5	530	35	2	2.45822E-04	
Cedrus libani	11.4%	5	530	35	2	2.45822E-04	
Fagus sylvatica	3.3%	2	717	54	1	4.26158E-05	
Larix decidua	3.3%	6	604	54	2	3.37258E-05	
Pinus radiata	11.4%	4	453	100	2	1.25828E-04	
Populus tremula	3.3%	5	450	56	1	2.61905E-05	
Pseudotsuga menziesii	11.4%	5	542	35	2	2.4038E-04	
Quercus robur	3.3%	8	722	58	1	9.85051E-06	
Sequoia sempervirens	11.4%	35	390	123	2	1.35799E-05	
Thuja occidentalis	11.4%	1	350	99	2	6.58009E-04	
Tilia cordata	3.3%	5	540	105	1	1.16402E-05	

[I] Earle (2023a); Earle (2023b); Forstbetriebsgemeinschaft Oberallgäu e.V. (2018); Forstbetriebsgemeinschaft Südhannover w.V. (2016); Şen et al. (2011, p. 47); Wald Schweiz (n.d.)

[II] Houtinfo (2019); Johansson (2011, p. 15); Meier (n.d.-a); Meier (n.d.-b); Meier (n.d.-c); Richter and Dallwitz (2019); Sorbus Aucuparia (2003); Zeidler (2012, p. 147)

[III] Miles and Smith (2009, pp. 8–12)

Table 3. The multi-criteria analyses for determining the fire sensitivity scores of the tree species and the average fire sensitivity scores of the tree species compositions of the climate-smart forests generated by AI.

Climate-smart forests | artificial intelligence							
Characteristics **Tree species incl. %**		Maximum bark thickness in cm	Density of air-dried wood in kg/m^3 (moisture content: 12%)	Average moisture content of the green wood in %	Contains resin? Yes = 2 No = 1	Fire sensitivity score of the tree species	**Average fire sensitivity score of the tree species composition of the forest**
Scenario I *Equal weights*							
Alnus glutinosa	5%	6	553	99	1	1.52215E-05	9.58928E-05
Betula pendula	10%	4	657	73	1	5.21257E-05	
Corylus avellana	5%	1	580	66	1	1.30617E-04	
Fagus sylvatica	10%	2	717	54	1	1.29139E-04	
Fraxinus excelsior	5%	4	694	46	1	3.91555E-05	
Larix decidua	5%	6	604	54	2	5.10997E-05	
Picea abies	10%	3	450	48	2	3.08642E-04	
Pinus sylvestris	10%	4	536	100	2	9.32836E-05	
Prunus avium	5%	2	657	53	1	7.17958E-05	
Pseudotsuga menziesii	10%	5	542	35	2	2.10859E-04	
Quercus robur	15%	8	722	58	1	4.47751E-05	
Salix caprea	5%	2	473	127	1	4.16174E-05	
Sorbus aucuparia	5%	2	650	66	1	5.82751E-05	
Scenario II *Avoid risks*							
Acer campestre	10%	3	690	57	1	8.47529E-05	8.86484E-05
Alnus glutinosa	10%	6	553	99	1	3.04431E-05	
Alnus incana	5%	6	553	99	1	1.52215E-05	
Carpinus betulus	10%	3	717	46	1	1.01065E-04	
Fagus sylvatica	20%	2	717	54	1	2.58278E-04	
Pinus sylvestris	5%	4	536	100	2	4.66418E-05	
Quercus robur	30%	8	722	58	1	8.95501E-05	
Salix caprea	10%	2	473	127	1	8.32348E-05	
Scenario III *Strengthen ecosystem services*							
Betula pendula	15%	4	657	73	1	7.81885E-05	1.33797E-04
Corylus avellana	5%	1	580	66	1	1.30617E-04	
Fagus sylvatica	20%	2	717	54	1	2.58278E-04	
Picea abies	10%	3	450	48	2	3.08642E-04	
Pinus sylvestris	10%	4	536	100	2	9.32836E-05	
Prunus avium	10%	2	657	53	1	1.43592E-04	
Quercus robur	15%	8	722	58	1	4.47751E-05	
Sorbus aucuparia	10%	2	650	66	1	1.1655E-04	
Ulmus glabra	5%	6	656	42	1	3.02458E-05	
Scenario IV *Generate high yields*							
Castanea sativa	3%	3	577	120	1	1.44425E-05	1.52113E-04
Fagus sylvatica	18%	2	717	54	1	2.3245E-04	
Fraxinus excelsior	5%	4	694	46	1	3.91555E-05	
Larix decidua	5%	6	604	54	2	5.10997E-05	
Populus nigra	3%	5	450	56	1	2.38095E-05	
Pseudotsuga menziesii	28%	5	542	35	2	5.90406E-04	
Quercus robur	38%	8	722	58	1	1.1343E-04	

Table 4. The multi-criteria analyses for determining the final fire sensitivity scores of all eight future climate-smart forests.

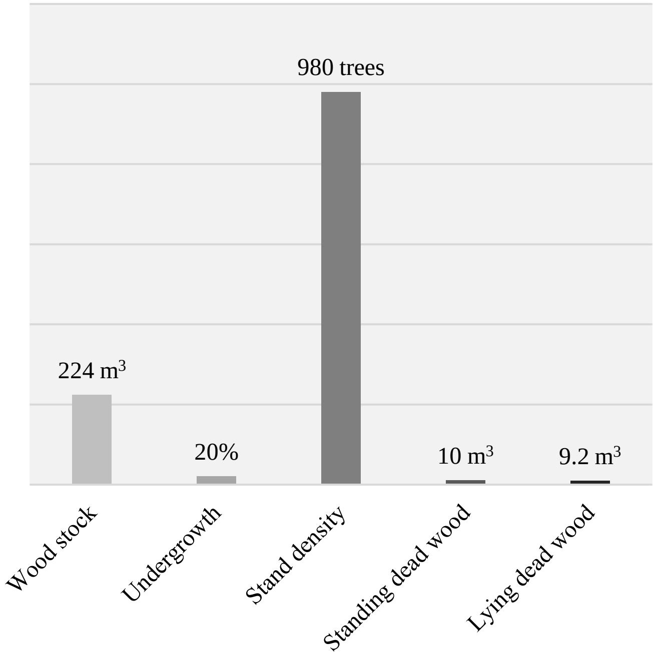
Climate-smart forest by scenario / **Factors incl. average score from the survey**		**Scenario I** *Equal weights* BS	**Scenario II** *Avoid risks* BS	**Scenario III** *Strengthen ecosystem services* BS	**Scenario IV** *Generate high yields* BS	**Scenario I** *Equal weights* AI	**Scenario II** *Avoid risks* AI	**Scenario III** *Strengthen ecosystem services* AI	**Scenario IV** *Generate high yields* AI
Wood stock in m^3 per ha	5.00	350	250	350	450	275	225	275	325
Undergrowth in %	6.67	31.7	50	15	30	35	45	35	12
Stand density in number of trees per ha	4.17	600	1000	300	500	900	1100	950	750
Standing dead wood in m^3 per ha	4.50	20.7	10	50	2	12.5	5	10	2
Lying dead wood in m^3 per ha	4.83	20.7	10	50	2	17.5	10	15	3
Average fire sensitivity score from the multi-criteria analyses of tables 2-3		1.2776E-04	1.4675E-04	9.17408E-05	1.32136E-04	9.58928E-05	8.86484E-05	1.33797E-04	1.52113E-04
Final fire sensitivity score		11,015,507.52	5,544,738.044	10,918,795.02	107,839.0619	5,492,482.308	1,492,176.608	5,546,931.006	80,693.009

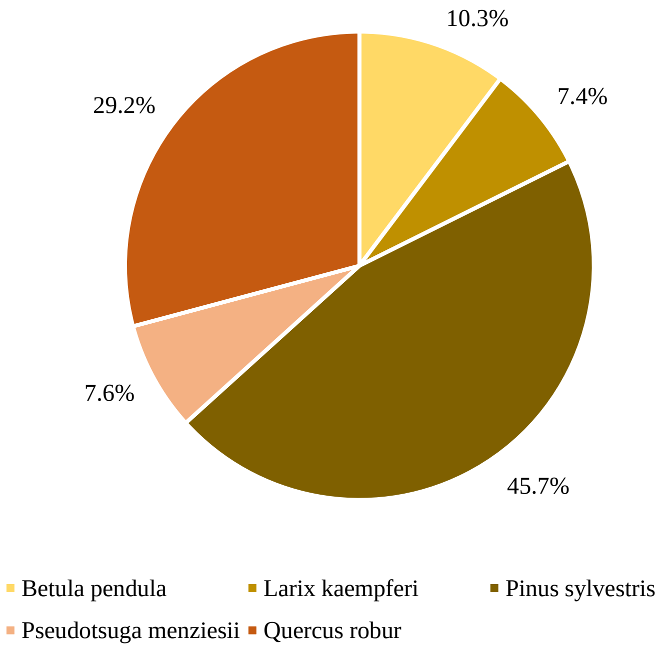
The following page describes the average Dutch forest. The pie chart depicts the five most prevalent tree species in the Dutch forest, with the percentage indicating the proportion of each tree species in the entire forest. The factors that determine the fire susceptibility of a forest from paragraph 3.2 are included in a bar chart. The values shown in the bar chart are expressed per hectare, except for the percentage of undergrowth pertaining to the whole forest. The image in the description was created by AI.

Table 5 provides the multi-criteria analysis for determining the fire sensitivity scores of the tree species and the average fire sensitivity score of the tree species composition of the average Dutch forest. The multi-criteria analysis for determining the final fire sensitivity score of the average Dutch forest is shown in table 6. The sources mentioned under table 2 were also accessed for the multi-criteria analysis in table 5. The other sources of tables 5 and 6 are referenced with footnotes to maintain a clear and readable table. The explanations and formulae for calculating the three different fire sensitivity scores are given in paragraph 2.2.

Average Dutch forest

Originally, the Netherlands comprised a vast land marked by water and its many heathlands. Sheep and cows grazed these heathlands, providing manure for the fields. With the advent of artificial fertilisers in the late 19th century, the moors were no longer needed as pasture for cattle. Instead, they were converted into farmland or forest. The tree species mainly planted was *Pinus sylvestris* for shoring up the galleries in mines in the south of Limburg. Species like *Pseudotsuga menziesii* and *Larix kaempferi* were also introduced during this period to produce timber.





Multi-criteria analyses

Table 5. The multi-criteria analysis for determining the fire sensitivity scores of the tree species and the average fire sensitivity score of the tree species composition of the average Dutch forest.

Average Dutch forest							
Characteristics **Tree species[IV] incl. %**		Maximum bark thickness in cm	Density of air-dried wood in kg/m^3 (moisture content: 12%)	Average moisture content of the green wood in %	Contains resin? Yes = 2 No = 1	Fire sensitivity score of the tree species	**Average fire sensitivity score of the tree species composition of the forest**
Betula pendula	10.3%	4	657	73	1	5.36895E-05	1.89996E-04
Larix kaempferi	7.4%	6	604	54	2	7.56275E-05	
Pinus sylvestris	45.7%	4	536	72	2	5.92092E-04	
Pseudotsuga menziesii	7.6%	5	542	35	2	1.60253E-04	
Quercus robur	29.2%	8	722	74	1	6.83162E-05	

Table 6. The multi-criteria analysis for determining the final fire sensitivity score of the average Dutch forest.

Factors incl. average score from the survey		**Average Dutch forest**
Wood stock[V] in m^3 per ha	5.00	224
Undergrowth[VI] in %	6.67	20
Stand density[VII] in number of trees per ha	4.17	980
Standing dead wood[V] in m^3 per ha	4.50	10
Lying dead wood[V] in m^3 per ha	4.83	9.2
Average fire sensitivity score from the multi-criteria analysis of table 5		1.89996E-04
Final fire sensitivity score		2,319,673.878

[IV] Schelhaas et al. (2022, p. 48)

[V] Schelhaas et al. (2022, p. 75)

[VI] Schelhaas et al. (2022, p. 65)

[VII] Daamen et al. (2007, p. 20)

The bar chart in figure 5 compares the final fire sensitivity scores of the prospective climate-smart forests with that of the average Dutch forest. Differences are expressed as a percentage increase or decrease from the zero point. The zero point represents the final fire sensitivity score of the average Dutch forest. The percentage increases and decreases range from -97% to +375%. In five of the eight future climate-smart forests, fire susceptibility increases. Fire susceptibility decreases for the remaining three climate-smart forests. The forests with an increase in fire susceptibility are coloured orange and those with a decrease are coloured green. The average percentage of all climate-smart forests relative to the average Dutch forest is an increase of 117%.

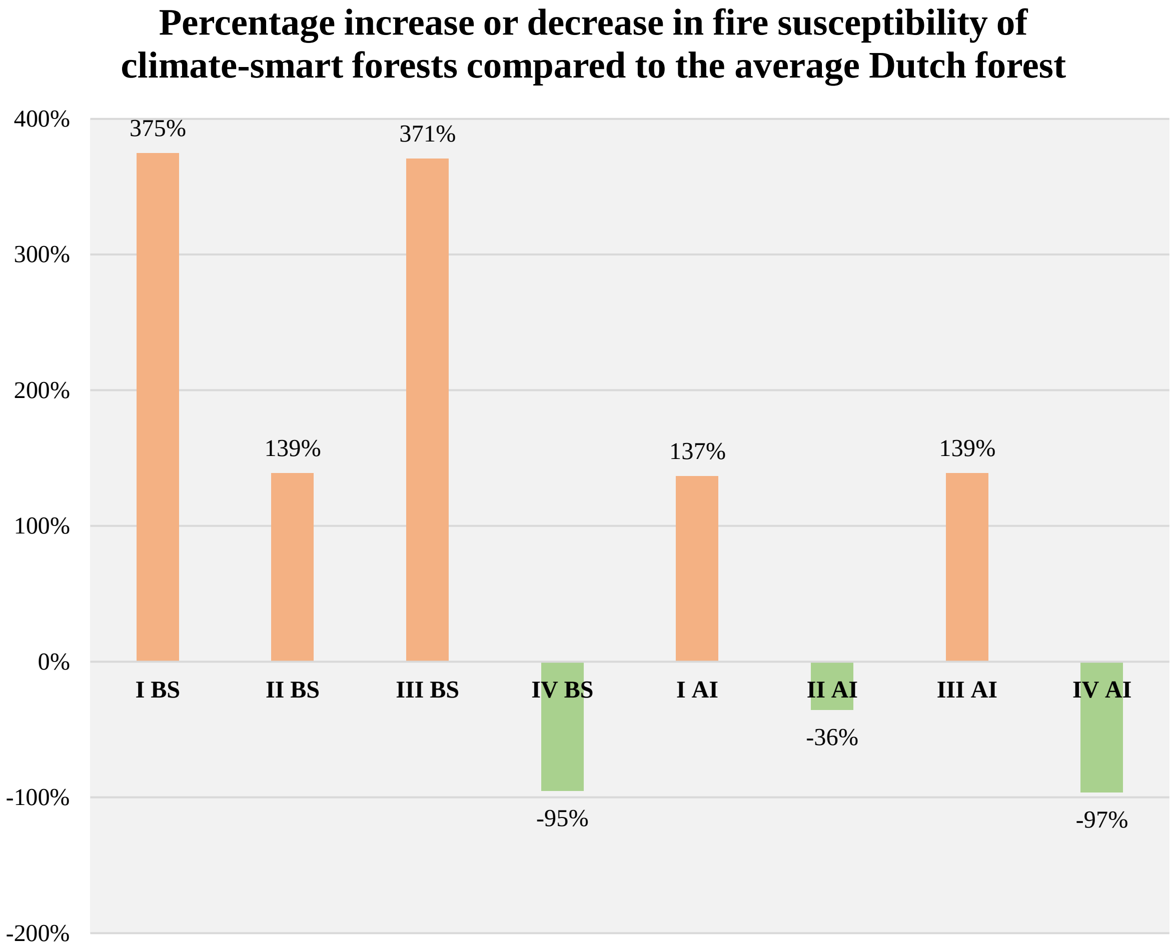


Figure 5. The percentage increase or decrease in fire susceptibility of the eight conceived climate-smart forests in the Netherlands in the year 2100 compared to the average Dutch forest in 2023.

Chapter IV

Discussion

4 Discussion

This chapter deals with the discussion, interpreting the results and addressing the constraints of the study.

The final fire sensitivity scores of the eight conceived climate-smart forests in the Netherlands in the year 2100 are, respectively: I BS = 11.02m, II BS = 5.54m, III BS = 10.92m, IV BS = 0.11m, I AI = 5.49m, II AI = 1.49m, III AI = 5.55m and IV AI = 0.08m. The final fire sensitivity score of the average Dutch forest is 2.32m. The percentage increases and decreases of the climate-smart forests compared to the average Dutch forest are, respectively: I BS = +375%, II BS = +139%, III BS = +371%, IV BS = -95%, I AI = +137%, II AI = -36%, III AI = +139% and IV AI = -97%. The fire susceptibility of a climate-smart forest increases on average by 117% compared to the average Dutch forest. Considering that nearly all tree species listed in the climate-smart forests are already present in the Dutch forest, the likelihood of increasing fire susceptibility is significant. According to research by Khabarov et al. (2014, p. 21), the potential increase in forest fires in Europe without any forest modification is about 200% by 2090 relative to 2000-2008. In addition, research by Dupuy et al. (2020) found that the probability of forest fires occurring in Europe will increase by 2-4% per decade. Assuming the maximum increase, this results in a rate of 30.8% in 2100. Thus, the results of this study broadly coincide with the findings of other scientific studies.

Contrary to initial assumptions, all but one of the perceived results were unforeseen. It was expected that the fire susceptibility of the four climate-smart forests of scenarios I and III would decrease because, in general, a climate-smart forest is more resistant to the effects of climate change than a monoculture such as the Dutch forest. The percentage increase in fire susceptibility of the climate-smart forest for scenario II from the brainstorming session is also unexpectedly high. This scenario represents risk avoidance as the consequences of climate change. It was reasonable to presume that this forest would decrease in fire susceptibility. This was true for the climate-smart forest of the same scenario only conceived by AI. Additionally, fire susceptibility decreases significantly for both forests of scenario IV. Scenario IV stands for generating the highest possible yield and forests that generally fit this are production forests marked by a few species like *Larix kaempferi*, *Picea abies* and *Pseudotsuga menziesii*. These forests are not known for their resistance to bark beetles, drought or other effects of climate change and were therefore estimated to be more susceptible to fire. A possible explanation could be the low number of standing and lying dead wood, as the other values are fairly similar to the other climate-smart forests. The average increase in fire susceptibility of all climate-smart forests is also at odds with expectations. A plausible statement for this could be that there are hardly any climate-smart tree species mentioned in the conceived climate-smart forests. In other words, according to the brainstorming session participants and by AI, there will hardly be any modification in species. One may be cautious about introducing non-native climate-smart tree species because of virus susceptibility or invasiveness.

A number of issues may have affected the results and hence the validity of the study. It was intended that during the brainstorming session, each group would be represented by two individuals. Unfortunately, one student and one forest manager did not appear during the brainstorming session. Nevertheless, the turnout was sufficient for the brainstorming session to proceed, partly because the forest manager could be replaced by Juriaan Zandvliet. The student could not be substituted. There is a chance of bias as Juriaan knew about the subject of fire susceptibility at the time of the conversation. As noted, the other participants were not aware of the topic. Moreover, there was not enough time to organise another brainstorming session and a survey for the characteristics that determine the fire susceptibility of a tree. Other experts may have a different view on the tree species currently conceived. There were also no international participants present at the brainstorming session to add a different perspective. Furthermore, the standard deviation of the survey for lying dead wood and stand density is large. Therefore, it may not provide a representative picture of which factor is most important in determining the fire susceptibility of a forest. An explanation is the low number of respondents of six. Another point of discussion is that the amount of resin may vary by conifer species, this distinction was not made. This study excluded a number of factors that determine the fire susceptibility of a forest such as litter layer and roots. This may have affected the results. Finally, it is questionable whether the tree species of the conceived climate-smart forests can grow optimally in such a ratio and thereby also reach the average moisture content of the green wood and the maximum bark thickness in tables 2 and 3.

A study by Delforterie (2020, p. 6) indicates that planting new non-native climate-smart tree species should be regarded as an absolute emergency brake in the system. These species should be planted only when the current familiar tree species prove to succumb under the changing climate. It further describes that large-scale planting of these species is not obvious and that introduction should be done only after careful research on the species in question. The new species could potentially be invasive, displacing native species. Nonetheless, the results of this study and those of others emphasise the urgency of developing a deeper comprehension about these species and their interactions with existing tree species at the earliest convenience. The recommendation for follow-up research is to find a way how to apply these climate-smart tree species in the Netherlands and in other countries across Europe without compromising current forests. This potentially contributes to making forests more resilient to the impacts of climate change such as forest fires or droughts. In addition, it is advised to assess the susceptibility of climate-smart forests to other climate change impacts, such as drought or storms.

Chapter V

Conclusion

5 Conclusion

This chapter comprises the last part of the study and deals with the conclusion. The chapter answers the main question.

This study examined the susceptibility of a climate-smart forest in the Netherlands in the year 2100 to forest fires. Through a combination of literature, qualitative, and quantitative research, answers were sought to the research questions posed. The findings suggest significant changes compared to the average Dutch forest in 2023.

The results showed that maximum bark thickness in cm, density of air-dried wood in kg/m^3 (moisture content: 12%), average moisture content of green wood in per cent and whether the tree species contains resin are characteristics that determine the fire susceptibility of a tree. Standing wood stock in m^3/ha, percentage undergrowth of the entire forest, stand density in number of trees per hectare, and standing and lying dead wood in m^3/ha are factors that determine the fire susceptibility of a forest. A total of eight climate-smart forests for the Netherlands in the year 2100 were conceived, four of which were created during the brainstorming session and the other four through AI. For the eight climate-smart forests, tree species including percentage were conceived and values were assigned for the factors that determine the fire susceptibility of a forest. Using this information and the retrieved data on tree species characteristics, the final fire sensitivity scores were calculated. The final fire sensitivity scores are, respectively: I BS = 11.02m, II BS = 5.54m, III BS = 10.92m, IV BS = 0.11m, I AI = 5.49m, II AI = 1.49m, III AI = 5.55m and IV AI = 0.08m. The final fire sensitivity score of the average Dutch forest is 2.32m. The final fire sensitivity score of the average Dutch forest was taken as a baseline to calculate the percentage increases or decreases of the climate-smart forests. The percentage increases and decreases are, respectively: I BS = +375%, II BS = +139%, III BS = +371%, IV BS = -95%, I AI = +137%, II AI = -36%, III AI = +139% and IV AI = -97%.

This research has revealed that the fire susceptibility of a climate-smart forest in the Netherlands in 2100 increases on average by 117% compared to the average Dutch forest in 2023. Based on this conclusion, it can be inferred that it is desirable to transform the current Dutch forest into climate-smart forests IV BS, II AI and/or IV AI, with the aim of reducing susceptibility to forest fires. Stewards and ecologists from Eelerwoude and forest managers from other organisations can adopt this recommendation in their reports.

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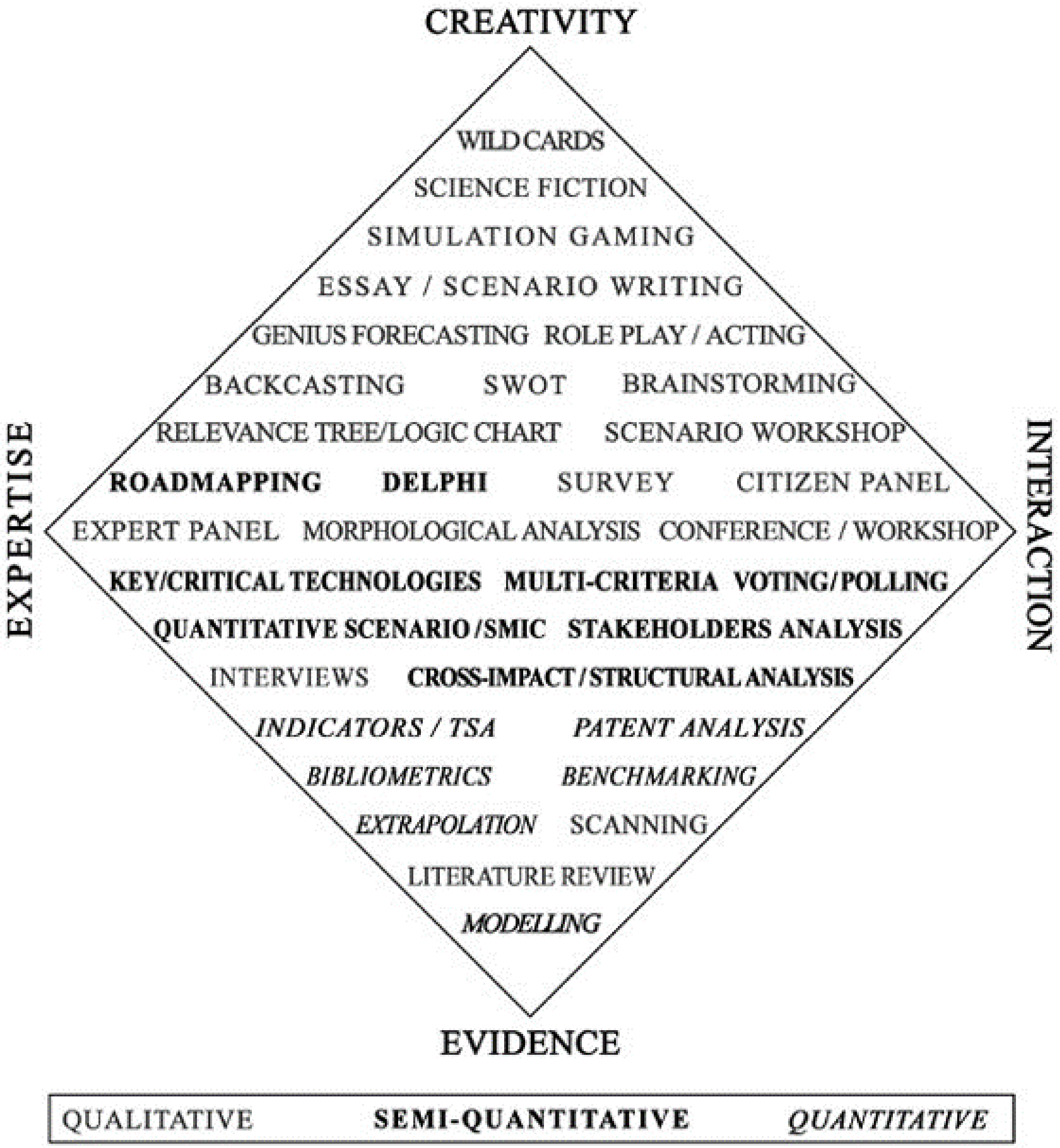
Appendices

Appendix I	The foresight diamond
Appendix II	Flowchart brainstorming session
Appendix III	Prompts used in ChatGPT 4.0 (AI)
Appendix IV	Survey Nature Fire Symposium 2023

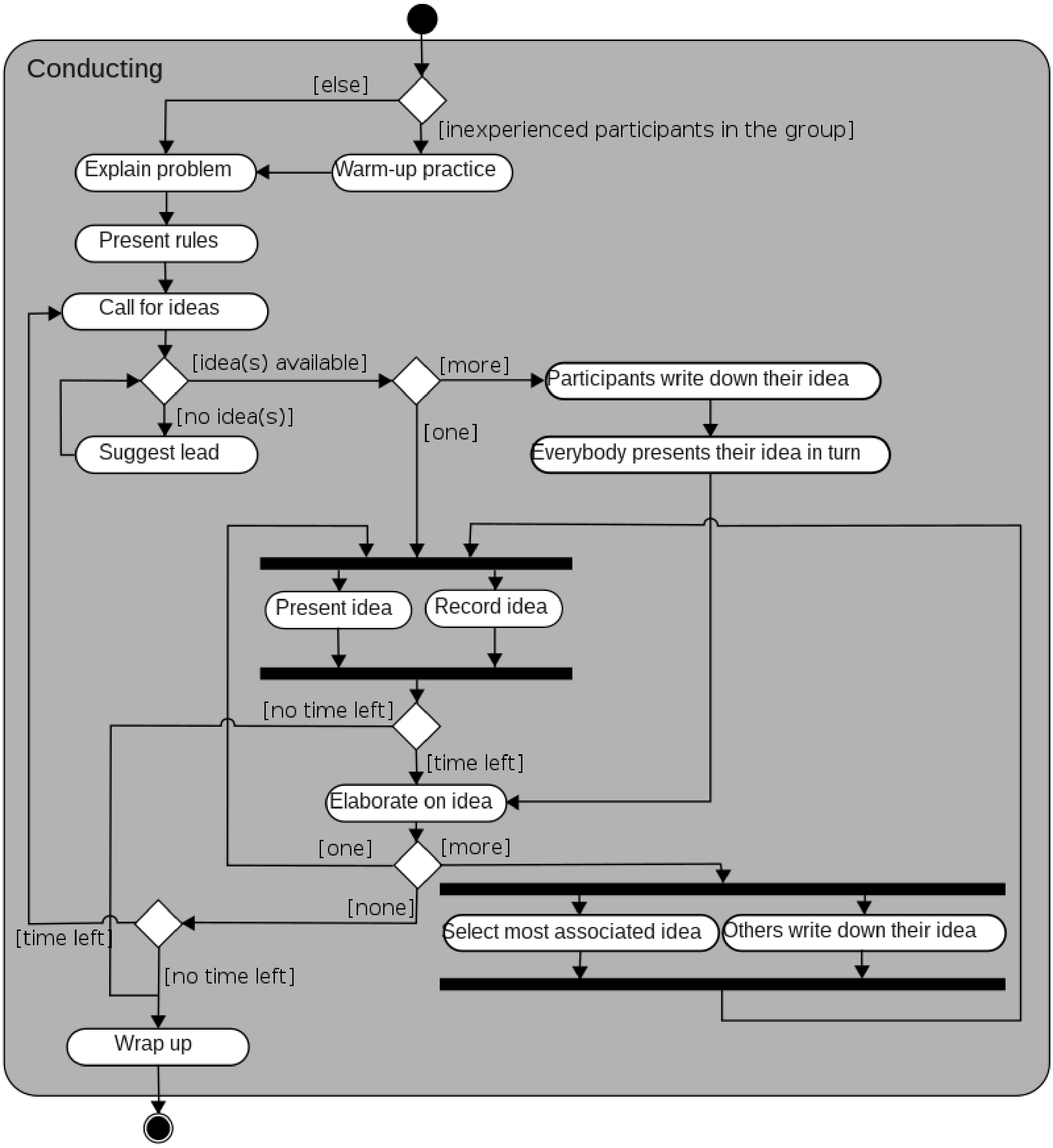
Appendix I The foresight diamond

The foresight diamond is a framework that positions methods based on their main type of knowledge source (creativity, expertise, interaction or evidence). Brainstorming positioned between creativity and interaction corresponds to a brainstorming session.



Appendix II Flowchart brainstorming session

The flowchart below was used during the brainstorming session on Wednesday 8 November 2023 (*Brainstorming*, 2011).



Appendix III Prompts used in ChatGPT 4.0 (AI)

The prompts below were used to generate the climate-smart forests through ChatGPT 4.0 (AI).

1. I would like to conduct a foresight exercise for Dutch forests in the year 2100, considering the impact of climate change and other environmental factors.
2. Please create detailed scenarios for the future state of these forests under different objectives.
3. Specifically, I would like to explore the following scenarios:
   - 3.1 Quality Timber Production: Focus on producing high-quality timber.
   - 3.2 Ecosystem Services Enhancement: Aim at increasing the biodiversity and ecosystem services of the forest.
   - 3.3 Risk Reduction: Develop a scenario aiming to minimize risks like disease, pests, and the impact of climate change.
   - 3.4 Unified: A combination of the above objectives into a balanced approach.
4. Please include details on tree species composition, forest stock, the amount of standing and lying dead wood, and understory percentage.
5. Detail the tree species composition, forest stock, the amount of dead wood, and understory percentage.
6. Provide specifics on tree species composition, forest stock, the amount of dead wood, and understory percentage.
7. Describe how this scenario would integrate aspects of timber production, ecosystem services, and risk reduction, detailing tree species composition, forest stock, dead wood, and understory percentage.
8. For each scenario, please specify the exact species (spp.) and their precise percentages in the forest composition.

Appendix IV Survey Nature Fire Symposium 2023

Enquête over de brandgevoeligheid van klimaatslimme bossen

Beste meneer/mevrouw,

Ik ben Rowan Karssen, een 24-jarige bos- en natuurbeheer student aan de Hogeschool Van Hall Larenstein. Voor mijn afstudeerscriptie onderzoek ik de brandgevoeligheid van klimaatslimme bossen. Dit onderzoek is gericht op het begrijpen van verschillende factoren die de brandgevoeligheid van een bos beïnvloeden. Uw expertise en inzichten zijn van onschatbare waarde voor dit onderzoek.

Het invullen van deze enquête zal ongeveer 1 minuut in beslag nemen. Uw antwoorden zullen vertrouwelijk worden behandeld en alleen worden gebruikt voor academische doeleinden. De resultaten van dit onderzoek zullen beschikbaar worden gesteld aan de respondenten mits gewenst. Indien u belangstelling heeft om dit rapport te ontvangen, verzoek ik u vriendelijk om uw e-mailadres te verstrekken.

Hartelijk dank voor uw deelname.

Persoonlijke informatie (optioneel):

Naam:

Functie:

E-mailadres:

Vragenlijst:

De volgende factoren zijn van belang bij het bepalen van de brandgevoeligheid van een bos?

	Helemaal mee oneens	Sterk mee oneens	Oneens	Neutraal	Eens	Sterk mee eens	Helemaal mee eens
Houtvoorraad	O	O	O	O	O	O	O
Ondergroei	O	O	O	O	O	O	O
Stamtal	O	O	O	O	O	O	O
Staand dood hout	O	O	O	O	O	O	O
Liggend dood hout	O	O	O	O	O	O	O

Hartelijk dank voor het invullen van deze enquête. Uw bijdrage is essentieel voor het succes van dit onderzoek.