BIODIVERSITY IMPACTS OF GROUND-BASED INDUSTRIAL SCALE SOLAR POWER PLANTS IN FINLAND

Lappeenranta–Lahti University of Technology LUT

Master's thesis in Circular Economy

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ABSTRACT

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Biodiversity impacts of ground-based industrial-scale solar power plants in Finland

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108 pages, 25 figures, and 31 tables

Examiners: Professor (tenured) Jouni Havukainen and MMM Esa Laine

Keywords: biodiversity, industrial-scale ground-based solar power, carbon footprint, habitat hectare.

This master's thesis examined the impacts of industrial-scale solar power projects on biodiversity using three real-life case studies. A carbon footprint was calculated for each project, covering all stages of the life cycle from construction to demolition and recycling. In addition, carbon sink losses due to tree felling were calculated for the projects. Finally, the ecological status of the areas was assessed using the habitat hectare method. The aim of the work was to identify the most significant environmental impacts of the life cycle of solar power plants.

Based on the results, most of the carbon dioxide emissions are generated in the manufacture of solar power plant components. Habitat type studies showed that locating solar power plants in areas that have already been modified by humans, such as former landfills, can significantly reduce biodiversity losses. It was also found that the biodiversity of areas can be improved, for example, by planting sun-lit habitats species in the vicinity of the power plants.

The use of the habitat hectare value proved to be a useful tool in assessing the ecological status of areas. In addition, the method could be further refined so that it could be used to assess the need for compensation and compare biodiversity impacts between different projects. The work provides a methodological basis for a comprehensive assessment of the environmental impacts of solar power projects and for promoting sustainable investment.

TIIVISTELMÄ

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Teollisen kokoluokan maa-asenteisten aurinkovoimaloiden biodiversiteettivaikutukset Suomessa

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Tässä diplomityössä tarkasteltiin teollisen kokoluokan aurinkovoimalahankkeiden vaikutuksia biodiversiteettiin kolmen todellisen tapausesimerkin avulla. Kullekin kohteelle laskettiin hiilijalanjälki, joka sisälsi kaikki elinkaaren vaiheet rakentamisesta purkuvaiheeseen ja kierrätykseen asti. Lisäksi puustonhakkuista aiheutuvat hiilinielujen menetykset laskettiin hankkeille. Lopuksi arvioitiin alueiden ekologinen tila habitaattihehtaari-menetelmällä. Työn tavoitteena oli tunnistaa aurinkovoimaloiden elinkaaren merkittävimmät ympäristövaikutusten aiheuttajat.

Tulosten perusteella suurin osa hiilidioksidipäästöistä syntyy aurinkovoimaloiden komponenttien valmistuksessa. Luontotyyppiselvitykset osoittivat, että aurinkovoimaloiden sijoittaminen jo ennestään ihmisen muokkaamille alueille, esimerkiksi entisille kaatopaikoille, voi merkittävästi vähentää biodiversiteettihaittoja. Lisäksi havaittiin, että alueiden monimuotoisuutta voidaan parantaa esimerkiksi istuttamalla paahdelajeille soveltuvaa kasvillisuutta voimaloiden yhteyteen.

Habitaattihehtaari-arvon käyttö osoittautui hyödylliseksi työkaluksi alueiden ekologisen tilan arvioinnissa. Lisäksi menetelmää voisi jatkojalostaa, jolloin sitä voisi hyödyntää kompensaation tarpeen arvioinnissa ja biodiversiteettivaikutusten vertailemisessa eri hankkeiden välillä. Työ tarjoaa menetelmällisen pohjan aurinkovoimahankkeiden ympäristövaikutusten kokonaisvaltaiselle arvioinnille ja kestävän sijoittamisen edistämiselle.

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Lappeenranta, 21.11.2025

Nellinoora Paananen

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DECLARATIONS

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The author, Nellinoora Paananen, takes full responsibility for the content of this thesis and has reviewed and edited the content generated by the possible use of AI tools.

1 Introduction

Mitigating climate change and transitioning to fossil-free energy production are widely recognized goals and achieving it needs a rapid increase in renewable energy production among other actions. In Finland, this development is particularly visible in the strong growth of wind and solar power. As for now, Finland is undergoing a major energy transition as the country moves from imported fossil energy towards domestic clean energy. Finland needs solar power beside wind power as these emission-free forms of energy productions complement each other; solar power is most efficient during summer and during the day, while the windiest weather is on average in the winter. (Renewables Finland, 2025, a) This hybrid solutions balance Finland's electricity system. Solar panels are already a familiar sight in Finland, as panels can be seen on the roofs of houses and summer cabins, and workplaces as well as big solar power plants for example on fields. As technology develops, industrial-scale solar power production is also becoming more common in Finland, and solar power is currently one of the fastest developing forms of energy production in the world. (Renewables Finland, 2025.b.)

Although renewable energy is needed to replace fossil energy production, they require a lot of space, which directly affects to the habitat where the plants are built on. While green transition is necessary in curbing climate change, and avoiding other disasters, Finland among other countries is struggling with the loss of biodiversity due to several reasons. Wind and solar power construction in Finland is predicted to increase more than tenfold over the next few decades, and concern about the impacts of new energy infrastructure on Finnish nature is justified. (Jalkanen, J. et. al. 2025, page 2.) Industrial scale (>1 MW) ground-based solar power plants require large areas, and in many unfortunate cases, for example forests or other natural areas are cleared to make way for power plants. This has a major impact on biodiversity and the inhabitants of the area. On the other hand, solar power plants can also offer new opportunities for species conservation, for example by transforming previously intensively exploited areas into less burdensome environments. (Renewables Finland, 2025. c.) For example, so called brownfields, are an example of human altered areas which could be transformed into energy production area instead of clearing managed forests for this purpose. Brownfield is a property or an area, of which expansion, redevelopment, or reuse of may be complicated by the presence of a hazardous substance, pollutant, or a contaminant (e.g. a former old municipal waste landfill area). (EPA, n.d.) These human-altered areas already have lower natural values, which is why their utilization as energy production areas reduces the burden on biodiversity-rich areas.

This thesis focuses on ground-based industrial sized solar power plants and their impact on biodiversity. The ground based solar panels are more suitable for industrial-scale production as they can be spread over larger areas. The panel's angles can be optimized to get most of the radiation of the sun whereas panels that are attached to a building are not as flexible in that sense, also the space is limited to the size of the surface (Kaurala, M. 2023). As these characteristics are beneficial to the power plants, these can be also harmful for the biodiversity. Even though renewable energy forms are emission free production types when they are in the production phase, the space that they take might require logging of forests, removing inhabitants to another place, or complete clearing of the vegetation, which has a significant impact on the biodiversity. On the other hand, solar power production areas can offer a habitat for sun-lit species as they can tolerate heat and light, but do not grow tall.

The current research on the biodiversity impacts of solar power plants is fragmented, and most of the studies have been conducted in Central European and North American conditions, which differ significantly from the climate, soil and species composition of Finland. Therefore, it is important to study the biodiversity impacts of solar power plants in Finland. The Finnish Renewable Energy Association has started the work as they conducted a study in 2025 about environmental impact of wind and solar power. According to the study the overall environmental impacts of solar power in Finland are lower than many other energy production forms, but there are still factors to consider. The most significant local impacts arise from land use changes, such as the loss of forest habitats and the fencing of solar power areas, which can reduce the movement of animal species, and fragment habitats. Globally, the largest environmental impacts are related to the production of building materials for the power plants, which often takes place outside Finland. Although the construction of solar power causes local environmental impacts, its climate benefits and low pollution impacts make it more sustainable alternative for nature compared to fossil and bio-based fuels. All in all, the Renewables Finland suggest that in the future, it will be important to plan solar power projects carefully to preserve biodiversity and minimize harmful impact. (Jalkanen, J. et al. 2025.)

The Renewables Finland also conducted a road map in 2025, which is a strategic document that guides the development of wind and solar power projects in a way that supports biodiversity. The road map was prepared in collaboration with the environmental consultancy One Planet, and the main goal is to achieve nature-positive energy production by 2030. (Renewables Finland. 2025. c.). The previously mentioned study about environmental impact of wind and solar power worked as a base for this roadmap. The key objectives and measures from the roadmap focus on reaching nature positivity by the year 2030. The aim is to create as many new solar and wind power projects as possible that are net positive for nature, meaning that they improve biodiversity more than they will reduce it. This can be done by minimizing the environmental impact and promoting positive impacts by for example locating them away from the most valuable natural areas. In addition, proactive measures are implemented- such as restoring peatlands and creating heathland environments (areas where sun-lit species can grow), in project areas. The roadmap also introduces ecological compensation, which means that any unavoidable environmental harm is offset by enhancing biodiversity elsewhere. (Renewables Finland. 2025. c.).

AFRY conducted background material for biodiversity work in the energy sector, and they stated that the biodiversity impacts of solar energy utilization largely depend on whether solar panels or thermal collectors are placed on the ground or, for example on the roofs of buildings. Solar power plants require a lot of space in relation to production, as panels are built in rows instead of on top of each other. The impacts of manufacturing solar panels and collectors have been excluded from the review. However, it must be considered that the extraction of the minerals required for manufacturing has an impact on the biodiversity of the mining or processing area and thus on the indirect impacts of solar energy. The biodiversity impacts of solar power plant areas mainly affect land use. To reduce the impacts, solar energy can be placed in areas that are already degraded and in connection with other constructions. The fences of a solar power plant located on land delimit the area from the use of larger land mammals. In addition, the panels shade the soil below them, which has a negative impact on the vegetation in the soil. To promote biodiversity, for example, vegetation transplants or plantings can be carried out in areas outside the panels in the power plant area, which can promote pollinator activity in the area. (AFRY, n.d.)

As mentioned, the studies done regarding biodiversity impact of wind and solar power plants in Finland are still quite narrow but that is because the whole industry is relatively new in Finland. Some study has been done in middle European countries such as Spain, but there the vegetations etc. are quite different compared to Finnish nature.

This master's thesis complements the Renewables Finland's Nature roadmap by producing concrete research data on the biodiversity impacts of solar power plants in different land use areas. This thesis introduces a new calculation method to the roadmap, the habitat hectare, which can be used, among other things, to calculate compensation measures. This thesis aims to provide a tool which a renewable energy company can use to evaluate its projects impacts on the biodiversity of the project area.

The research questions this thesis aims to answer are:

- How can biodiversity impacts be evaluated?
- How can the biodiversity of a project area be improved?
- How much carbon dioxide (CO_2) emissions are generated during the life cycle of industrial-scale ground-based solar power plants when the plants are built on different types of human-altered areas?
- How do the biodiversity impacts differ between solar power areas built on human-altered land and those built in commercial forests?

2 Biodiversity

In this chapter, biodiversity is explained in more detailed sub-headings. The first paragraph explains what biodiversity is and its ecological relevance. The second chapter concludes the current state of biodiversity. The third chapter explains biodiversity loss and how solar power relates to it. Finally, the last chapter examines what targets EU has set relating to biodiversity.

2.1 Definition of biodiversity and its ecological relevance

Biodiversity, also known as biological diversity, imply to variety of life on Earth. While there are multiple definitions for the term, one of the most accepted is provided by the Convention of Biological Diversity:" Biological diversity means the variability among living organism from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complex of which they are part; this includes diversity within species, between species and of ecosystem." This comprehensive definition highlights the breadth of biodiversity and its relevance across ecological context. As mentioned in the definition, biodiversity can be understood on three distinct levels: genetic diversity, species diversity and ecosystem diversity. (Gaston and Spiecer, 2004).

Biodiversity is essential for both, human survival and resilience of ecosystems. It forms the basis for functioning ecosystems which provides crucial services such as clean air, fresh water, natural medicines, pollination, and food security. The variety of life supports key ecological processes and services. For example, genetic diversity allows adaptability and resilience within populations, species diversity enhances ecosystem productivity and stability, and ecosystem diversity supports a wide range of habitats, biogeochemical cycles, and regulatory functions. (WHO, n.d., a). Collectively, these components enable ecosystems to purify water, regulate climate, pollinate crops, decompose waste, and provide food, shelter, and cultural benefits. Healthy and biodiverse ecosystems are most capable of withstanding environmental stressors such as climate chang, diseases, and human disturbance. They are essential for sustaining life-support systems that human societies depend on. (WHO, n.d., b) However, the loss of biodiversity weakens these functions, posing risks to ecological integrity, human health, and socioeconomic stability. Therefore, protecting biodiversity is not only an ecological necessity, but a socioeconomic one, critical for enabling sustainable development and safeguarding future generations. (OECD, 2023.)

According to WWF's living planet report, to guarantee a long-standing health and ecosystems and sustaining nature's contribution to people, preserving healthy and divers species population is essential. (WWF 2024) Species diversity is fundamental to the functioning of many of the natural systems that agriculture depends on, i.e. pollination, water retention, and nutrient cycling. Habitats with diverse specie are more adaptable and therefore can be more productive and resistant. (IFAD 2024.) However, Habitat degradation is a critical global challenge, which is driven by a range of anthropogenic pressures including pollution, invasive species, illegal wildlife exploitation, and unsustainable land use.

2.2 Drivers of biodiversity loss

The main reason for the loss of nature is that humanity has taken over the vast majority of our planet's land surface and modified it too drastically. Wild plants and animals have been forced to give way to crops and domestic animals. In addition, natural resources such as fish stocks are being exploited unsustainably. Nature is also burdened with emissions, which accelerates biodiversity loss. (SYKE, 2025.)

Earth's biodiversity has been in decline for a long time. It is studied that human actions have accelerated biodiversity loss, and it is predicted that Earth is facing the sixth mass extinction. According to a study made by AFRY, approximately one million species are at risk of extinction, and by far over 82% of the biomass of wild mammals has already been lost. If current trends continue, it is estimated that by 2050, between 38-46% of current global biodiversity may be lost, and by the end of the century, the climate could be an average of 3 Celsius or even warmer, which would only accelerate the biodiversity loss. (AFRY, n.d.a).

According to the same study, signs of biodiversity loss are also visible in Finland. It has been stated that 77% of forest ecosystem types are threatened and 68% of their conditions has been lost. 56% of peatland ecosystem types are threatened and 43% of their conditions has been lost. Of all ecosystem types 48% are threatened and 61% of their conditions has been degraded. Finally, 12% (2700) of the 22 400 estimated species are at risk of extinction. The loss of biodiversity is primarily caused by human action and their consequences. (AFRY, n.d.a).

Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem services (IPBES) lists five most significant factor threats to biodiversity are:

1. Changes in land use (e.g. deforestation, intensive agriculture, and urbanisation)
2. Pollution
3. Climate change
4. Overexploitation of natural resources

5. Invasive species.

Energy sector is linked to all five drivers, and many forms of energy production are directly dependent on nature. (IPBES, 2022.)

Biodiversity loss refers to the decrease of any aspect of biological diversity, i.e. diversity of genetic, species and ecosystem level. United Nations Office for Disaster Risk Reduction (UNDRR) describes that, it can be through death (including extinction), destruction or manual removal, and these can refer to many different scales from global to population extinction. (UNDRR, n.d.)

Evaluating the current state of biodiversity in broader scale can be challenging because of biodiversity's multidimensional and intricate nature. Monitoring and quantifying biodiversity has still major challenges, and numerous assessments and reporting methods have been developed to address these challenges. (Watermeyer et al., 2020). The planetary boundaries framework defines the environmental limits within which humanity can safely operate, ensuring the continued development and wellbeing of human society. The framework identifies nine critical Earth system processes: climate change, novel entities, stratospheric ozone depletion, atmospheric aerosol loading, ocean acidification, biogeochemical flows, freshwater change, land-system change, and biosphere integrity. Alarmingly, six of these boundaries have already been crossed. (Richardson et al., 2023.) From the figure 1 below, the illustration of the planetary boundaries can be seen.

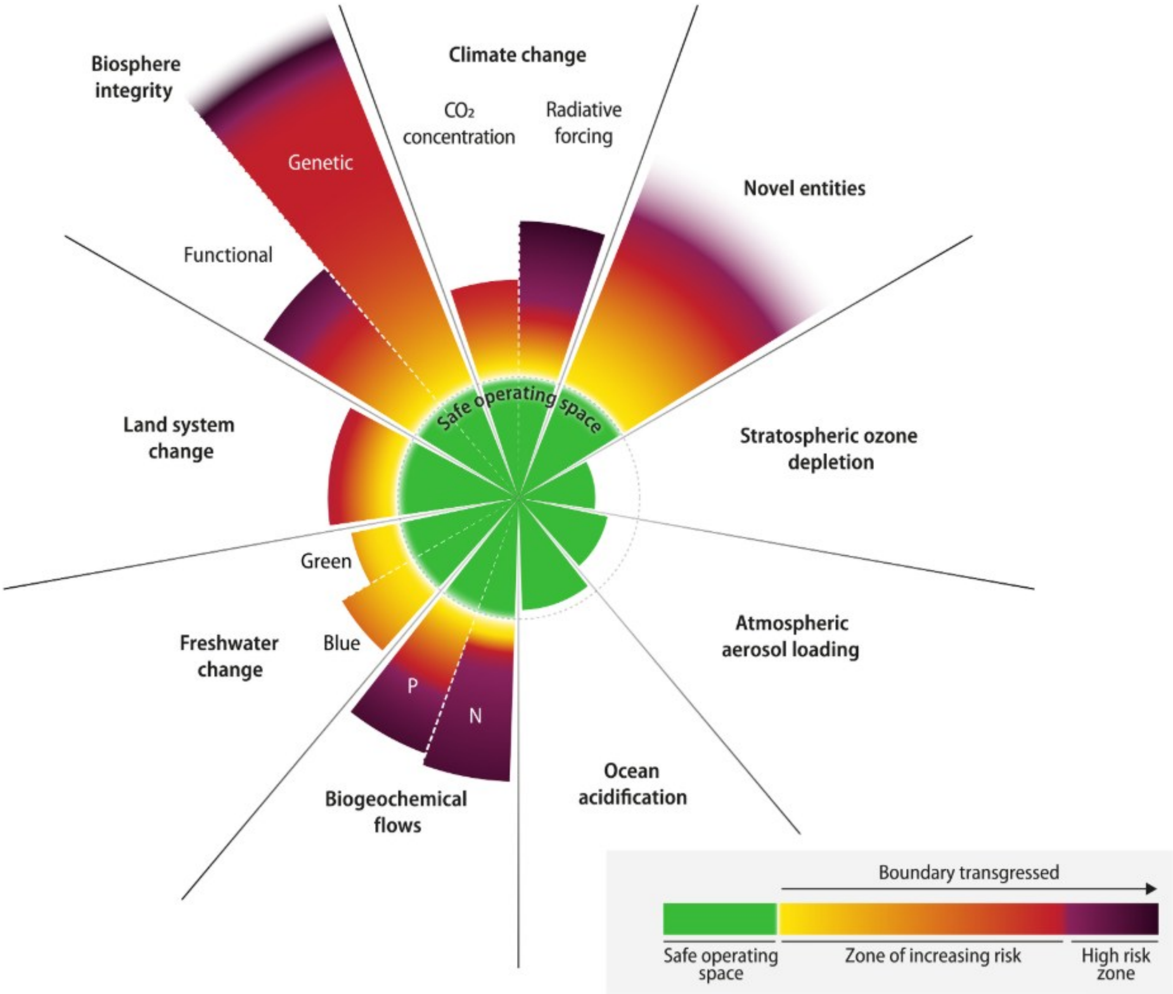


Figure 1. Planetary boundaries (Richardson et al., 2023).

The energy industry is one of the most significant drivers behind the crossing of planetary boundaries. Fossil-fuel based energy production has accelerated climate change, weakened the integrity of the biosphere, increased air and water pollution, and changed land use on a large scale. Given these environmental impacts, a shift towards renewable energy sources is essential. However, it is important to recognize that renewable energy sources have their own environmental impacts, for example trough land use, materials and waste, which can affect planetary boundaries if not managed sustainably.

2.3 Biodiversity in Finland

Finland is geographically portrayed by forest landscapes and a significant number of inland water areas. Finland also has a high number of islands. Finland's land area is over 338 000 square kilometres, while its maritime area covers over 81 000 square kilometres. The most of Finland's land is covered by forest ecosystems, which cover 73.6% of the country. Rivers, and lakes take up to 9.9% of the land area, agroecosystems occupy 5.01%. The smallest portion is taken by heathland ecosystems (1.9%) and urban areas (1.5%). (BISE, n.d.)

According to the Finnish Environment Institute, the sixth wave of extinction is currently underway. Humanity has mistreated nature and as a result, about a third of the world's natural diversity has been lost due to human activity. Over 300 species have already been lost in Finland, and one in nine is endangered. In Finland too, the main cause of nature loss is land use, primarily forestry and agricultural use. A lot of nature is also being destroyed by construction. Roads and other infrastructure fragment natural areas, dams block the passage of fish. Eutrophication and climate change alter ecosystems. An additional threat is caused by alien species that take over habitats from native species. (SYKE, 2023.)

The common goal of European Union member states is to halt the loss of European Nature by 2030. The task requires a lot of work, but it is possible. It is possible to use nature sustainably and treat it with respect. In Finland, the biodiversity and its threats are well known, which makes the start of tackling biodiversity loss easier. The state of nature and changes in it are monitored closely. Valuable natural areas have been mapped, and management plans have been drawn up for water bodies. The assessment of the threat of Finnish species is one of the most comprehensive in the world. The share of protected land are in Finland is now around 14%, and protection is focused on treeless and sparsely wooded lands in the north. Around 11% of the sea surface area has been protected. There is also a noticeable change is people's attitudes for the better. The importance of biodiversity is understood better, and many are also wiling to change their practices. However, this should be done in much faster phase than is currently the case in order to slow down or stop the biodiversity loss. Protected nature areas play a key role in maintaining the diversity of Finland's species and habitats. However, these areas alone cannot fully secure the preservation of biodiversity. In addition to protection, active and varied nature management is required – for instance in commercial forests, traditional rural landscapes, and urban environments. National parks, nature parks and Natura 2000 sites together form the core of Finland's conservation network. However, some areas are not protected by the actual Nature Conservation Act or through state redemption, but have been taken under private protection, for example through temporary or site-specific tailored conservation solutions offered by the METSO program. (ELY, n.d.)

These protected areas also contribute to the safeguarding of national landscapes, cultural heritage, and provide important space for recreation and outdoor activities. Finland currently has 41 national parks, and the country's 1866 Natura 2000 sites cover around five million hectares of land and water. (SYKE, 2023.) In figure 2 below, all the protected areas designated under national law are marked on the map of Finland.

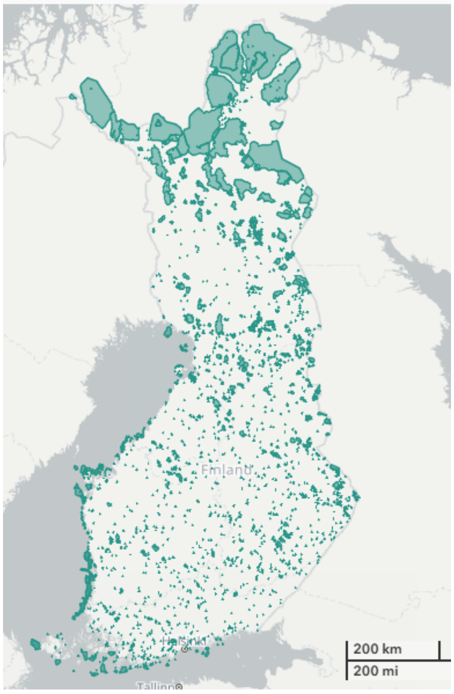


Figure 2. Protected areas in Finland designated under national law. (BISE, n.d.)

Finnish Renewable association has created common biodiversity targets for the entire industry together with its member companies. In collaboration with One Planet consultant, a comprehensive nature impact assessment for wind and solar power, as well as nature positive operating models, were created. Based on the nature impact assessment, a biodiversity roadmap was created as a guideline for the operators in the field. (Renewables

Finland, 2025. c.) The Finnish Renewable association has recognised the impacts of solar power on the five main drivers of nature loss in their report "*Suomen tuulivoiman ja aurinkovoiman luontovaikutukset"*. (Pasanen, A., et.al. 2025 p. 30-35). The five impacts can be seen from the Table 1 below.

Table 1. The impacts of solar power on the five main drivers of nature loss. (Pasanen, A. et al. 2025)

The recognised drivers of nature loss	The impacts
Land use	• Habitat fragmentation and barrier effect • Habitat loss caused by the production of building materials
Climate change	• Carbon footprint of building materials • Positive climate impact in replacing fossil and bioenergy
Use of natural resources	• Soil and building materials • Metals and minerals in the supply chain
Alien species	• Species that may spread through transport and soil materials
Pollution	• Risk of toxic building components entering the environment in special situations • Air pollution from production processes and traffic

There is also widely used framework developed for different stakeholders to use to avoid, minimise, restore or offset biodiversity loss caused by their operations. It is called a mitigation hierarchy, and it is also widely recognised method in Finland. A mitigation hierarchy is a set of guidelines as opposed to a legislative framework, and developers can utilise it to clearly define and establish how to improve the biodiversity value of the project. Currently, there is no legal requirement to follow the mitigation hierarchy process as a single entity or measurement. Mitigation hierarchy works on the basis that development plans will try and aim for as little biodiversity loss as possible. The measurement of biodiversity loss can be categorised into the following four stages: complete avoidance, minimisation where it is possible, restoration of areas within the development, and offsetting either onsite or offsite. (Ecology by design, 2022.) The mitigation hierarchy is illustrated in Figure 3.

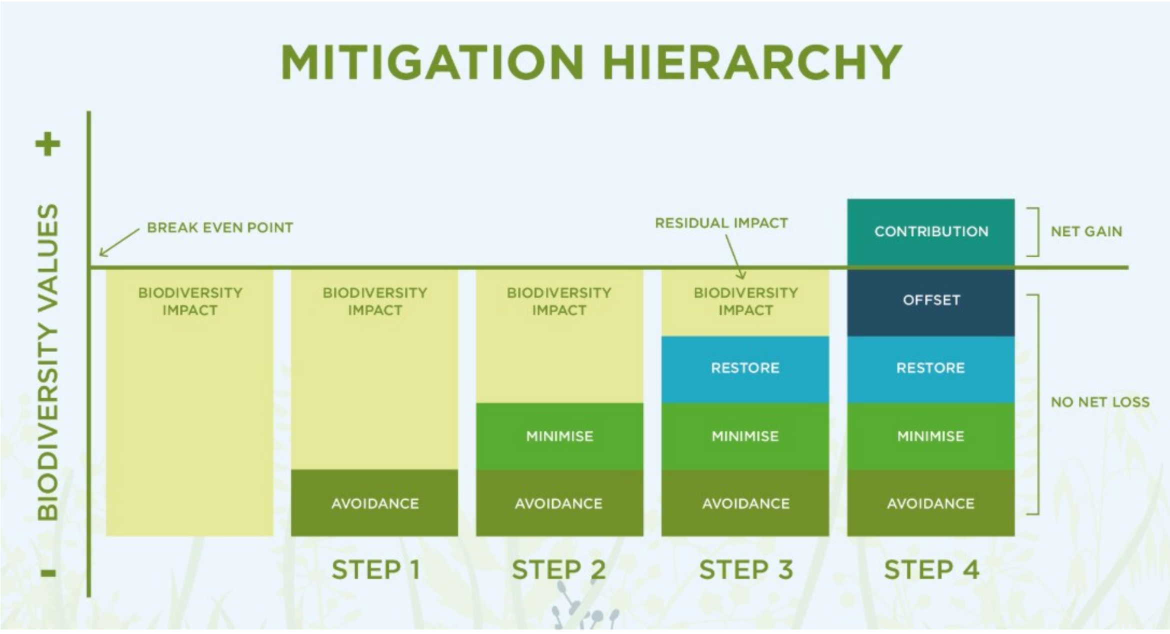


Figure 3. Mitigation hierarchy. (Ecology by design, 2022)

2.4 Political framework

Finland’s biodiversity policy is based on a national biodiversity strategy and action plan. In addition to national targets the strategy considers the objectives of the UN Convention on Biological Diversity and the EU Biodiversity strategy. A new national biodiversity strategy and related action plan for 2035 are currently being prepared. The strategy aims to halt nature loss and turn biodiversity development into recovery path. The framework, targets, and scope regarding biodiversity mitigation are listed in table 2 below.

Table 2. The framework, targets, and scope concerning biodiversity mitigation (Table is modified from: Visala, 2025).

Framework	Key targets	Scope
Finnish Biodiversity strategy	Stopping biodiversity loss by 2030 and trend towards recovery by 2035, maintain and restore habitats, species, and ecosystems. (Finnish Government, 2021.)	National
EU Biodiversity Strategy	Halting the loss of biodiversity by 2030 30% of land and sea area in EU protected (Environment, n.d.a	EU (affects Finland as EU member)
Nature Restoration regulation	• Improving and re-establishing biodiverse habitats on a large scale, • Reversing the decline of pollinator populations by 2030, achieving an increasing trend for standing and lying deadwood, no net loss of green urban space and tree cover by 2030, • Increasing grassland butterflies and farmland birds (EU. n.d.)	EU (affects Finland as EU member)
Nature Concervation Act (Luonnonsuojelulaki, 1096/1996, amended 2023)	Protected valuable natural areas, regulate conservation areas, introduce voluntary ecological compensation for degraded habitats (Finlex, n.d., a)	National
Forest Act	Promotes sustainable forest management, maintain biodiversity in commercial forests. protect habitat of endangered species (MMM, n.d.)	National/Regional
Environmental protection Act (Ympäristönsuojelulaki 527/2014)	Control environmental impacts of human activities, reduce pollution affects species and ecosystems, prevent environmental pollution and its dangers (Finlex, n.d., b)	National
Natura 2000 network (EU directive implementation in Finland)	Protect sites of high biodiversity value, preserve habitats of threatened species	Regional/National
Water Act (119/2001)	Ensure good ecological status of waters, protect aquatic species and habitats (Finlex, n.d. c.)	National / Local
Finnish Species Protection Regulations	Protect endangered species from exploitation and habitat destruction, maintain population viability (YM, n.d.)	National

One of the goals of the EU Biodiversity Strategy is to find a balance between measures that support and those that weaken natural values. The Nature Conservation Act allows ecological compensation, i.e. compensation for the impairment caused to biodiversity. In accordance with the mitigation hierarchy, compensation is possible when the impairment has primarily been avoided and secondarily mitigated or minimized, and possibly the impaired natural values have been restored on site. (Whalsten, A. 2025.)

The Finnish Renewable Energy Association prepared a Nature Roadmap for industry operators, to minimize the impact on nature in their operations. In the Nature Roadmap it is stated regarding solar power development that, in accordance with the mitigation hierarchy for nature impacts, compensation for natural values is always a last resort when nature impacts have not been avoided or mitigated. Compensation refers to measures that compensate for nature damage, which are used to improve the state of nature in similar habitats elsewhere. In ecological compensation, the relationship between the damage caused and the amount of compensation, the habitat type in question, and, for example, the temporal and spatial dimension, are essential. Compensation for nature damage is currently based on voluntary legislation. (Renewables Finland, 2025.c.)

3 Solar power in Finland

This chapter explains the solar power in Finland with more detailed sub-headings. The first paragraph examines the current situation of solar power in Finland. The second chapter explains what ground-based solar panels are, and third chapter examines in which kind of areas solar power plants are usually built on. Finally, the fourth chapter discussed of the lifespan of the solar power plant.

3.1 Solar power energy production

Finland's climate policy mimics the national Climate act which lays down emission reduction targets for 2030, 2040 and 2050. According to the Act, Finland must be carbon neutral by 2035 at the latest. The obligations and policy decisions under the European Union climate and energy legislation are binding on Finland as well. The EU is committed to reducing greenhouse gas (GHG) emissions by at least 55% by 2030, compared to 1990. Another aim for the EU is to make Europe the first climate-neutral continent by 2050. These national and EU- level climate targets strongly steer investments towards renewable energy sources. Achieving carbon neutrality requires a rapid shift away from fossil fuels, which has created both regulatory pressure and economic incentives for clean energy development. Ympäristöministeriö, n.d.)

To meet the goals, Finland and the EU have introduced various support mechanisms, such as investment grants, and climate financing programs that lower the financial risks of renewable energy projects. (Suomen Vetylaakso, 2025.) These policies make large-scale solar and wind projects more attractive to investors and energy companies. (Business Finland, 2025.) Furthermore, the tightening of emission trading schemes and the gradual increase in carbon pricing have made fossil-based energy production less profitable, further accelerating the transition toward renewables. These guide investments towards renewable energy and makes projects more attractive, which increases project development in Finland.

Solar power development in Finland has accelerated partly because the permitting process of solar projects is generally faster and less complex than for wind power. This makes the administrative process more predictable and attractive for investors. (Sweco, 2025) Many projects can be built for example on former industrial, agricultural, or peat production areas, which reduces environmental conflicts and improves public acceptance (Pasanen, A. et al (2025). This considerate siting, combined with simplified administrative procedures, has made solar energy an increasingly appealing option for both investors and municipalities pursuing renewable energy goals. In the figure 4 below the cumulative number of solar power plants (1MW>) installed in Finland between 2018-2024 can be seen.

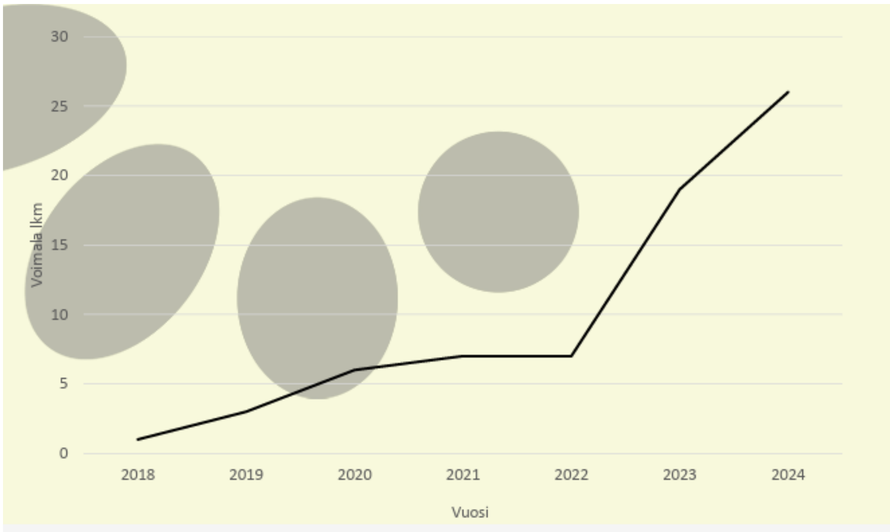


Figure 4. Cumulative number of solar power plants (1MW>) in Finland installed between 2018-2024. (Renewables Finland, 2025. e.)

According to LUT University, Finland has solar energy production potential on a same level as some of Central European countries. (LUT, 2023. b) Finland is undergoing a significant shift in its energy sector. Transitioning from imported fossil fuels to domestic clean energy sources, will attract more industrial investments. The Renewables Finland emphasizes that, a strong expansion of solar power is needed to support wind power production, and for which Finland has great prospects. (Renewbles Finland, n.d. d.) Finland’s irradiation and solar electricity potential is illustrated in figure 5 below.

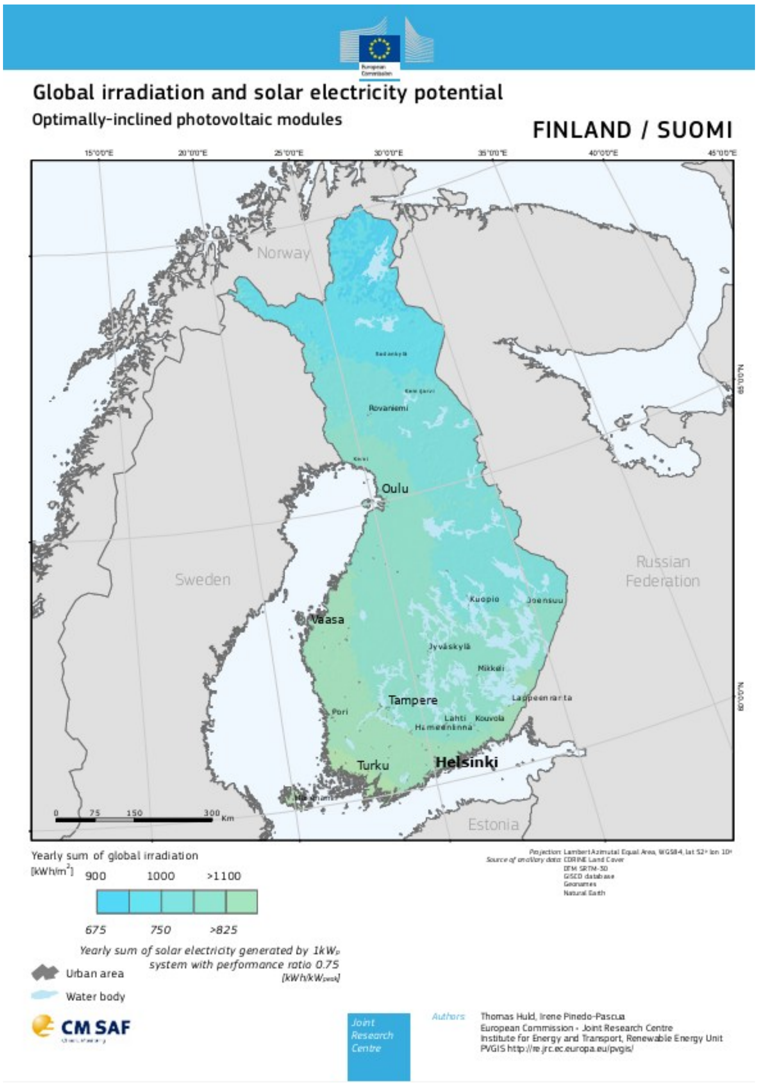


Figure 5. Global irradiation and solar electricity potential, optimally inclined photovoltaic modules. (JRC, 2019.)

Solar power can be produced in large, centralized solar parks, in which case it is called industrial-scale solar power. Industrial-scale solar power plants produce electricity with a high number of panels, and the electricity is typically fed into the electricity grid. These solar power plants can produce significant amounts of electricity, the largest projects in Finland have currently an output of several hundred megawatts. The construction of industrial-scale solar power plants requires significant investments and infrastructure, as well as large land areas. (Energiateollisuus, n.d.a.)

Since 2019, the grid-connected capacity of solar power in Finland has grown by around 100 megawatts annually and in 2022 the growth more than doubled. To this day, solar power capacity rose to 635 megawatts, which was more than 240 megawatts more than the previous year. Yet, Finland is still behind the leading European countries – for example, in the Netherlands, solar power capacity per capita is more than seven times higher. Globally, doubling of capacity has typically reduced the price of modules by around 20 percent, and solar power has become the most affordable new form of electricity generation almost everywhere, which naturally accelerates the solar power development. Several solar power parks are now under construction in Finland that produce electricity directly into the grid, which improves economic profitability. Although the annual radiation amount in Finland is lower than in the best regions, it is still comparable to northern Germany's or Denmark's radiation level. However, the capacity in these countries is many times higher compared to Finland's. According to LUT University, the share of solar energy will most likely increase up to 10 percent of the whole energy production by 2050. (LUT, 2023.b) The share of solar power in Finnish electricity production is still relatively small. The figure 6 below shows that solar power only covered 1.4 % of total electricity production and net imports in 2024.

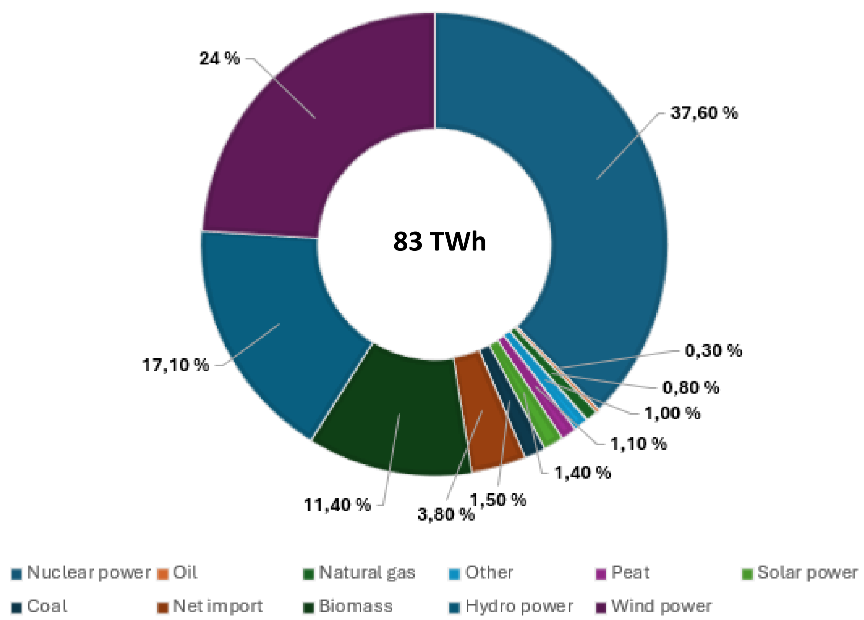


Figure 6. Electricity production by energy source and net imports in 2024. (Energiateollisuus. 2025b)

Industrial-scale solar power plants, i.e. with an output of over one megawatt (1 MW), has been built in Finland in larger scale for about two years now. By the end of year 2024, there were just over 120 megawatts of industrial scale solar power in production, and almost half of this, just under 60 megawatts, was completed in 2024. (Renewables Finland. 2025.e)

The growth in solar power development id due to several reasons. The price development of solar panels has been declining for the past few decades. The price development of solar panels is expected to continue to decline according to a learning curve, whereby the price of solar panels will decrease by 20% as the global cumulative production volume doubles. The long terms decline in the price development of the panels can be explained by the growing solar electricity market, the growth of production and the development of technology, the service life of the panels is also increasing. The service life can already reach more than 30 years. (Seistola, E. 2023.)

In Finland, the regional electricity price development was steady at around €50/MWh from 2018 until 2020. At the beginning of 2020, the impact of the corona epidemic caused a decrease in oil demand, which resulted in particularly low exchange electricity prices. Low prices were followed by the end of 2021, when an unusual increase in the exchange electricity price was seen. Reasons for the record high price included, among others, the decline in waterpower, the increase in the price of fossil fuels, and emission allowances. Record high electricity prices were followed by another record high price spike in 2022, caused by the war in Ukraine and the resulting energy crisis. In the winter 2022, the prices fell significantly back closer to pre-crisis prices. The price decline was influenced by, among other things, the calming of the Europe, the increase in new production capacity such as wind and nuclear power, and the decrease in electricity demand. The growth of solar power production was also driven by the exceptionally high level of electricity process due to the increase in wholesale electricity prices caused by the energy crisis in 2022. This meant higher returns and improved profitability for renewable energy producers with low production costs. (Seistola, E. 2023.)

Figure 7 below shows the offers of different production forms according to marginal costs and the available production capacity. The production forms are arranged on the supply curve according to the variable production costs, forming a running order, or so-called merit order from the cheapest to the most expensive. (Seistola, E. 2023.)

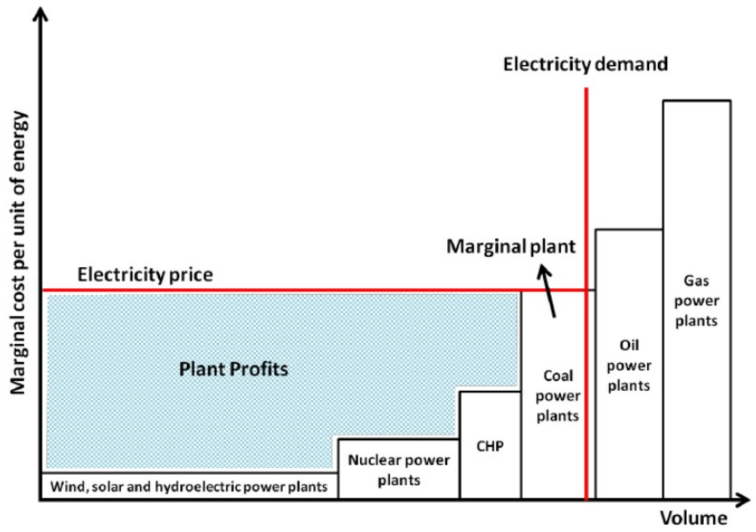


Figure 7**.** Electricity market supply curve. (Sauvage & Bahar, 2013).

3.2 Ground-based industrial-scale solar power plants

The installation method of solar panels depends on the purpose of the plant. Solar panels can be utilized on larger scale by installing panels on the ground instead, of placing them on the roofs or other man-built surfaces. Ground installation has several advantages compared to for example roof-mounted solar panels. The number of roof mounted panels is limited by the surface area, while ground-based panels can be spread over larger areas. This allows solar power to be produced more and utilized in many different environments, such as fields, industrials areas or wastelands. For this reason, ground-based panels are well suited as installation option for industrial-scale solar power plants. (Borret, G., 2024.) Industrial-scale solar powerplant has sever components. There are solar panels, inverters, transformers, the main transformer and cables. Illustrated picture ca be seen below from figure 8.

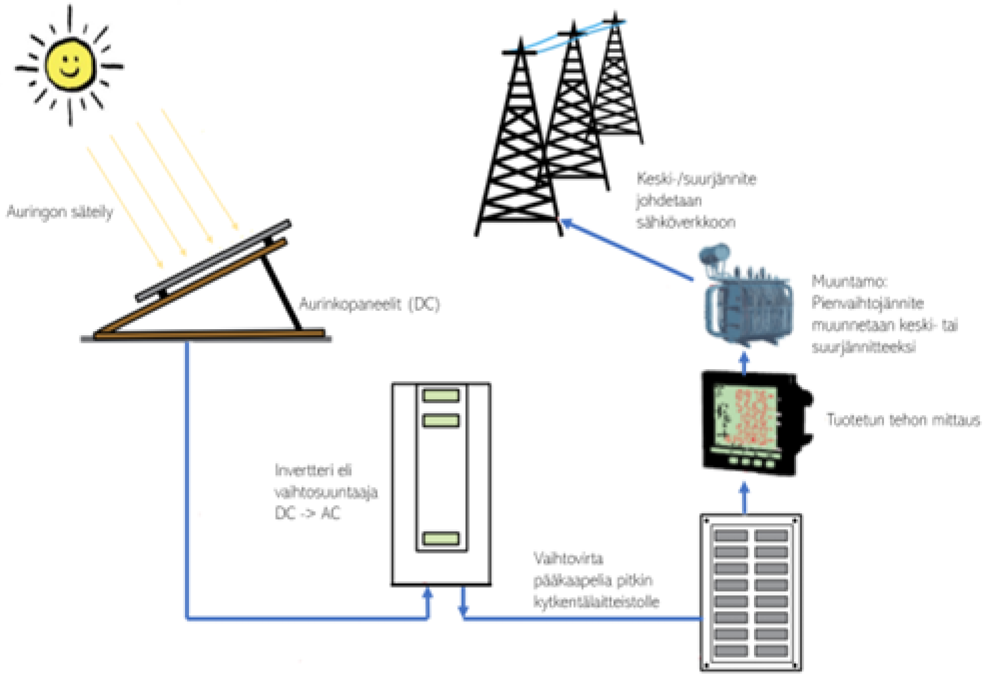


Figure 8. Components of an industrial-scale solar power plant. (Kaurala, M., 2023)

The way the panels are installed affects to the amount of energy that is produced by the panels. Energy production can be improved with solar tracker, which also increases the material, installation, and maintenance costs. As solar panels create different amounts of shading at different angles, different installation methods as well as orientation angles affect the installation density of the panels. Therefore, fixed panels can often be installed more densely, which reduces the electricity production advantage of panels equipped with solar tracker in relation to the usable area. (Nevalainen, 2022.)

When panels are installed to the ground, the mounting brackets for solar panels are attached to foundation. Foundations can be either above ground or underground. Above-ground foundations are most often elements made from concrete, which also hold the panels in place due to their mass. Above-ground foundations are most often used when the soil is not suitable for underground foundations, and the ground surface is strong enough to carry the foundations. For example, the soil may be too hard for the underground foundations to be economically viable. Different types of underground foundations include piles driven into the ground, screw piles drilled into ground, element foundations dug into the ground or foundations cast directly into the ground. Screw piles and driven piles are often the cheapest to use, but they require suitable soil to function correctly. (Nevalainen, 2022.)

As mentioned, industrial-scale ground-based solar power plants require a significant land area, and this can have a negative effect on the biodiversity of the area. To maximize the production of the panels, the shadowing of the area and its near surrounding need to be minimized. Therefore, taller trees and other plants need to be cut down. The vegetation growing under solar power plants should be kept short, and often in these areas, sun-lit species plants are preferred. In Finland, these plants do not grow naturally in many places, so for this reason, the natural vegetation of the area must be cleared away. In addition, the power plants must be fenced due to the risk of vandalism and to prevent accidents. This can make it difficult for various species to move around, which effects on species biodiversity of the area.

3.3 Solar power land use in different types of areas

Industrial scale solar power plants require large land areas, and several factors influence the selection of the optimal area for solar power plant. Not only the technical aspects but also the governmental regulations. Solar power plants can be built for example on forests, fields, peatlands and in areas which are not suitable for other uses.

When designing a solar power plant several aspects need to be considered. The soil and vegetation type of the designed area play a significant role. The distance from the area to the electricity grid is also important and whether significant natural values have been identified in the area. The most typical areas used for ground-based solar power production are former peatland production areas, arable lands, wasteland and forests. (Kaurala, M., 2023.) The government program of Petteri Orpo's government has taken a position on locating solar power plants elsewhere than on fields and forest land, with the aim of trying to avoid significant use of fields and forest land for solar power. (Pasanen, A, et.al. 2025, a)

There has been public discussion and debate about where to build solar power plants as they require a lot of land area. Fingrid has estimated that there would be 16 TWh of solar power plants in Finland in 2035, which equals to 16 GW of solar power capacity. That would mean approximately 0.03 million hectares of land. To give perspective, Finland's agricultural land area is 2.2 million hectares. Therefore, even if all the predicted solar power plants were to be build, which is very unlikely, less than 2 % of Finland's fields would be used. Finland also has forestry area of approximately 26.3 million hectares. (Renewables Finland, 2025. f.)

3.3.1 Peatlands

Peatlands, also known as peatbogs, have thick layers of peat that can store large amounts of carbon and therefore they act as carbon sinks. When peat bogs remain waterlogged and no oxygen can reach the ground, organic matter only partially decomposes, allowing carbon to accumulate over thousands of years. However, when peatlands are drained - for example for peat extraction, the peat becomes exposed to air. This leads to microbial decomposition, releasing carbon dioxide (CO_2) into the atmosphere and contributing to climate change. (IPS, n.d.)
Peatlands are globally important for climate regulation as they store approximately 500 gigatonnes of carbon, equivalent to more than half of the current atmospheric carbon. In Finland, peatlands cover approximately one third of the total land area, making them one of the country's most significant carbon storages. If the hydrological balance of these ecosystems is disturbed, they can shift from carbon sinks to carbon sources, releasing substantial amounts of greenhouse gases (GHG). (University of Eastern Finland, 2022).

The use of peat as an energy source increased in the 20th century but began to decline sharply in the 2010s. The main reason for this decline was climate policy measures and EU's emission trading scheme, which made energy peat less competitive in the energy market. Burning peat produces approximately 106 gCO2, eq./MJ of energy, which is more than either natural gas (56.1 g) or coal (94.6 g) (Bioenergia n.d.). Due to high emission costs and environmental concerns, the Finnish government has set a target to halve the use of energy peat by 2030 (Energia uutiset, 2022).

As peat extraction ends, extensive areas of former peat production land are becoming available for alternative uses. Traditionally, these areas have been afforested, converted into agricultural land, or restored as wetlands. However, new opportunities are emerging through renewable energy production, particularly large-scale solar power. According to Renewables Finland, solar power plants offer a sustainable reuse option for former peat production areas producing clean energy while simultaneously enabling biodiversity restoration. (Pasanen, A., et.al. 2025.)

Although former peat production areas can be promising locations for solar farms, they also pose technical challenges. The remaining peat layer and high soil moisture can make construction and maintenance difficult, often requiring additional water management measures. To ensure profitability, solar power plants on peatlands need to be large scale projects, typically connected to high voltage grids.

While few industrial-scale solar power plants have yet been completed on peatlands, most planned projects are located on these areas. The Finnish government programme also encourages prioritising former peat production sites when planning new solar power projects. (TAPIO, 2025.)

Since drained peatlands release large amounts of CO_2, one promising approach is to rewet these areas while also producing renewable energy. Research by German Fraunhofer Institute for Solar Energy Systems proposes the concept of “Peatland Photovoltaics” (Peatland PV) – a dual-use system in which peatlands are rehydrated to restore their carbon storage capacity, while solar panels are installed above to generate clean energy. (Fraunhofer ISE, n.d.) This approach could potentially be applied in Finland as well.

Even after conversion into solar power plants, former peatlands can still support additional productive land uses between solar panel rows. These can include grassland cultivation, melliferous (honey-producing) crops, grazing, or berry farming (Kaunismäki, 2025). Such combined uses can enhance biodiversity, support local economies, and make the project more socially and environmentally sustainable.

Nevertheless, the sustainability of each peatland site for solar power depends heavily on economic, technical and environmental factors – particularly the peat thickness, soil stability, and water management requirements. In some cases, these factors may limit or even prevent solar development on certain peatland areas.

3.3.2 Forest areas

Forest areas are defined as areas where trees cover more than 10% of the surface and reach a height of at least five meters (FAO, 2020). Another definition for forest is that the growing site can produce at least one cubic meter of wood per year. (LUKE, 2021.) Finland is one of the most forested countries in the world: around 75% of Finland's total land area is covered by forests (Luke, 2024). Finnish forests are primarily managed for economic purposes, meaning that silvicultural logging is carried out to promote the growth of commercially valuable tree species. This practice has led to the predominance of coniferous (mainly pine and spruce) and deciduous (mainly birch) forests, with less species diversity in many managed areas (Luke, 2024).

According to Statistics Finland, forest soils in Finland are divided into mineral soils and organic soils. Organic soils include peat soils, which are further classified into four subcategories according to vegetation type. If more than 75% of the organic matter in the soil consists of peat, the forest is classified as a peat forest (Statistics Finland, 2024).

When a solar power plant is established on forested land, clearing and deforestation are typically required to make space for the solar panels. Industrial-scale solar power plants demand large, open areas, and the presence of trees, roots, and stumps creates challenges for site preparation. Remaining organic material in the soil may slow down foundation work and increase construction costs.

In addition to technical and economic challenges, the environmental and carbon impacts of building solar power plants on forest land must be carefully considered. Forest ecosystems store substantial amounts of carbon in both vegetation and soil. When trees are removed, this carbon stock is released into the atmosphere over time, potentially offsetting part of the climate benefits achieving by renewable energy generation. (Luke. 2025.a.)

While forests can technically provide land for solar energy projects, their conversion into energy production sites involves a complex balance between renewable energy benefits and ecosystems and carbon costs. Future solar development in Finland should therefore prioritise low-value or already degraded land, such as former peat extraction areas or unused fields, to minimise environmental trade-offs. (Renewables Finland. 2025.a.)

3.3.3 Arable lands

Arable lands, or fields, are areas of land primarily used for agriculture and crop cultivation. They play a vital role in food production, local economies, and landscape management. The characteristics of arable land vary depending on soil composition, typography, and climate conditions, as well as on the farming practices applied. (Dalal, D. 2025.)

From technical perspective, arable lands offer several advantages for solar power development. Fields are generally flat and open, which makes them ideal for the installation of solar panels and minimises shading losses. They also often have an existing road network and access routes, which can be upgraded for construction and maintenance purposes. The bearing soil in agricultural fields is usually firm and close to the surface, and since these areas are already drained and easily accessible, they are suitable for the foundation structures required for solar panels. (Boom power. 2024.)

The construction of solar power plants on fields can alter local ecosystems. Permanent ground shading reduces photosynthesis in underlying vegetation, which may affect soil biodiversity and nutrient cycling. However, properly planned solar farms can also bring environmental benefits: by minimising soil disturbance, sowing low-growing grass or pollinator-friendly vegetation between panel rows, and reducing the need for pesticides and fertilisers, solar farms can help restore soil health and biodiversity. (Li, C. et.al. 2023.)

An emerging solution to reconcile the dual use of land for energy and food production is agrivoltaics – systems that combine solar power generation with continued agricultural activity on the same land. In these systems, solar panels are installed at a higher elevation or spaced to allow sunlight penetration for crops or grazing. Agrivoltaics systems can enhance land-use efficiency, reduce water evaporation from soil, and provide partial shading that benefits some crop types during heatwave. The figure 9 below illustrates how in agrivoltaics applications the panels are installed to allow crops, grass or fruit to grow normally. (European Union, 2023.)

Figure 9. Combining farming and solar photovoltaic electricity production (European Union, 2023).

In Finland, the sustainability of arable lands for solar energy production depends on local zoning regulations, grid connections, and environmental impact assessments. When selected sites, low-yield or underutilised fields, abandoned agricultural area, or marginal lands that are no longer economically viable for cultivation are generally preferred. These locations minimise conflicts with food production while still offering technically optimal conditions for solar development.

Arable lands provide an attractive and technically feasible options for solar power development due to their flat topography, accessibility, and strong soil foundations. However, their use for energy production must be carefully assessed to avoid competition with food production and to preserve soil and ecosystem integrity. One compromise and approach could be multi-purpose land use, such as agrivoltaics systems or solar installations on degraded or abandoned agricultural areas, where renewable energy generation and environmental restoration can coexist.

3.3.4 Human-altered areas

Humam-altered areas are lands that have been permanently modified by human activity and where the natural values of the area are often already lost. Such areas can include, for example, parking lots, former industrial sites, ash disposal areas, landfills, soil extraction sites, or other similar degraded lands. Because these areas have already undergone significant alteration, the construction of solar power plants on them typically does not cause additional harm to natural habitats or biodiversity. Building a solar power park on these areas might also gain more social acceptance comparing to a commercial forest. Many of these areas have already infrastructure (e.g. roads and power lines) reducing the need for additional infrastructure. (OECD, n.d.)

In addition, the land does not usually require extensive preparation, as it is already cleared and compacted. The ground-level emissions or soil structures are not significantly affected by the installation of solar power plant components. These areas are usually cleared, levelled and compacted, meaning installation costs are lower compared for example to forests or peatlands. Many human-altered area are located near roads, electricity network or industrial facilities, which reduces the costs and complexity of connecting solar power plants to the grid. Some sites are pre-approved or zoned for energy production, depending on its former utilization. (OECD, n.d.) This can significantly accelerate permitting processes and reduce regulatory hurdles.

Although human-altered areas can offer a sustainable solution for ground-based solar powers, there are also some technical challenges. For, example, landfills and ash disposal areas may have limited bearing capacity or gas emissions from decomposing waste that require careful design of panel foundations and maintenance systems. However, with proper engineering solutions, these sites can be safely and efficiently converted into productive energy-generating areas. (Ethical power. n.d.) There is limited availability of human-altered areas with no use. Industria-scale power plants may need multiple sites or land expansion, which can complicate planning.

3.4 Solar power biodiversity impacts

Increasing the use of solar energy can increase climate benefits by reducing GHG emissions, and in this case, areas need multiple habitats for different species. Solar power construction changes land use and the structure of habitats, which can locally reduce biodiversity. Placing solar areas in areas with significant changes in the environment or in forestry areas can have very different consequences. Recognizing and understanding these differences is essential for renewable energy production to be developed in an ecologically sustainable way.

3.4.1 The negative impacts

Finnish Renewables has conducted a study with One Planet on the environmental impacts of solar and wind power plants to guide operators in the sector to reduce the biodiversity impacts of their projects. According to the study, most significant negative impacts on biodiversity of solar power are from production of building materials outside Finland's borders as the cause a habitat loss. From soils and building materials to supply chain metals and minerals. At local level the biggest negative impacts come from land use changes if the solar plants fragments, reduces or weakens habitats or restricts the movement or organism around the project area. This also causes carbon sink losses. The most harmful local environmental impacts occur if solar power plant is places in natural habitats such as forests or undrained bogs. The power plants may also create a barrier effect and prevent the passage and movements of animals. However, biodiversity impacts of solar power have been studied quite little so far. (Pasanen, A., et.al. 2025). The Table 3 below shows the negative environmental impacts of solar power plants and the targets of the impacts according to the research.

Table 3. The negative impacts of solar power plants on biodiversity. (Pasanen, A et.al. 2025)

Target of impact	Negative impacts
Land use	• Large areas can change habitats; clear-cutting of forests and land cultivation can permanently destroy forest ecosystems. • Risk of drying out of mires and peatlands
Biodiversity	• Disruption of mammal movement, reduction of territories - fence creates obstacles for animals • Fragmentation of habitats for species that require large territories • Deterioration of habitats for forest birds and protected species
Fauna	• Bats and species of conservation importance avoid solar power plants • Loss of resting places for migration birds • Aquatic insects may be disturbed by the reflection of solar panels
Climate and carbon footprint	• The production of building materials causes emissions • Land use changes in forest lands reduces carbon sinks and carbon stocks
Materials and pollution	• High demand for critical materials (copper, aluminium, manganese) • Processing raw materials pollutes • Panels contain toxic substances (lead, tin) that can endanger organisms, environment and humans

3.4.2 The positive impacts

The transition to renewable energy is often linked to only reducing GHG emissions and combating climate change, but an equally important dimension which is also intertwined with combating climate change, is its potential to protect and even some cases enhance biodiversity for the better in a specific area. Among other renewable technologies, solar power is offering opportunities for ecological restoration and reduced environmental pressures when implemented accordingly. From the Table 4 below can be seen the positive impact of solar power to biodiversity.

Table 4. Positive impacts of solar power to biodiversity (Pasanen, A et.al. 2025)

Target of impact	Positive impact
Land use	• Good location can improve biodiversity • Solar power plants placed on human-altered can create new diverse habitats
Biodiversity	• Supports bird species that prefer open areas (e.g. the wood warbler) • Increases the diversity of insects and pollinators • Opportunity for diverse meadow and moorland vegetation
Fauna	• The number and diversity of pollinators can increase • The living opportunities of insects and birds in open areas are improved • Appropriate planning and green connections support the success of species.
Climate and carbon footprint	• Replaces fossil energy • Reduces GHG emissions • Solar power is more environmentally friendly than fossil fuels over its life cycle
Materials and pollution	• As technology develops, the material efficiency of modules improves and metal consumption decreases • Thin-film panels reduce life cycle emissions

3.5 Lifespan of a solar power plant

The life span of a solar power plant is approximately 25-35 years, depending on different factors such as the components used, environmental conditions and maintenance operations. (U.S. Department of Energy. n.d.) However, the life cycle of the plant starts before the construction, and it consists of several stages. The stages the life cycle involves are raw material extraction, raw material processing and refining, manufacturing of the modules and other system components, installation, system operation and maintenance, and plant decommissioning and disposal or recycling. Solar power plant can be planned for several years before it is completed. The figure 10 below shows the development process of an industrial- scale ground-based solar power plant project.

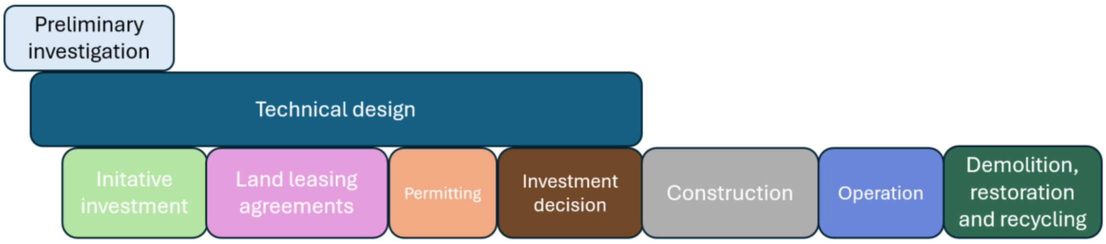


Figure 10. Process diagram of a ground-based industrial scale solar power plant.

During the preliminary investigation phase, the suitability of a potential land area for a power plant is mapped. During this stage the size, shape and soils of the area is investigated thoroughly to determine whether it makes sense to build a power plant in the area. Other aspects investigated in this phase are a grid connection point, and roads in the area. After the area has been found to be suitable for solar power, the land leasing process begins. When enough land has been secured, the permitting stage starts, and during this phase, the necessary permits are applied for to build the power plant. Preliminary technical planning begins during the preliminary investigation phase, but the final technical planning starts after the land lease agreement(s) are signed. In this stage the more detailed planning for example the placement of the racks and panels, and earthwork plans, and electrical planning is done. The final investment decision is made after the permits have been approved. The investment decision is made when the components to be used have been selected and the prices have been reviewed. At the beginning of the construction the area is cleared of trees and vegetation that might cause shading for the panels. The area is levelled, and drainage is ensured to ensure that water is drained away from the area. Cabel routing is done during earthwork. After earthwork is done the foundation are installed, the scaffolding and panels can be installed. The electrical work can start after the mechanical work has been completed. After the electrical work is completed, the power plant is ready for commissioning. (Kaurala, M., 2023.)

Maintenance and upkeep-work for ground-based power plants is generally minimal. Solar power plants have relatively few wearing parts. However, as the lifespan can be up to 30 years, it is likely that some parts might need to be replaced or at least maintenance. In principle, inverters will have to be replaced during the lifespan of the plant as the lifespan of inverter is approximately 15-20 years (Leppäkoski, 2021). Power plants can be monitored remotely. At the end of the life cycle, solar panels and other materials are dismantled from the areas and sent for recycling and the area is restored. (Hakola, L., 2023.) The whole life cycle of solar power plant is illustrated in the figure 11 below.

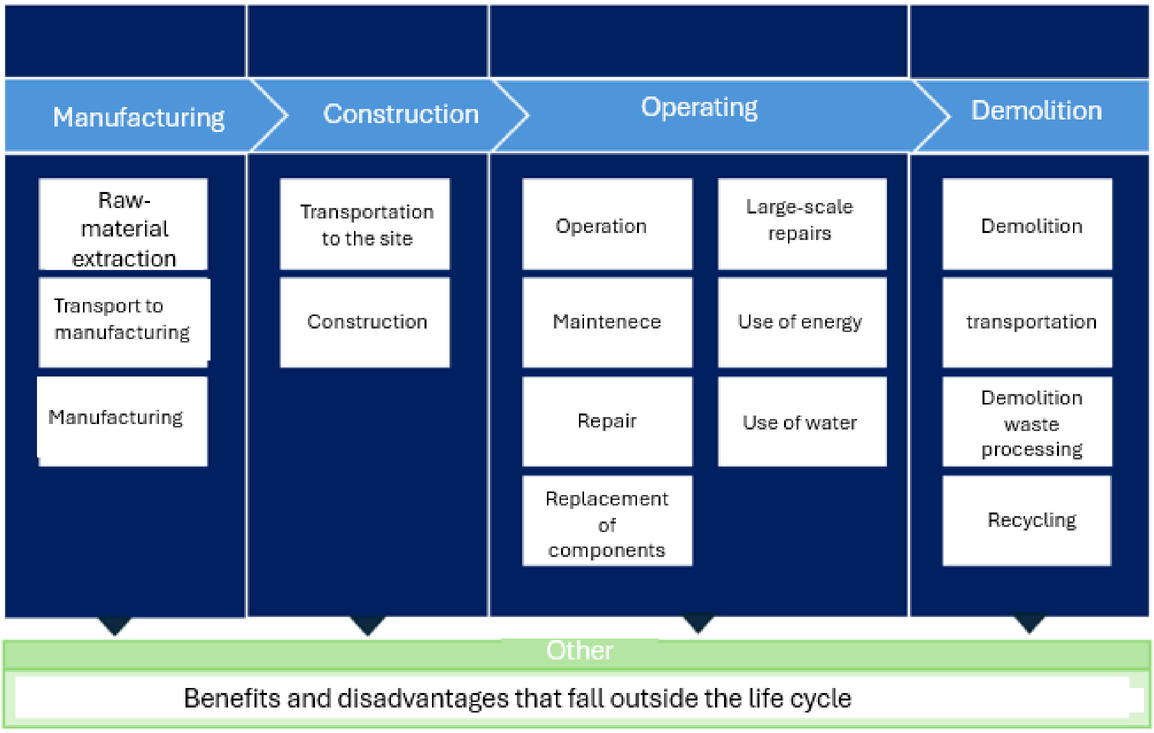


Figure 11. The whole life cycle of solar power plant. (Imitates: Forus, 2023.)

4 Methodology

In this thesis the biodiversity impact of industrial scale solar power plants in Finland is done by calculating carbon footprint and a habitat hectare to three real life case examples. The carbon footprint is calculated using Nordi's calculation tool, and the habitat hectare calculations are based on "*Luontotyyppien ekologisen tilan arviointi ekologisessa kompensaatiossa*"- report (Jalkanen, Nieminen & Ahola 2025). The first chapter explains the goal and scope of the calculations. Second chapter introduces Nordi's calculation method for the carbon footprint calculations with the initial data. Third chapter focuses on the habitat hectare calculations. The final chapter 4.4 introduces the case examples used in this thesis.

4.1 The goal and scope

Solar power is a renewable energy form, which makes it a better option compared to fossil fuels. However, it is not emission free energy form if looking at the whole life cycle. For a project developer to be able to influence the emissions generated during the life cycle of their projects, it is necessary first to identify how much emissions are generated at each point in the life cycle of a solar power plant. For this reason, carbon footprint emissions are calculated for each life cycle stage for three case examples. The calculation uses a lifetime of 30 years for solar power plants. In this thesis the functional unit used for life-cycle carbon footprint assessment is one kilowatt-hour (1 kWh) of electricity generated by the solar power plant, expressed as grams of CO_2 - equivalent per kilowatt-hour (gCO_2-eq./kWh).

Because industrial-scale solar power plants take up a significant area of land, building a solar power plant has impacts on the biodiversity of the area, and therefore the natural values and state of the area must be examined. This will then allow an assessment of how the area's biodiversity can be increased. The habitat hectare calculation method is used for this analysis.

4.2 Nordi's carbon footprint calculation method

The carbon footprint calculation aims to describe the climate impact of a project. The aim is to calculate the amount of greenhouse gases that will be released in the atmosphere during the whole life cycle on the plant. Nordi's carbon footprint calculation method takes into account all stages, from component manufacturing to dismantling of the solar power plant, in other words from cradle to crave. The calculations are divided into five stages: manufacturing of components, transportation, construction (including emissions caused by the forest logging), operation and dismantling and recycling. Components that are included in the calculations are solar panels, inverters, transformers, racks, and the main transformer. In addition, emissions caused by the construction of service roads and cable routes, emissions caused by the requires earthmoving work, and emissions caused by maintenance have also been considered in the emission calculations. Emissions from the component recycling have also been considered during the dismantling phase. The calculations take into account the share of lost carbon sinks, as well as emissions caused by cutting of trees. Figure 12 below shows the system boundary considered in these calculations.

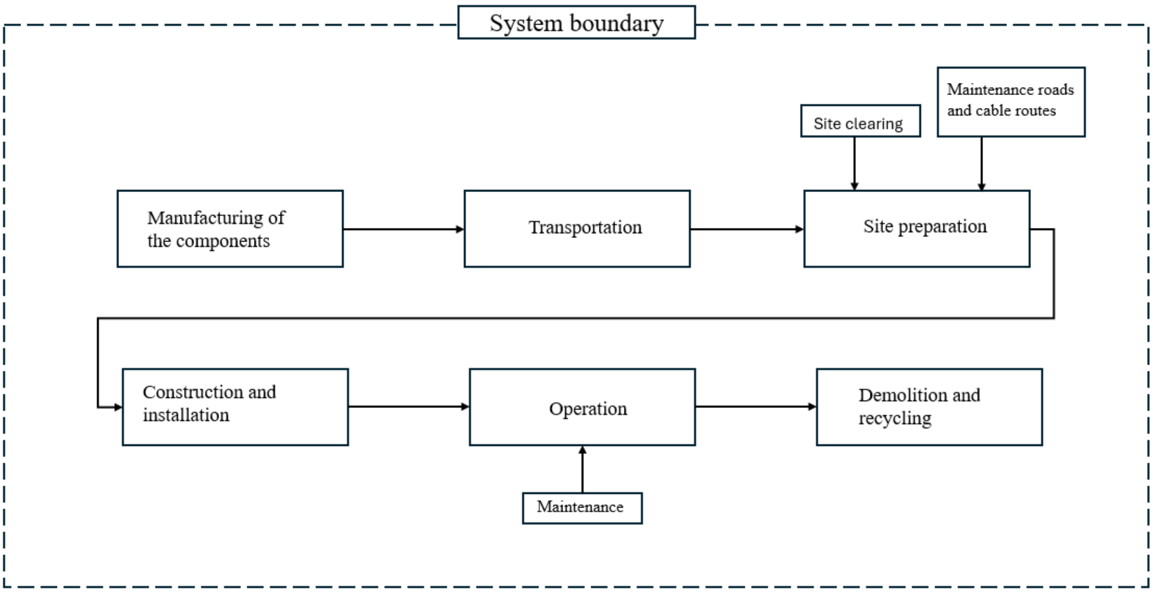


Figure 12. The system boundary considered in the carbon footprint calculations.

As mentioned in the chapter 3.3 the life span of a solar power plant is estimated to be approximately 25-35 years. However, the service life of all components is not the same. This has been considered in the calculations. In the manufacturing phase the calculation method includes the components manufacturing process and building of the components. Precise calculations of carbon dioxide emissions from the procurement of raw materials and the transportation of materials and components have been excluded from the calculations at this stage, as accurate data is not available, and the aim was to keep the work within a reasonable scale. The calculations include site preparation, including tree felling, construction of maintenance roads and cable routes, and transportation of components to the site. It includes carbon dioxide emissions from the construction of the facilities. Emissions from energy use and water use have been excluded from the operation phase to ensure that the work can be carried out on a reasonable scale. The dismantling phase includes the dismantling of all components and the emissions from the work tools involved. In addition, emissions from the recycling of components have been included. Other benefits and disadvantages that arise outside the life cycle of the solar power plant have been excluded from the calculations to keep the work within a reasonable scale.

Initial data for case examples that will be used in the carbon footprint calculations in paragraph 5.1 are listed below in table 5.

Table 5. Initial data of case examples.

Case 1	Amount	Unit
Annual production	41849	MWh/a
	967	kWh/kWp/a
Power of the plant	43	MWp
Operating life of the plant	30	a
Case 2	Amount	Unit
Annual production	51564	MWh/a
	956	kWh/kWp/a
Power of the plant	53,9	MWp
Operating life of the plant	30	a
Case 3	Amount	Unit
Annual production	56378	MWh/a
	979	kWh/kWp/a
Power of the plant	60	MWp
Operating life of the plant	30	a

4.2.1 Manufacturing of materials

The emissions generated during the manufacturing process have been calculated for each component of solar power plant. The calculation is made for a specific model, but the model might change before the power plant is completed, which is why the results are indicative. The components are the same for each case example. The output data of the components can be seen from the table 6 below.

Table 6. Component's initial data.

Components	Type	Power (W)	Weight (kg)	Peak power (MWp)	Number of units	Emission Factor (kgCO2e/kg component	References
Panels	TW 66HD695-715W	720	38.7	Case 1: 53.9 Case 2:53.9 Case 3:60		11	Syke, n.d.
Inverters	SG350HX	350	116	Case1:34.65 Case2:44.1 Case3:137		33.83	SKE. n.d. Brüstle, F. 2022.
Racks	Corab/WS-017NB	-	642.3	-		4.9	Syke, n.d.
Main transformer	Hitachi KTPU/M 123 NC 63000	63 (MVA)	81700		1	2.97	Rintala, N. 2021 Hitachi, n.d.
Transformers	NEP7ps	7000000	25000			2.97	Syke, n.d.

The emissions from the manufacturing of solar panels have been calculated for a TW 66HD695-715W type solar panel. The panel power (W) and weight (kg) have been obtained from the solar panel manufacturer's website. According to the panel manufacturer, the power of one panel is 720 W. The number of solar panels ($N_{p,\ tot}$) is calculated by converting the power of one individual panel to MW and then the peak power of the power plant is divided by the power of individual solar panel, as shown in equation 1. The number of panels obtained is then multiplied by the weight of the panels according to the manufacturer's information to obtain the total weight of all panels ($m_{tot,p}$) by equation 2. The weight of the panels is then multiplied by the emission factor. The resulting emission value is then divided by 1000 to get the answer in tCO2, as shown in formula 3.

$$N_{p_{tot}} = P_{peak,tot,plant}/P_{ip} \quad (1)$$

, where $N_{p,tot}$ is the total number of solar panels, P_{ip} is the power of one individual solar panel (W), and $P_{peak,tot,plant}$ is the peak power of the solar plant.

$$m_{tot_p} = m_{ip} * N_{p_{tot}} \tag{2}$$

, where $m_{tot,p}$ is the total weight of the panels (kg), m_{ip} is the weight of individual panel (kg), and $N_{p,tot}$ is the total number of solar panels.

$$CF_{p_m} = m_{tot,p} * EF \tag{3}$$

, where $CF_{p,m}$ is carbon footprint of solar power in the manufacturing phase (tCO_2eq.), $m_{tot,p}$ is the total mass of solar panels (kg), and EF is emission factor ($kgCO_2eq. per\ kg\ panle.$

Inverter's carbon footprint in manufacturing phase is calculated the same way. The number of inverters is calculated by dividing the total peak power of inverters with the peak power of individual inverters. The carbon footprint of transformers is calculated differently. Their number depends on the number of inverters. Nordi has calculated that 14 inverters per one transformer is needed. First, the number of transformers is obtained by dividing the number of inverters by 14 as in formula 4. Then, the total weight of the transformers can be calculated by multiplying the weight of one transformer (kg) by the number of transformers, as shown in formula 5. The result is then multiplied by the emission factor, and the answer is divided by a thousand to get the answer in the desired form (tCO2) as shown in equation 6.

$$N_t = (N_{i,tot})/14 \tag{4}$$

$$m_{t,tot} = m_{,it} * N_t \tag{5}$$

$$CF_{t,m} = m_{t_{tot}} * EF_t \qquad (6)$$

, where N_t is the number of transformers, $N_{i,tot}$ is the total number of inverters, $m_{t,tot}$ is total mass of transformers, m_{it} is the mass of one individual transformer, $CF_{t,m}$ is the carbon footprint of transformers in manufacturing phase, EF_t is the emission factor transformers.

The emissions from manufacturing the racks are calculated the same way as transformers. The number of racks depends on the number of panels. The number of racks is calculated by dividing the number of solar panels by 20. The total weight of the racks is calculated by multiplying the weight of one rack by the number of racks. The total weight of the racks is then multiplied by an emission factor, and the answer is the carbon dioxide emissions caused by manufacturing the racks.

Only one main transformer will be installed per solar power plant. Its manufacturing phase emissions are calculated by multiplying the weight of a single main transformer by an emission factor.

In addition, the emissions from the materials (crushed stone and filter fabric) needed to build the necessary maintenance roads have been calculated. The emissions from the cables and their protective conduits are also included in the calculation. For those the emissions are calculated by multiplying by the length of the cable needed and its cover material with the emissions factors. Nordi has estimated the length to be for both 5701m. The estimation is done for case 2. Emission factor for cable is 25.87 kg CO_2e/m, and for the cover it is 0.19 kgCO2e/m. The same estimation is used in all case examples, as the lengths of the cable routes in different case examples will be specified in a later planning phase.

To calculate the emissions for the maintenance road in manufacturing phase, first the volume (m3) of the material required needs to be determined. The calculations are done for aggregate. The volume (m3) is calculated by multiplying the height, width and length of the roadway together. A protective fabric is placed between the aggregate and the ground, the volume of which is calculated by multiplying the length and width together. The weight of the aggregate is obtained by multiplying its density and volume together. The weight of the aggregate is multiplied by the emission factor, and thus the emissions of the aggregate are calculated. The emission factor of the protective fabric is multiplied by the volume and divided by a thousand to get the answer in the correct unit (tCO2). The initial data is shown in table 7 below.

Table 7. The initial data for the construction of the service road.

	Materials	Density (kg/m3)	Length (m)	Width (m)	Height (m)	Volume (m3)	Emission factor (kg CO_2e /kg) (Syke, n.d.a)	References
Maintenance-road	crushed stone	1500	2500	8	0.5	1000	0.007	SYKE, n.d. a
	filter cloth		2500	8			0.65	SYKE, n.d. a

4.2.2 Transportation

The transport routes for solar panels have been estimated based on current information, and when ordering project components, the situation will be reassessed, and therefore route may differ from the invoices. The components for the projects will have to be ordered from abroad, and the components will be shipped by sea. The shipping routes have been calculated for the port closest to the project, in which the cargo ships can be unloaded.

Solar panels and inverters will be transported by sea on container ships first from Shanghai to Hamburg with travel distance of approximately 20 000 km (Sea-distance, n.d.). After that the ships sail to Finland. Cargo ships arrive at the port closest to the solar power plant in Finland, where container cargo can be received and unloaded from the ships. However, it is not possible to unload ships' cargo in all Finnish ports, so routes must be planned accordingly. After arriving to harbours the components will be transported by semi-trailers (40 t) to the project area by land, here the distances differ between the case examples.

The transformers will come from Hamburg to Finland by sea on container ships, after which the transformers will be transported from the port to the project area on a semi-trailer (40 t).

The main transformers within Finland will be transported by full trailer combination (76 t). The racks will be transported within Poland from Bartoszyce to the port of Gdansk on a semi-trailer, after which they will be transported from Gdansk to Finland on a container ship. From the port to the project area, the racks will be transported by semi-trailer (40 t).

Transportation emissions take into account transportation distances, cargo weights, and the emission factors of the means of transport. The initial data is marked in the to the table 8. The transport vehicles and marking distances are the same in each case example, except where they are specified separately for each case.

Table 8. Vehicles used for transporting components, their travel distances and the emission factors for each vehicle.

Component	Vehicle	Travel distances	Emission factor (kg CO_2e/ton km)	Reference
Solar panels	cargo ship	20 831 km	0.045	SYKE, n.d. a
	semi-trailer (40 t)	Case 1:70km / Case 2: 15km /Case 3:30km	0.082	SYKE, n.d. a
Inverters	cargo ship	20 831 km	0.045	SYKE, n.d. a
	semi-trailer (40 t)	Case 1:70km / Case 2: 15km / Case 3:30km	0.082	SYKE, n.d. a
Transformers	cargo ship	Case 1:1232 km / Case 2:1715 km / Case 3:1432 km	0.045	SYKE, n.d. a
	semi-trailer (40 t)	Case 1:70km / Case 2: 15km /Case 3:30km	0.082	SYKE, n.d. a
Main transformer	cargo ship	Case 1:1232 km / Case 2:1715 km / Case 3:1432 km	0.045	SYKE, n.d. a
	Full trailer combination (76 t)	Case 1:70km / Case 2: 15km / Case 3:30km	0.042	SYKE, n.d. a
Racks	1.semi-trailer (40 t)	Case 1: 768 km / Case 2: 175 km / Case 3:922 km	0.082	SYKE, n.d. a
	cargo ship	Case 1: 768 km / Case 2: 1390 km / Case 3: 922 km	0.045	SYKE, n.d. a
	2.semi-trailer (40 t)	Case 1:70km / Case 2: 15km / Case 3:30km	0.082	SYKE, n.d. a

Carbon dioxide emissions from transportation (T) for each component are calculated as shown in the equation below

$$tkm = m_{tot} * td \tag{7}$$

, where m_{tot}, is the total mass of the components, and td is travelling distance. The result's unit is tkm which is a tonne-kilometre. It is a unit that measures the work of transporting goods.

After the tonne-kilometre is calculated it is multiplied with the emission factor. This is how the carbon emissions are calculated for all the transportations of the components.

4.2.3 Site preparation

Before construction can begin on the project site, the terrain must be prepared so that it can be accessed by construction machinery and equipment. Site preparation includes stump removal, land leveling and round clearing. Depending on each project's certain characteristics, the processes might vary. In addition, any trees and vegetation that could shade the solar panels must be felled at this stage. If the project site is built, for example, in a forest, carbon sinks will be lost as a result of the construction of an industrial-sized power plant. For this reason, Nord's calculation methods include a section that calculates the share of lost carbon sinks, as well as the carbon dioxide emissions of the machinery used for felling trees. The total amount of carbon sinks lost and the emissions from logging equipment depend on how large an area is to be cleared. In addition, the carbon binding is affected by the age of the stand and the condition of the forest.

4.2.3.1 Forest loss

Tall trees or other vegetation that would shade the solar panels will be cleared from the site during the site preparation phase before construction phase can begin. As a result of the site preparation, valuable carbon sinks are also lost, as trees bind carbon as they grow. As part of Nord's carbon footprint calculation, the size of the lost carbon sinks is also calculated, as well as the emissions caused by forestry machinery.

Ministry of Agriculture and Forestry evaluates that there are 22.8 million hectares of forests in Finland (MMM, n.d.), and according to Luke, in 2023 the difference between growth and loss of trees produced a net carbon sink of 13.2 Mt CO_2-eq (LUKE, 2025). These values are used in Nordi's forest loss calculation methods. A forest growth coefficient has been calculated for the forests in each case example project, which is calculated by multiplying the annual growth of the forest by the age of the forest in relation to the average growth and age of Finnish forests. The forest growth coefficient of each case example is marked on the table 9.

First, the amount of carbon dioxide that can be bonded in the forest area of the project area is calculated, and this is expressed in carbon dioxide equivalents. Here, the proportion of forest in the project area (in hectares) is divided by the total number of hectares of forests in Finland, after which the result is divided by a number that corresponds to the amount of carbon bonded in Finnish forests. After this, the result is multiplied by the growth factor of the forest in the project area, so that the result corresponds to the carbon sequestration capacity of the forest in question. The forest lost is calculations are calculated as follows:

First, the amount of carbon bound in the project areas forests is calculated. The forest area is the area of forests that will be cleared, due to the site preparation. It is calculated by dividing the forest area (ha) with the total forest area of Finland (ha), and the this is multiplied with the total amount of carbon bound in the Finnish forests (tCO_2-eq.). The equations is shown below:

$$BC_p = \left(\frac{A_p}{A_{tot F}}\right) * BC_{tot,F} \tag{8}$$

,where BC_P is the amount of carbon bound to trees in the project area, A_p is the forest area of the project area in hectares, $A_{tot,F}$ is the total forest area of Finland in hectares, and $BC_{tot,F}$ is the amount of carbon bound to trees in Finland.

After this the forest loss in the project area can be calculated. This indicates the amount of carbon sink loss resulting from tree removal. It is calculated by multiplying the forest coefficient value with the amount of carbon bound to trees in the project area, which was just calculated in equation 8 above. The forest loss is calculated as follows:

$$FL_p = CO_f * BC_p \tag{9}$$

, where FL_p is the Forest loss of the project area (tCO_2-eq.), CO_f is the forest coefficient, which is specified for each project area, BC_p is the amount of carbon bound to trees in the project area.

Table 9. Initial data for forest loss calculations.

Forest loss	Hectares	Forest coefficient
Case 1 forest area	6.12	0.72
Case 2 forest area	44.52	0.68
Case 3 forest area	25	0.76

The carbon dioxide emissions of the felling machine have also been calculated for each case examples. Emissions have been calculated for the harvest machine and a forward machine. Working hours have been estimated for both machines. The total consumption of the machine is calculated by multiplying the fuel consumption (fuel l/h) by the estimated working hours (logging time, h). After this, the total consumption is multiplied by the emission factor. Initial data can be seen from table 10 below.

Table 10. Initial data for logging calculations.

Logging machine	Fuel (l/h)	Loging time (h)	Emission factor (kg CO^2eq./l)	Referenced
Harvest machine	12.3	Case 1: 8 h Case 2: 100 h Case 3: 16 h	2.3	Estimation based on Kärhä, K., et.al. 2024.
Forward machine	10	Case 1: 10 h Case 2: 105 h Case 3:18 h	2.3	Estimation based on Haavikko, H., 2023.

4.2.4 Construction phase

During the construction phase, emissions from the installation of solar panels, racks, and cables are calculated. In addition, emissions from the earthmoving work have been taken into account. The calculations take into account the emissions of construction machinery and their estimated operating time during the construction phase. A personal lift and a wheel loader have been used to install the solar panels. A piling machine has been used to install the racks, and an excavator (25 t) is used to install the cables.

Each machine is given hours per installed peak power megawatt multiplier. (Hakola, L. 2023.) This is multiplied with the solar power plant's peak power, which can be found from chapter 4.2.1 table 12. Then the result obtained is multiplied by the emission factor, after which it is divided by 1000 to get the result in the correct form (kg CO_2e/h). The initial data for construction is in table 11 below.

Table 12. Initial data for components construction.

Component	Machine	h/MWp	Emission factor (kg CO_2e/h)	References
Solar panels	A person lift	250	7.4	Hakola, L. 2023
	A wheel loader	20	39.4	Hakola, L. 2023
Racks	A piling machine	250	45.3	Hakola, L. 2023
Cables	An excavator (25 t)	18	40.66	Hakola, L. 2023

A truck, a lorry and a van are used for earthmoving work. The driving distances have been estimated for each vehicle. In addition, vehicles have their own emission factors, and these can be used to calculate the emissions caused by earthmoving work. First the emissions are calculated for the weight. The load of the vehicle is multiplied with the emission factor. After this it, the answer is multiplied with the travels distance of the vehicle. The initial data for earthmoving work, is marked in table 13 below.

Table 13. Initial data for earthmoving work.

Vehicle type	Distance (km)	Load weight (kg)	Emission factor (tCO_2-eq./km)	Referenced
Dumper	0.3	78	63	SYKE n.d.a
Truck	0.3	34	52	SYKE n.d.a
Truck	50	15	217	SYKE n.d.a
Van	50	2,7	199	SYKE n.d.a

4.2.5 Operating phase

The use of the solar power plant does not cause emissions, but emissions have been calculated for the need to replace solar panels and inverters, which includes the transportation and installation of components. In addition, emissions have been calculated for maintenance runs, which are estimated to occur three times during the operation of the solar power plant. Maintenance runs are carried out with a van (2.7 t), of which 50% is street driving.

The estimated need for replacement of solar panels is 10 percent. The number of solar panels to be replaced can be calculated by subtracting 10 percent from the total number of solar panels. The weight of the panels to be replaced is then calculated by multiplying the number of panels by the weight of an individual solar panel. The total weight can then be multiplied by the emission factor and divided by 1000 to get the correct form (t CO_2). After this, the emissions for the solar panels are calculated for transportation in the same way as in the previous paragraph. Now only the weight used in the calculation is 10% of the total weight. Otherwise, the route and calculation are the same. After this, the emissions caused by the installation are also calculated, but only for the solar panels to be replaced. The work run quantities of the machines used in the installation have been calculated for the number of solar panels to be replaced.

The current estimated lifespan of the inverters is 20-25 years and since the estimated lifespan of the solar power plant is 25-35 years, the inverters will be replaced at least once during the life of the solar power plant. Therefore, the inverter replaceability rate is 100%. Therefore, the emissions are the same as during the manufacturing and transportation phase for the inverter.

Maintenance trips are made with a van (2.7 t), and 50% of the trips are on the street, which means they drive half of the trips without any load. Maintenance is estimated to occur approximately 3 times per year over the entire life cycle of the solar power plant. Therefore, it is calculated 3 times 35, which makes 105 maintenance trips in total. The total distances caused by maintenance trips can be calculated by multiplying the maintenance distance by the number of maintenance trips. After this, ton km is calculated, which is calculated by multiplying the weight of the vehicle by the total distance, and the result is divided by 1000. After this, ton km is multiplied by the emission factor and divided again by 1000. The result is the emissions caused by maintenance trips in units (t CO_2). Initial data is listed in table 14 below.

Table 14. Initial data for carbon footprint calculations of the maintenance work.

Maintenance	Weight (kg)	Travel distance (km)	Number of maintenance trips
Van (2.7t) 50% of the trips is without any load	1350	Case 1: 16 Case 2: 19 Case 3: 12	105

4.2.6 Demolition and recycling

Emissions from the dismantling phase have been calculated for all components. A forklift, wheel loader and semi-trailer (40 t) are used to dismantle the solar panels. An excavator (25 t), a semi-trailer (40 t) are used to dismantle the racks. A semi-trailer (40 t) is used to dismantle the inverters and transformers. A full-trailer combination (76 t) is used to dismantle the main transformer. Emissions from the recycling of all components have also been calculated.

Emissions from dismantling the solar power plant have been calculated in the same way as during the construction phase. For a personnel lift and wheel loader, as well as an excavator, the working hours are calculated by multiplying the value of the working machine (h/MWp) by the peak power of the solar power plant. The result is multiplied by the emission factor. For the rest of the vehicles/machines, the tonne-kilometre (tonn km) value is calculated by multiplying the distance driven by the total weight of the components and the result is divided by 1000. Finally, the result is multiplied by the emission factor. The initial data can be found in table 15.

Table 15. Initial data for demolition and recycling phase.

Component	Vehicle/machine	(h/MWp)	Travel distance (km)	Emission factor (tCO_2-eq.)	References
Solar panel	Personnel lift	125	-	7.4	SYKE n.d.a
	Wheel loader	10	-	39.4	SYKE n.d.a
	Semi-trailer (40 t)	-	100	0.82	SYKE n.d.a
Racks	Excavator (25t)	125	-	40.66	SYKE n.d.a
	Semi-trailer (40t)	-	100	0.082	SYKE n.d.a
Inverters	Semi-trailer (40t)	-	100	0.082	SYKE n.d.a
Transformers	Semi-trailer (40t)	-	100	0.082	SYKE n.d.a
Main transformer	Full trailer combination 76 t	-	100	0.042	SYKE n.d.a

Emissions from recycling components are calculated by multiplying the total weight of the components by an emission factor. The emission factors are listed in table 16 below. Instructions for calculating the total weight of components can be found in section 4.2.

Table 16. The emission factors for recycling of the components of solar power plant.

Components	Emission factors (tCO_2eq.)	References
Solar panels	0.579	Sunpower, 2021
Racks	0,0246	SYKE, n.d.c
Inverters	0.317	SYKE, n.d.c
Transformers	0.287	SYKE, n.d.c
Main transformer	0.287	SYKE, n.d.c

4.3 The habitat hectare

The Finnish Nature Panel published in 2023 a report titled "The importance of nature goals, indicators and the choice of a reference state", which introduces the concept of the Habitat hectare, also known as the natural value hectare (Lakka et al., 2023). This indicator expresses the proportion of natural state remaining in a given area on a scale from 0 to 1, where 1 represents a fully natural state and 0 indicates complete degradation. One Habitat hectare corresponds to one hectare of fully natural Habitat of the same type. For example, if a hectare's condition is estimated at 0.35, about 65% of its natural value has been lost. The measure provides a general overview of an area's ecological condition, using structural features relevant to species occurrence such as the amount of deadwood in Forests or the water level in bogs as proxies for biodiversity. It enables comparisons of environmental damage and restoration (ecological footprint and handprint) across Habitat types and can also be used to estimate an organization's regional environmental impact (Lakka et al., 2023).

According to the Ministry of the Environment's decree on voluntary ecological compensation, the hectare of natural value is equivalent in definition and calculation to the Habitat hectare. It represents the natural value per hectare of an area compared to one in a fully natural state (Lakka et al., 2023).

Finsilva (n.d.) further explains that a natural value hectare combines both the quantity and quality of biodiversity into a single comparable value, much like how different greenhouse gases are converted into CO_2 equivalents. It serves as a standardized measure in voluntary ecological compensation and natural value markets, used to assess the loss of natural values and determine compensatory actions before developments, i.e. solar power parks, are implemented.

First, the habitat types occurring in the project are determined and their characteristics are listed according to the instructions in the report. After that, the natural condition of the habitat types is estimated and given a value between 0 and 1 depending on the state of the habitat. The condition classes and their descriptions of the ecological status of natural habitats can be seen in table 17 below. The characteristics of the habitat types receive a coefficient of 1 or 2 depending on its significance. The characteristics of primary importance receive a coefficient of 2 and secondary ones receive a coefficient of 1.

Table 17. Condition classes and their descriptions of the ecological status of natural habitats. (Jalkanen, J. et.al. 2025.)

Habitat status value	Description of the state of the nature
0	Not a nature type
0.1	Very weak
0.3	Weak
0.5	Moderate
0.7	Good
1	Excellent

When assessing the ecological status of a habitat type, a condition class is assigned to each habitat type pattern on a ten-point scale from 0 to 1 (Finlex. 2023.d. 933/2023). A value of 0.1 indicates that the habitat type is very severely degraded, while a value of 1 represents a natural or comparable state of the habitat type. (Hoikkavaara, 2025.) The habitat types used to assess the ecological status of habitat type groups can be seen in table 18 below.

Table 18. Indicators used to assess the ecological status of habitat type groups. (Jalkanen, J. et.al. 2025.)

Habitat type group	Indicators used to assess ecological status
Forests: Esker forest	Development class (2), presence of tree structure features characteristic of the habitat type (2), amount of dead wood (2), representativeness of vegetation (1), number of robust trees (1), harmful alien species, other human impacts (1)
Forests: Barren pine heath	Development class (2), presence of tree structure features characteristic of the habitat type (2), amount of dead wood (2), representativeness of vegetation (1), number of robust trees (1), harmful alien species, other human impacts (1)
Forests: Dry heath forest	Development class (2), presence of tree structure features characteristic of the habitat type (2), amount of dead wood (2), representativeness of vegetation (1), number of robust trees (1), harmful alien species, other human impacts (1)
Forest: Herb-rich spruce swamp forest	Representativeness of bog vegetation (2), water management, relationship of bog to the environment (2), structure of the tree stand (2), amount of decayed wood (1), other human impacts (1)
Forest: sub-dry heat	Development class (2), presence of tree structure features characteristic of the habitat type (2), amount of dead wood (2), representativeness of vegetation

	(1), number of robust trees (1), harmful alien species, other human impacts (1)
Mires: Slightly drained peatland forest	Representativeness of bog vegetation (2), water management (2), relationship of bog to the environment (2), structure of the tree stand (2), amount of decayed wood (1), other human impacts (1)
Mires: Sedge aapa mire	Representativeness of bog vegetation (2), water management (2), relationship of bog to the environment (2), structure of the tree stand (2), amount of decayed wood (1), other human impacts (1)
Rock: Rock outcrop area	Representativeness of vegetation (2), rock morphological diversity (2), other human impacts (1)

In table 18 above, after the indicators there is marked either the number one or two in brackets. The number indicates the coefficient of the natural value, (2) corresponds to the primary coefficient metrics and (1) is the secondary coefficient metrics.

When the condition evaluations are done, the value of the ecological condition of the habitat pattern can be calculated. From the formula 8 below the simplified way of the calculation of the ecological condition value is shown. For this thesis the natural condition of the project areas has been assessed by Nordi’s employee who is a specialist in nature issues. The assessments of natural conditions are based on site visits, map images, and various survey reports. The nature values of the projects have been assessed in accordance with the *Luontotyyppien ekologisen tilan arvio ekologisessa kompensaatiossa* (Jalkanen, J. et al, 2025).

$$ECV = \frac{2*(\sum pcm) + \sum scm}{(2*N_{tot,pri}) + N_{tot,sec}))} \quad (9)$$

, where EVC is the ecological condition value, pcm is primary coefficient metrics, scm is secondary coefficient metrics, $N_{tot,pri}$ is total number of primary coefficient metrics, $N_{tot,sec}$ is the total number of secondary coefficient metrics.

After that the number of habitat hectares is calculated by multiplying the ecological condition value with the area size in hectares. Since in the case examples used in this thesis the solar power plants are sited on human-altered areas with low existing natural values, it is preferable for the initial habitat hectare score to be low. In such cases, ecological construction practices can even enhance the area's biodiversity, while minimizing stress on the local ecosystem. Moreover, by taking the calculations further, habitat hectare calculations can be used to determine the need for ecological compensation if biodiversity is negatively affected by the solar power development. From the equation 9 below the simplified way of how the habitat hectare is calculated can be seen.

$$Number\ of\ habitat\ hectare = Ecoloical\ condition\ value * area\ of\ the\ habitat\ type \tag{10}$$

4.4 Case examples

This chapter examines three real solar power projects from Finland, which are built on different types of areas. All case examples are planned to be built on a human-altered area, which means that the areas have been modified due to human action to a point that it has no other use. The natural values of the areas are low compart to natural state environment. This chapter examines each case study and gives deeper understanding of their natural values and the environmental state of the areas. This section works as a basis for the habitat hectare calculations.

The information provided in this section is based on Nordi's own materials, to reports commissioned by the company or to the company's own reports. The information between the case examples is different scope and different issues may have been studied in different project areas, which means that the same information has not necessarily been taken into account for each project. From figure 13 below the locations of the case examples can be seen. The exact location of the project is not provided as not all of the projects are public yet. It is also important to mention that some projects have been developed longer than others, and for this reason more studies have been conducted on them.

Figure 13. Case examples on the map.

4.4.1 Case 1

Case example one is located in Satakunta and the planned project area is approximately 90 hectares. The project's planned capacity is 43 MW. The project area is strongly human altered area as the area is former earth material extraction site, and the extraction of raw materials has been carried out for several decades. The area is on top of a groundwater area. The area has not been restored. In terms of landscape, the area constitutes extensive landscape structure cannot be fully repaired because large land masses and with them landforms have been removed. Therefore, by building a solar power plant to the area it might even have a positive effect on the area's biodiversity.

The area is on top of a gravel ridge, and its soil mainly consists of coarse-grained soil material. There are mixed soil material and bedrock, where the soil cover is generally a maximum of one meter. The area is uneven and due to the former purpose of the area it has no organic material growing there. The extraction activities are coming to an end in most of the area.

In the project area, there are still some unsorted soil and larger batch of sorted coarse gravel, as well as screened tailings and rock material have been left in the area. In addition, the project developer has purchased soil from the western edge of the ridge, which will result in approximately 20 000 m3 of coarse screened gravel and topsoil. Concrete gravel will be screened out of this soil before it is transferred to the project developer for use in filling the bits and evening out the shape of the area. The remaining earthen piles in the area will be used to raise the ground surface of the deepest parts. The soil can be used to shape the surface structure of the area with soil types of natives to the area without any soil types imported from afar.

The surface waters in the area flow into the near river and the quality of the river is satisfactory. The area is located on top of two groundwater areas. The 1st groundwater area is formed by a longitudinal ridge valley approximately 6 km long, which is bordered by rocky ridges in some parts. The area is uneven, and the ridges consists of gravel and sand, while the edges are comprised of silt and clay. Groundwater’s flow into the lake next to it. Groundwater also partially seeps out at the edges of the ridge.

The vegetation of the area is typical of the altered heaths of a material extraction site and the shrub vegetation of dry uplands. Willows, bilberries, lingonberries, crowberries, heather, and sedges can be found in the older parts of the area, but most of the area has been outside of material extraction for such a short time that no vegetation has had a chance to develop on the coarse sand. Only little bit of cat’s foot (Antennaria diocia) was found among the heath-loving species, but it is assumed that a richer variety exists on the edges of the area. Hawkweeds (Hypochaeris maculata) and wild thymes (Thymus serpyllum) are almost completely missing, and it would be good to transfer to the area or highlight their populations during production. Other sun-lit species would also be a very good addition to the area, and the heat tolerance should be emphasized when planning production.

The vegetations that needs to be taken into account are on the mineral extraction site, as well as patches of forests located at its edges. After the ending of mineral extraction activities, the area has naturally regenerated into young managed forest and samplings, which have only been partially maintained according to forest management recommendations.

The forested patches in the central and southeastern parts of the study area are classified as young managed forests and seedlings of fresh mineral soil. There are very fer mature managed forest patches, and they are quite small size. In the southeastern part, there is a small amount of regeneration-ready dry mineral forest.

The environment of the project area mainly consists of mature or young managed forests of fresh dry sandy substrate, but also somewhat of seedling stands. The western edge of the project area borders two regeneration-ready forests of fresh sandy substrate, as well as in the shouter part of the area, on its southwestern side, there is a mature deciduous sandy area and a very small plot of mature/regeneration-ready deciduous forest.

The representativeness and potential of the latter plots are habitats for demanding species will be investigated alongside natural assessments conducted in the area, as well as the extent to which the study area includes vegetation of sun exposed habitats- in areas where minerals extraction has already been discontinued for a longer period.

In the area of the preliminarily planned underground cable route and the preliminary location of the substation, the forests primarily consist of mature fresh and deciduous sandy substrates. There are also small portions of seedling stands and young forests. In particular, the representativeness and potential of the mature, more lush forest patterns as a habitat for demanding species such as flying squirrel, will be examined in connection with the nature studies conducted in the area.

After a site visit and some research, it came apparent that the area has functioned as an unofficial landfill for some time, and as a result, now the edge of the project area is home to approximately 5 hectares of apple trees, cherry trees, and silver willows, as well as other species that have spread from gardens. Large patches of harmful invasive species, giant balsam and especially giant hogweed, are growing around them. Their management and removal must be taken into account during the area’s construction work. Lupines grow all along the road, and they have also spread to the gravel extraction area. For these reasons, it is likely that a large portion of the eastern edge’s slope and surrounding area will need to be removed from all areas where foreign biomass is found. This soil material must be handled properly.

There are no known other endangered or protected species from the planning area or its immediate vicinity, apart from the bird observation mentioned below. There are also no sights of species listed in Annex IV A of the habitat Directive within the planning area or its surrounding area (within 1 km).

According to Laji.fi data, there have been species such as the Eurasian owl (EN) and the sand martin (EN) in the planning area or its vicinity, which are endangered bird species and species listed in Annex I of the Birds Directive, as well as the nightjar and the woodlark (NT), which are also listed in Annex I of the Bird Directive.

The breeding bird population in the vicinity of the planning area, the proposed underground cable line, and the nearby substation area will be studied in connection with the environmental assessment which will be made later. This will ensure that potential breeding areas for sand martins on the slope of earth material extraction sites are adequately considered in the project, for instance, in the placement of panels and the underground cables, as well as in the scheduling of construction activities, taking into account the nesting season of the species.

Groundwater protection in Finland is based primarily on the prohibition of groundwater pollution in §17 of the Environmental Protection Act (YSL, 527/2014) and the prohibition soil pollution (YSL §16), which protect the quality of groundwater from pollution, groundwater may not be polluted or its quality endangered. The prohibition of pollution has been specified in the Government Decree on Substances Harmful and Hazardous to the Aquatic Environment (1022/2006), §4a of which provides for a prohibition of discharges into groundwater (Ympäristöministeriö, 2023).

Depending on local conditions, such as the soil and bedrock and the height of the groundwater table, changes in groundwater quality and flow may occur during the construction phase.

The solar power area will be partially covered with crushed stone, as well as green and maintenance corridors, so the solar power area is not expected to have significant impacts on groundwater levels. The crushed stone will have a positive impact on ground water by acting as a protective layer. During operation, the solar power plant is not expected to have any impacts on groundwater, depending on maintenance measures.

During the dismantling phase, the impacts on groundwater are similar, but smaller than during the construction phase, depending on weather the panel foundation are removed from the soil.

The construction of solar powerplants will not have an impact on the water intake located in the groundwater area and its possible expansion, as the water intake is located far away, at the closest point approximately 2 km from the solar power plant.

The solar power plant area is mostly bare ground, but there are also young plantation forest, saplings and scrub. The construction of the solar power plant will cause adverse quality effects on surface water during construction and in the years after construction, until the new soil settles. The adverse quality effects arise due to the soil preparation and the varying elevations of the terrain. The elevation difference will increase erosion in the area, which will worsen, the solids load on surface water. On the other hand, in the longer term, the quality of stormwater in the area may improve, as the current bare ground will be transformed into a more water-retaining undergrowth and the plants used will be grasses characteristic of the ridge area.

Table 19 below lists the habitat types in the area, their assessment of their natural condition, the value given to the habitat type, and the total number of hectares of the habitat type in the area. Only those habitat types are included that occur in the area where the power plant will be built and that will be affected by the impacts caused by the construction of the power plant.

Table 19. Evaluation of the habitat types in the area of case 1.

Habitat type	Evaluation	Habitat status value	Number of hectares per habitat type
Eskers forest	The habitat has almost completely disappeared due to logging, no trees, no dead trees, isolated species of sun-lit species, no robust trees, there are many harmful alien species in the area, the area has been completely transformed into a gravel extraction area	0.12	41
Barren pine heath	The area's trees have been felled for gravel extraction, the native species have almost completely disappeared, no trees, no dead trees, isolated sun-lit species, no robust trees, harmful alien species have spread to the area, the area has been significantly modified due to gravel extraction activities	0.17	1.2
Dry heath forest	The area's trees have been felled for gravel extraction, the native species have almost completely disappeared, no trees, no dead trees, isolated sun-lit species, no robust trees, harmful alien species have spread to the area, the area has been significantly modified due to gravel extraction activities	0.18	2

4.4.2 Case 2

The project is located on a former municipal waste landfill and is approximately 65 hectares in size. The maximum output of the solar power plant is 54 MWp. The solar power plant consists of panels, their racks, step-up transformers and inverters. In total, an estimated number of panels is 75 000, 9 step- up transformers and 126 inverters, will be installed to the area. The closing structures of the closed landfill located in the area have been taken into account in the planning.

The nature of the study area consists mostly of young pine-dominated forests in forest commercial forests; drained bogs and a low deciduous-dominated seedling stand under the power line. Part of the project area is a former landfill, which is in the pioneer stage of secondary succession, i.e. dominated by milkweed and other herbaceous plants.

The area includes the Small Open Marsh, surrounded by old drainage ditches. The marsh is a mixture of different bog types in a small area, from sedge swamp to grassy sedge swamp. There is also a large open bog, which is otherwise in a natural state, but there is a small ditch next to the train tracks. The bog below the existing power line has been preserved in an almost natural state. The bog also contains more demanding species, such as the protected marsh moorhen. A narrow moorland remains next to the existing power line, which on one side blends into the eastern bighorn sheepshead and on the other side is exposed to the large edge effect caused by the line.

Two invasive species are growing in the area, the lupine and the shepherd's purse, the first of which is classified as a harmful alien species. According to Section 3 of the Act on the Management of Risks from Invasive Species (2015/1709), the release of all alien species into the environment is prohibited. Therefore, all alien species, including those classified as non-harmful, must be taken into account when handling soil to prevent assisted spread. In addition, repeated mechanical control is recommended, for example by cutting off inflorescences or digging up plants with their roots.

Table 20 below lists the habitat types in the area, their assessment of their natural condition, the value given to the habitat type, and the total number of hectares of the habitat type in the area. Only those habitat types are included that occur in the area where the power plant will be built and that will be affected by the impacts caused by the construction of the power plant.

Table 20. Evaluation of the habitat types in the area of case 2.

Habitat type	Evaluation	Habitat status value	Number of hectares per habitat type
Sub-dry heath forest	The area is a pre-thinned commercial forest, the area is a normal even-aged commercial forest, few dead trees, vegetation is typical for the habitat type, some robust trees on the northern edge, no alien species, normal signs of human activity	0.41	36.5
Slightly drained peatland forest	The area is a pre-thinned commercial forest, the area is a normal even-aged commercial forest, few dead trees, vegetation is typical for the habitat type, some robust trees on the northern edge, no alien species, normal signs of human activity gravel extraction activities	0.59	1.9
Sedge aapa mire	The representativeness of the mire's vegetation is quite good, the open bog is rather dry due to the drainage of the surrounding area, the water management is weak, the bog's relationship with the environment is good, the bog is slowly turning into a peat fabric, the bog is drained, no other signs of humans	0.59	1.9

4.4.3 Case 3

This project area is approximately 70 hectares, and it consists of municipal’s former waste landfill, former ash disposal area used by a coal-fired power plant, and a forest plot which underwent a regenerative logging before the project developer was interested in the area. The former landfill area and the former ash disposal area were closed in 2023. 30 hectares of the area are areas that have been used as landfills or storage areas. A little less than 15 hectares of trees were cut down in 2022, and the remaining 25 hectares is almost entirely unmanaged forest on the property of the storage area.

The planned peak power of the project is 60 MWp. The final power will be specified during the planning phase, where the placement possibilities of the panels will be clear. This depends on the landfill's heap closure structures and other aspects of the terrain. The preliminary number of panels is 86 000.

The forest bordering the area are lingonberry and blueberry type mineral soil (VT and MT), which are in intensive forestry use. The mineral soils are rocky and in places there are also exposed rocks. There are no bogs at all in the planning area and the forests in the area are only slightly swampy in the southern parts of the project area. There are some fresh type peat soils on the edges of the area. The landfill and ash disposal areas do not have any special natural values. During their operation, the impacts on the environment have been monitored by various monitoring obligations.

The area's edge forests, consisting of saplings and young plantation forests, will be cleared to maximize the size of the panel area and due to shadowing effects. The forests in the area are seedling stands and young nurseries. As the owner of the area, the city has expressed its willingness to cut down the forests that are owned by the city. The forests owned by private individuals have not been marked as natural sites. There are some trees left standing, and their faith will be evaluated in the planning process.

Part of the project area has previously been subject to nature assessment during EIA process implemented by previous project developer. In addition, Nordi conducted several site visits. Based on the reviews, the area does not have significant nature values, and no significant nature impacts are expected from the operations. The former landfill and the ash disposal area have been in industrial use for long time. The area is bordered by forestry land in economic use from all directions. There have been no findings of any nature conservation areas, valuable and protected habitats pursuant to section 10 of the Forest Act, or observations of protected species.

There are no nature reserves or endangered species in the immediate vicinity of the planning area. Approximately one and a half kilometres to the south from the edge of the site, there is 135-hectare field, which was added to the Natura 2000 network as a SPA in accordance with the Birds directive by a government decision in 2005 (FI0800162). The area is protected by the Land Use and Building Act, as well as a management and use plan agreement made in cooperation with the landowners.

As the area will be cleared from tall vegetation to minimize shading effects and to maximize light access to the panels, not all vegetation will be cleared in the area. In these open areas sun-lit plants thrive, as they require a lot of light and tolerate heath. They suite well with solar power plants as they do not grow tall and therefore do not shade the panels. As the panel area may in the future attract many insects that like hot environments, and from their perspective, it is worth keeping the area hot and open.

Impacts on birds will be minor. Based on the tern study, the area has a normal bird population, and no special protected species have been observed except occasionally. The forest cut down on the western edge of the area would have possibly been popular with nesting birds, but now that the logging area is cleared, the impact has been eliminated, expect from the conservation trees. Nordi's goal was to try to save individual large deciduous trees and groups of conservation trees, if they do not pose a threat to electrical safety. In the former ash disposal area no major species changes are expected, but the interest of the birds towards the area will be taken into account in the planning of the project, for example, the clearing work can be carried out outside of the breeding season. The old structures of the area has formed areas some animals use e.g. a former equalization pond serves as a resting place for small sucks, and at least one pair of tern's nests in the pond.

No significant species of invertebrates and amphibians have been observed in the area, but monitoring and observation will continue and, if necessary, the situation will be responded to together with the city and other authorities.

Fencing the area may affect the passage routes of the animals, but according SRVA-Suurriistavirka auxiliary statistic, no deer, wild boar or large predator collision accidents have been in the planning area. (SRVA, n.d.) However, the animal passageways are the natural depressions at the edges of the area. According to the statement of the area's Game Management Association, the area will not have significant impacts on the routes of game animals, and there will be no particularly significant impacts on local populations in the planning area. The ecological connection need is fulfilled on the north and south sides of the area. In addition, the choice of fence structure can take into account the passage and under passing of small animal. (TASSU, n.d.)

According to the environmental assessment, there are no natural or similar streams or rivulets in the area, but the watercourses in the area are heavily man-made ditches. The area contains an equalization basin for the ash disposal area, which was built in accordance with the requirements of the permit documents by the former operator. The basin is asphalted at the bottom, reinforced and supported by earth masses. The basin structures were last inspected in 2019. The waters in the basin are filtered through the filtration bank in the direction of adjacent highway along the ditch and the flow of the ditch is low. The filtration efficiency has been monitored, and the filtration efficiency has been found to be efficient based on studies made in the area. The earth masses in the filtration bank may have to be partially replaced in the coming decades if the filtration efficiency weakens or the nutrient load is found to increase during further monitoring. The basin also has an overflow pipe in case of possible flood events and based on the permit from the Centre for Economic Development, Transport and the Environment (ELY), the overflow waters have also been led along the ditch towards the field area and the river if necessary. The water quality in the area is still being monitored through sampling.

The second channel leading away from the area starts from the south of the area, mainly to drain forestry waters, but possibly to a small extent also influenced by the waters of the planning area. The channel network starts 300-meter south of the planning area and leads south from the southern edge along two small channels, where a previously dug settling basin or water protection wetland can be found on the edge of the field clearing along the path of the second channel. The second channel continues east along field channels to the river. These channels receive their nutrient load mainly from forestry runoff and from the fields, and it is not assumed that the panel area will have any impact on the situation of this channel network. Although the project area of the solar power plant is larger than the area estimated for ash disposal, the channels are the same.

The ditch on the western side of the area is the only channel leading away from the area, and its monitoring will be important in the future due to the old use of the area and the logging on the western side of the highway. If the filtering and retaining effect of the forest is removed, it can be assumed that the water runoff will increase slightly in the existing ditch. Based on observations and during the monitoring of the former operator, no flow has been observed through the southern ditch, which would start from the design area. Since the solar panels or the construction work of the panel area does not extend into the area, it is not plausible that the flow or nutrient load of the southern ditch will increase after few years. The forests on the southern side of the area are intensively managed, but most of the patterns have been processed and the effect of the trees will even out the flow at the beginning of the ditch.

With the increasing emission-free and renewable electricity production, the project promotes the transition to a low-carbon society, which is in the line with national land use goals. As stated earlier the old landfill and the ash disposal area have been in industrial use for a long time. Even after the closure process, the possible further uses of the area a very limited, as the protective structures installed during the closure work must not be damaged, and for example, no forest may grow on top of them. Establishing a solar power plant is an area that has already been put into industrial use and has been heavily modified by humans is in line with the principals of the circular economy. The project will be able to utilize the existing infrastructure very efficiently: the implementation pf the project does not require the expansion of the road network or a new power line. The Orpo’s government program also hopes that solar power construction will be located in the human altered areas and wastelands so that significant use of fields and forest land in energy production is avoided.

Table 21 below lists the habitat types in the area, their assessment of their natural condition, the value given to the habitat type, and the total number of hectares of the habitat type in the area. Only those habitat types are included that occur in the area where the power plant will be built and that will be affected by the impacts caused by the construction of the power plant.

Table 21. Evaluation of the habitat types in the area of case 3.

Habitat type	Evaluation	Habitat status value	Number of hectares per habitat type
Barren pine heath	Pre-thinned commercial forest, normal even-aged commercial forest pattern, some solid deadwood, typical field vegetation, individual robust trees, no alien species, normal traces of human impact	0.45	6.5
Dry heath forest	Typical commercial forest stand, pine-dominated but mixed with deciduous trees and spruce, unthinned stand, but not particularly representative, low number of deadwoods, Typical field vegetation of commercial forest pattern, no large trees, no invasive species, traces of clear-cutting visible in the northern edge, no alien species, normal signs of human activity	0.54	18
Herb-rich spurce swamp forest	The area is rich in nutrients, the vegetation is quite representative, but clear-cutting has destroyed the shade trees and taken away the special features. There are many ergots and insects dependent on them along the ditch. This special species has been promised to be preserved, the natural stream was opened up at one time but could still be restored. The lower part was drained during logging, the area was affected by water. The area has been clear-cut, no longer representative as a site, no remaining trees, hardly any standing wood, the area has been logged and drained	0.32	6.5
Rock outcrop area	Partially moderately representative rock cover and slope vegetation, barren-like fabric on the rock, Rock formations varied, several rock types, Rock edge quarried	0.60	2.8

5 Results and discussion

This section examines the results of carbon footprint calculations, as well as the results of habitat hectare calculations. First, the results of carbon footprint calculations are discussed case by case, after which the results of the projects are compared with each other. After this, the results of habitat hectare calculations are discussed case by case, after which the results of the projects are also compared with each other.

Section 5.1 of this thesis focuses on carbon footprint calculations and addresses these research questions: how can the biodiversity impacts of industrial-scale ground-based solar power plants be evaluated, How much CO_2 emissions are generated throughout the life cycle of solar power plants, and how biodiversity impacts differ between projects built on commercial forests and those located on human-altered areas. The analysis provides an overview of emissions of each life-cycle phase, highlighting the phases that contribute most significantly to environmental pressures.

Section 5.2 presents habitat hectare calculations, which directly address the questions of how biodiversity impacts can be evaluated and how the biodiversity of a project area can be improved. By assessing the current ecological condition of project areas, these calculations offer insights into potential measures to enhance habitat quality and a foundation for the planning of compensation or restoration actions that can mitigate negative impacts and, in some cases, generate positive ecological effects.

Finally, Section 5.3 discusses the limitations of the calculations. Both the carbon footprint and habitat hectare assessments rely on data that are limited or uncertain, particularly regarding emissions from component manufacturing and site-specific ecological parameters. As a result, the findings should be interpreted as indicative, providing guidance for evaluating and managing biodiversity impacts rather than precise quantitative predictions.

5.1 Carbon footprint

5.1.1 Case 1 – carbon footprint

As mentioned in chapter 4.4.1, case 1 is former gravel extraction site, and therefore the area is strongly modified by human action. The natural values of the area are low due to its former purpose. The project area is approximately 90 hectares. The forest area that needs to be cleared before construction work can start is approximately 4 hectares.

The life cycle carbon footprint of Case 1 solar power plant is in total of 43151 t CO_2. This includes everything from the manufacturing phase to disassembly and recycling. The most emitting phase is the manufacturing of the components. The carbon footprint of each phase of the life cycle of the solar power park can be seen from table 22. below.

Table 22. The carbon footprint of each phase of the life cycle of the power plant.

Phase	GHG emissions t CO_2-eq.	Percentages
Manufacturing	36 385	84.8%
Transportation	2311	5.4%
Construction	871	2.0%
Operation	3124	7.3%
Disassembly	460	1.2%
Total	43 151	

Manufacturing has the most significant carbon footprint, and in this phase the solar panels cause most of the carbon footprint because they are needed in such significant quantities for an industrial-scale power plant. The emissions during operation phase come from the components that need to be replaced. These components are inverters and some of the solar panels. For example, the lifespan of inverters is 15-25 years, which means that when compared to the lifespan of a solar power plant (25-35 years), inverters need to be replaced at least once during the life of the power plant. Therefore, their replacement requirement has been calculated as 100%. Emissions of new materials of components and emissions from transportation are included in the emissions of inverters. In addition, the need to replace solar panels has been estimated to be at 10%, in case panels break down. This carbon footprint from solar panel materials and emissions from transportation and installation are also included in the operation phase. Otherwise, no emissions are generated during operation of the power plant, and the power plant is almost completely maintenance-free. However, the calculations include a few maintenance visits over the entire life cycle to make the result as realistic as possible. During the demolition phase, emissions are generated from the use of machinery and vehicles required for demolition. In addition, CO_2-emissions from the recycling of components are included in this phase.

During the manufacturing phase, the most significant carbon footprint comes from manufacturing the solar panels. This is because significant quantities of panels are needed for industrial-scale solar power plants. The CO_2 emissions from the transformers and the main transformers are calculated together. However, the result is only indicative, as there is no precise information about the manufacturing stages and the emissions they generate. The number of racks is also significant because their number depends on the number of solar panels. This also causes the emissions generated from their manufacture. CO_2 emissions from the manufacturing of components of case 1 can be found in figure 14.

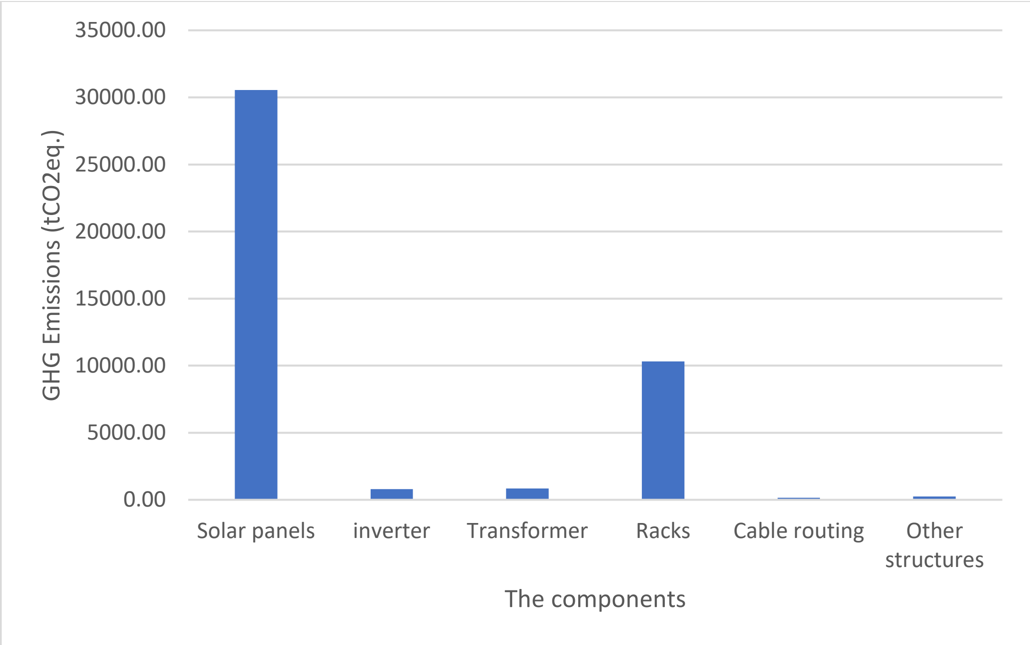


Figure 14. The carbon footprint of the components of case 1.

Before the construction work can start, the site preparation must be done. The CO_2 emissions from land use changes due to the site preparation and CO_2 emissions from mandatory felling of trees have also been taken into account. These are compared with emissions during the life cycle of the solar power plant in the figure 15 below. The figure illustrates that land use changes and forest clearing do not cause significant emissions compared to the emission caused by the building of the power plant. It can also be noted that harmful effects are only temporary, as the largest emissions from the power plant occur early in the plant's life cycle.

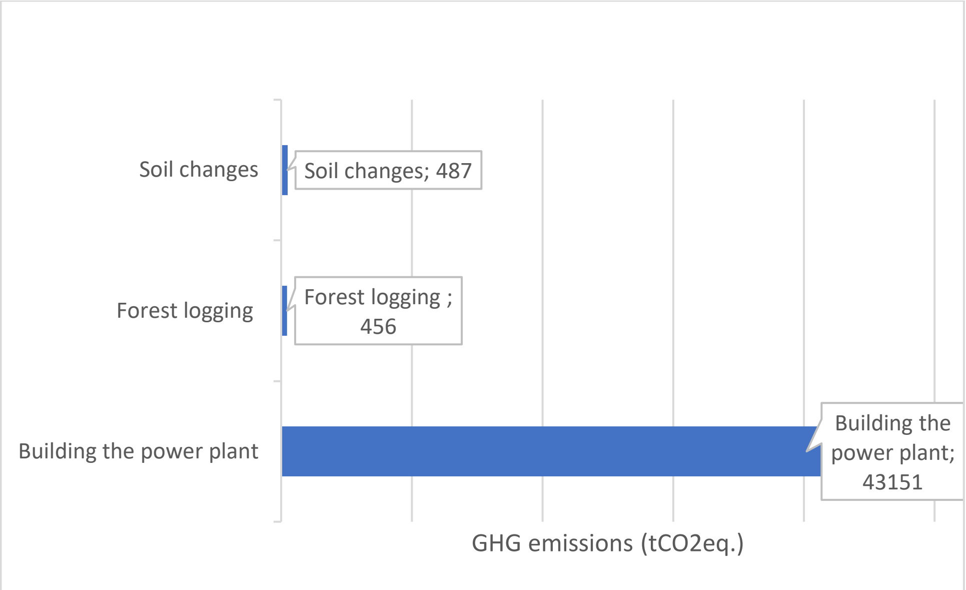


Figure 15. Different emission sources in comparison.

For the case 1 the calculated loss of carbon sink due to logging is 2,41 t CO_2-ekv. The forest area that needs to be cleared is approximately 6,12 hectares. The clearing work must be done to prevent the trees from shading the solar power panels and to get the maximum amount of sunlight. In order to see how significantly carbon sinks are saved when a solar power plant is built on an area already modified by humans, carbon sink loss was calculated for two scenarios. Scenario 1 is the real scenario, meaning that in this scenario can be seen how significant carbon sink is lost as a result of the tree removal for the project in question. That is, when a power plant is built on an area that has already been modified by humans. Scenario 2 is a hypothetical situation, where we imagine that the entire project area is forest that will be cleared to make way for the solar power plant. In real life scenario the carbon sink loss is 2,41 t CO_2-eq. Compared to the hypothetical situation if the project area of 90 hectares was entirely forest and it had to be cut down to make way for the solar power plant, the calculated carbon sink loss would be 36.27 t CO_2-eq. The comparison of these two scenarios can be seen from the figure 16 below.

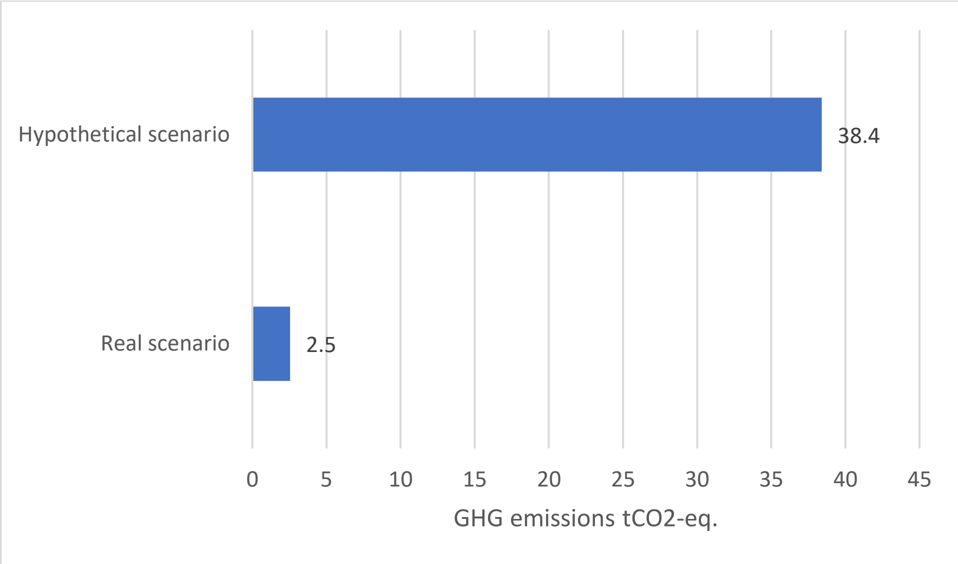


Figure 16. Carbon sink loss comparison between hypothetical and real scenarios of case 1.

Finally, based on the information obtained, emissions per megawatt produced can be calculated. The initial data is tabulated in table 5, including the annual production of the power plant and the power of the power plant from which are from Nordi's own materials, and carbon dioxide emissions are based on the calculated results, and for case 1 the amount is 42912 tCO2 eq. The working life of the solar power plant is estimated to be approximately 30 years.

The unit conversion is done by first calculating the emissions per MWp by dividing the power of the plant (MWp) by the total emissions ($tCO_2eq.$). After this, it is converted to kilograms by multiplying the answer by 1000. After that, the energy produced is calculated for the entire life cycle by multiplying the power plant power by the number of years in its life cycle. Finally, the life cycle emissions are calculated by dividing the total emissions (kgCO2) by the energy produced during the life cycle (MWh), and the converted to g CO2/kWh. The results are listed below in table 23.

Table 23. Emissions calculated per MWh.

Case 1	Amount	Unit
Emissionsa per MWp	991	t CO_2/MWp
Energy produced during the life cycle	1255470	MWh
Electricity production emissions during the life cycle	**34.2**	**g CO_2/kWh**

5.1.2 Case 2 – carbon footprint

As mentioned in chapter 4.4.2, the case 2 is located on a former municipal waste landfill and is approximately 65 hectares in size. Due to the area's former purpose, the natural values are low. There is approximately 42,4 hectares of forest area that need to be cleared before construction work can start.

The life cycle carbon footprint of Case 2 solar power plant is in total of 53 947t CO_2. This includes everything from the manufacturing phase to disassembly and recycling. The most emitting phase is the manufacturing of the components. The carbon footprint of each phase of the life cycle of the solar power park can be seen from table 24. below.

Table 24. Carbon footprint per life cycle phase of case 2.

Phase	**GHG emissions (tCO_2-eq.)**	**Share (%)**
Manufacturing	45402	84.2%
Transportation	30314	2.6%
Construction	1031	1.9%
Operation	3935	7.3%
Disassembly	566	1.1%
Total	53 947	

As in case example 1, the manufacturing phase has the most significant carbon footprint, and this is also due to the significant quantities required for solar panels. The emissions during operation phase come from the components that need to be replaced. The components that require replacement during the life cycle and the replacement requirement rate are same as in case example 1. Otherwise, no emissions are generated during operation of the power plant, and the power plant is almost completely maintenance-free. However, the calculations include a few maintenance visits over the entire life cycle to make the result as realistic as possible. During the demolition phase, emissions are generated from the use of machinery and vehicles required for demolition. In addition, emissions from recycling components are included in this phase.

During the manufacturing phase, the most significant carbon footprint comes from manufacturing the solar panels as in case example 1. The emission amounts for case 2 are also quite close when compared to case 1. The small differences are only due to the size of the project areas, and thus the number of components. The CO_2 emissions from the manufacturing of components of case 2 can be found in the figure 17 below.

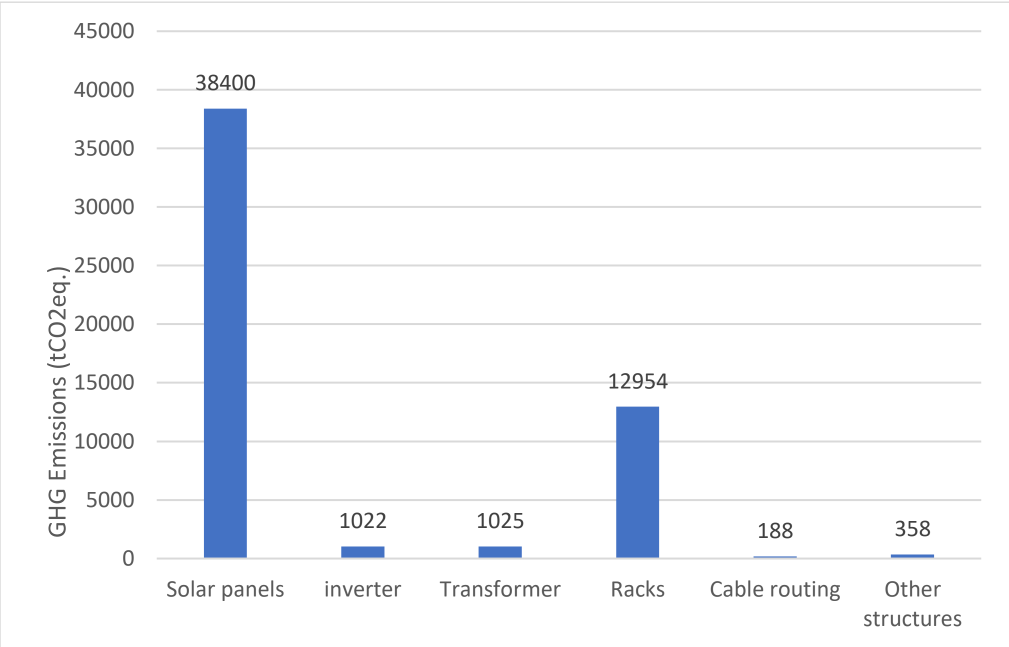


Figure 17. Carbon footprint of different components.

As in case example 1, carbon dioxide emissions from land use changes and carbon dioxide emissions from mandatory felling of trees have also been taken into account. These are compared with emissions during the life cycle of the solar power plant in the figure 18 below. The figure shows that land use changes and forest clearing do not cause significant emissions. It can also be noted that harmful effects are only temporary, as the largest emissions from the power plant occur early in the plant's life cycle.

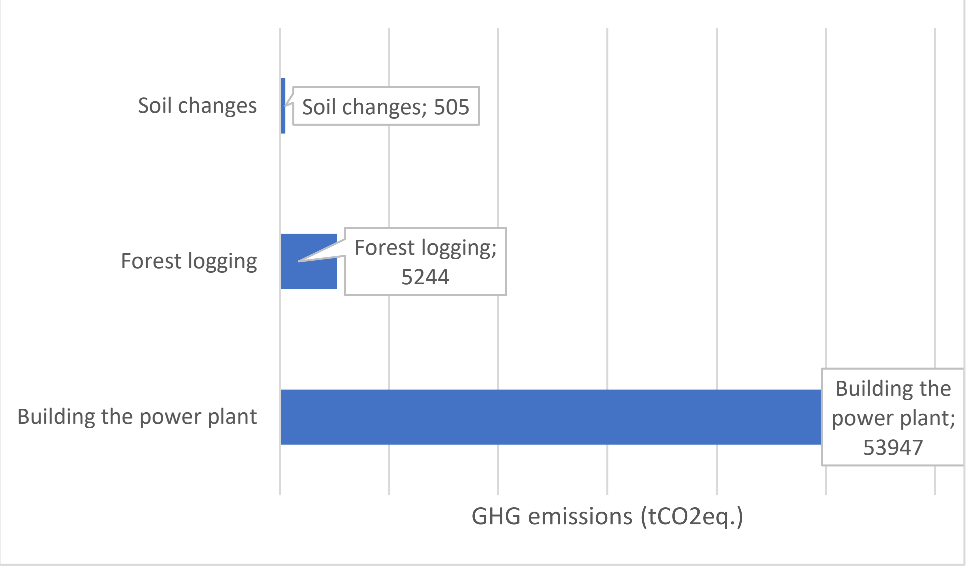


Figure 18. Different emission sources in comparison.

For the case 2 the calculated loss of carbon sink due to logging is 17,53 tCO_2-eq. The forest area that needs to be cleared is approximately 42,4 hectares, to prevent the trees from shading the solar power panels and to get the maximum amount of sunlight. Compared to the hypothetical situation where the project area of 65 hectares was entirely forest and it had to be cut down to make way for the solar power plant, the calculated carbon sink loss would be 26,42 t CO_2-ekv. The difference is not as significant as in case 1, because in case 2 in real scenario a significant forest are needs to be cleared. The comparison of these two scenarios for case 2 can be seen from the figure 19 below.

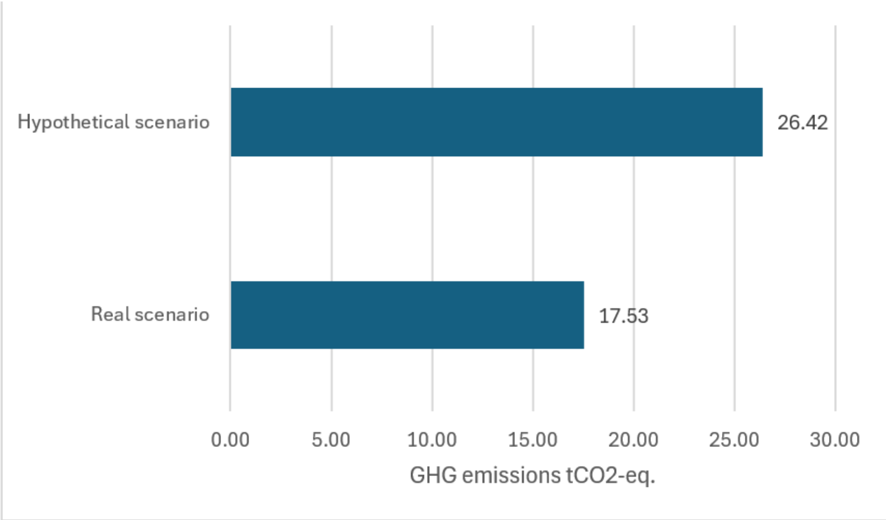


Figure 19. Carbon sink loss comparison between hypothetical and real scenarios of case 2.

Finally, based on the information obtained, emissions per megawatt produced can be calculated. The initial data is tabulated in table 5, including the annual production of the power plant and the power of the power plant from which are from Nordi's own materials, and carbon dioxide emissions are based on the calculated results, and the amount for case 2 is 53947 tCO2eq. The working life of the solar power plant is estimated to be approximately 30 years.

The unit conversion is done by first calculating the emissions per MWp by dividing the power of the plant (MWp) by the total emissions (t CO_2eq.). After this, it is converted to kilograms by multiplying the answer by 1000. After that, the energy produced is calculated for the entire life cycle by multiplying the power plant power by the number of years in its life cycle. Finally, the life cycle emissions are calculated by dividing the total emissions (kgCO2) by the energy produced during the life cycle (MWh) and then converted to gCo2/kWh. The results are listed below in table 25.

Table 25. Emissions calculated per MWh.

Case 2	Amount	Unit
Emissions per MWp	1001	t CO_2/MWp
Energy produced during the life cycle	1546920	MWh
Electricity production emissions during the life cycle	**34.9**	**g CO_2/kWh**

5.1.3 Case 3 – carbon footprint

As mentioned in chapter 4.4.3 case 3 is a combination of former ash disposal area and a former municipal waste land area. It is approximately 70 hectares, and there is approximately 25 hectares of forest that need to be logged before construction work can start. The area is significantly modified by human actions and therefore the area’s natural values are low.

The life cycle carbon footprint of Case 3 solar power plant is in total of 61 496 tCO_2. This includes everything from the manufacturing phase to disassembly and recycling. As in the two previous case examples, the majority of carbon dioxide emissions come from the manufacturing phase. The distribution of the carbon footprint between the different phases can be seen in table 26 below.

Table 26. Distribution of the carbon footprint between different phases.

Phase	GHG emissions (tCO_2-eq.)	Percentages
Manufacturing	51 1914.6	84.4%
Transportation	3356.2	5.5%
Construction	1120.3	1.8%
Operation	4477.0	7.3%
Disassembly	627.8	1.0%
Total	61495.6	

As in the previous two case examples, the manufacturing phase has the most significant carbon footprint, and this is also due to the significant quantities required for solar panels.

The emissions during operation phase come from the components that need to be replaced. The components that require replacement during the life cycle and the replacement requirement rate are same as in case example 1. Otherwise, no emissions are generated during operation of the power plant, and the power plant is almost completely maintenance-free. However, the calculations include a few maintenance visits over the entire life cycle to make the result as realistic as possible. During the demolition phase, emissions are generated from the use of machinery and vehicles required for demolition. In addition, emissions from recycling components are included in this phase.

During the manufacturing phase, the most significant carbon footprint comes from manufacturing the solar panels as in the previous two case examples. The emission amounts for case 3 are also quite close when comparing all three case examples. The small differences are only due to the size of the project areas, and thus the number of components. The CO_2 emissions from the manufacturing of components of case 3 can be found in figure 20 below.

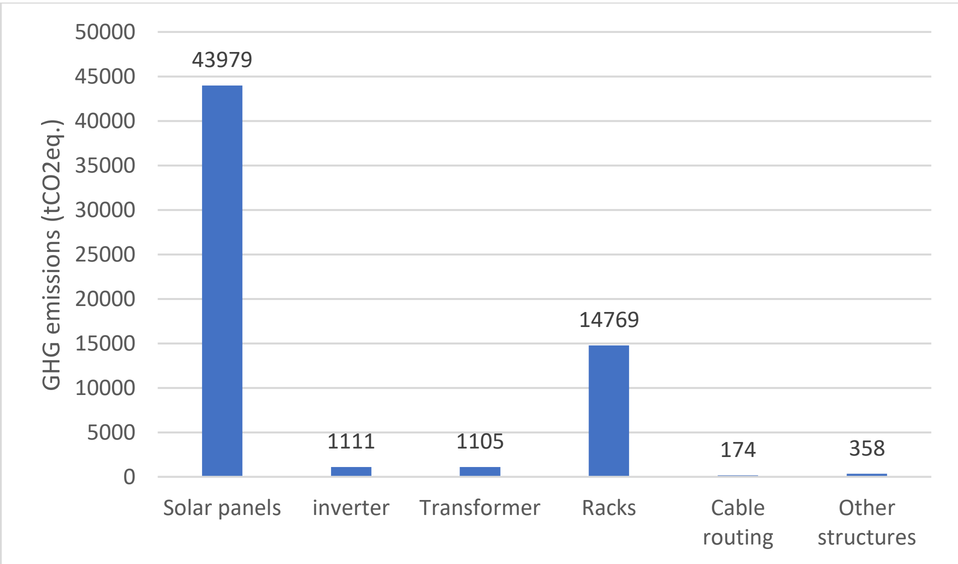


Figure 20. Carbon footprint of different components.

As in the previous case examples, the carbon dioxide emissions from land use changes and carbon dioxide emissions from mandatory felling of trees have also been taken into account. These are compared with emissions during the life cycle of the solar power plant in the figure 21 below. The figure shows that land use changes and forest clearing do not cause significant emissions. It can also be noted that harmful effects are only temporary, as the largest emissions from the power plant occur early in the plant's life cycle.

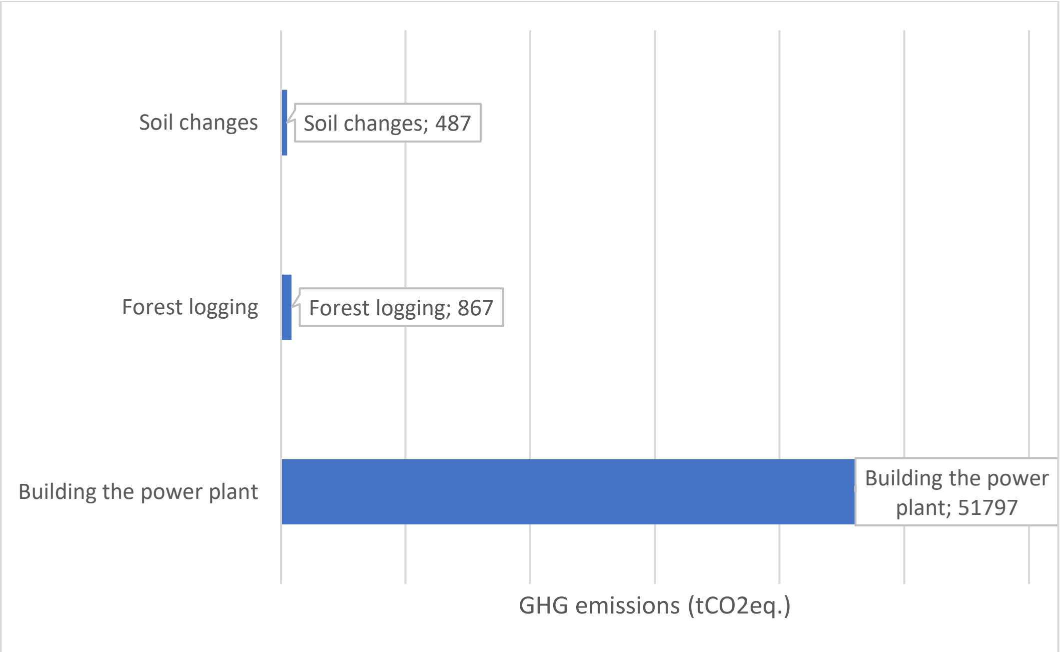


Figure 21. Different emission sources in comparison.

For the case 3 the calculated loss of carbon sink due to logging is 11 t CO_2-ekv. The forest area that needs to be cleared is approximately 25 hectares, to prevent the trees from shading the solar power panels and to get the maximum amount of sunlight. Compared to the hypothetical situation where the project area of 70 hectares is entirely forest and it had to be cut down to make way for the solar power plant, the calculated carbon sink loss would be 31,68 t CO_2-ekv. The comparison of these two scenarios can be seen from the figure 22 below.

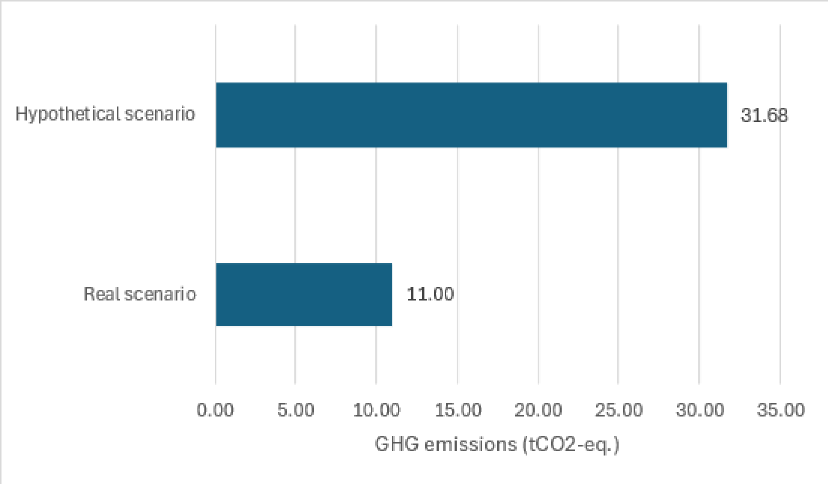


Figure 22. Carbon sink loss comparison between hypothetical and real scenarios of case 2.

Finally, based on the information obtained, emissions per megawatt produced can be calculated. The initial data is tabulated in table 5, including the annual production of the power plant and the power of the power plant from which are from Nordi's own materials, and carbon dioxide emissions are based on the calculated results, and for case 3 the amount is 61496 tCO2eq. The working life of the solar power plant is estimated to be approximately 30 years.

The unit conversion is done by first calculating the emissions per MWp by dividing the power of the plant (MWp) by the total emissions ($tCO_2eq.$). After this, it is converted to kilograms by multiplying the answer by 1000. After that, the energy produced is calculated for the entire life cycle by multiplying the power plant power by the number of years in its life cycle. Finally, the life cycle emissions are calculated by dividing the total emissions (kg CO_2) by the energy produced during the life cycle (MWh) and then converted to gCO2/kWh. The results are listed below in table 27.

Table 27. Emissions calculated per MWh.

Case 3	Amount	Unit
Emissions per MWp	1025	t CO_2/MWp
Energy produced during the life cycle	1691340	MWh
Electricity production emissions during the life cycle	**36.4**	**g CO_2/kWh**

5.1.4 Comparison of the case examples

The results of the carbon footprint calculations do not differ significantly between the case examples as they are quite close in size. However, some differences are in component unit amounts which directly has an impact on the manufacturing CO_2 emissions. In addition, the life cycle phases are the same for every project, and the components are ordered from the same countries, and therefore the travel distances are almost the same. The travel distances vary depending on in which port the cargo ships arrive in Finland. Also, the travel distance from the port to the project area are different between the case examples. The carbon footprints of the case examples are compared in the figure 23 below.

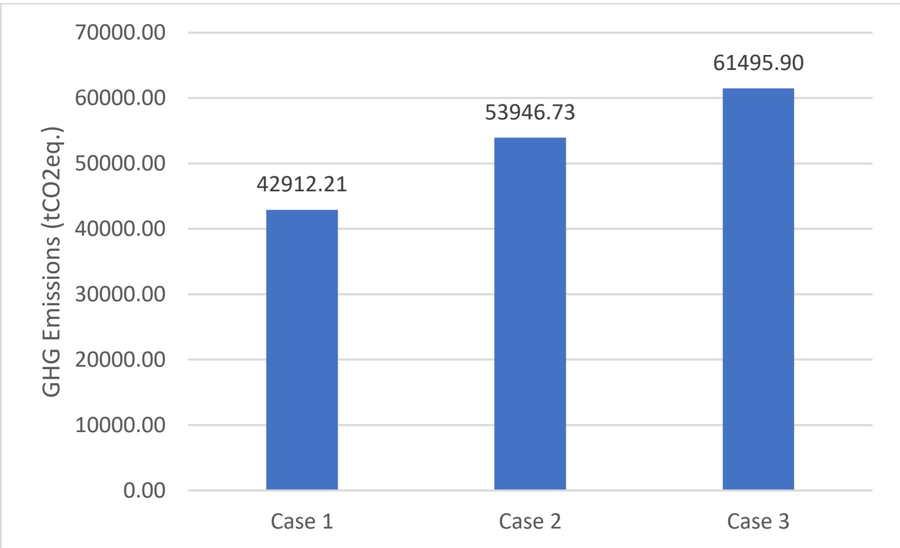
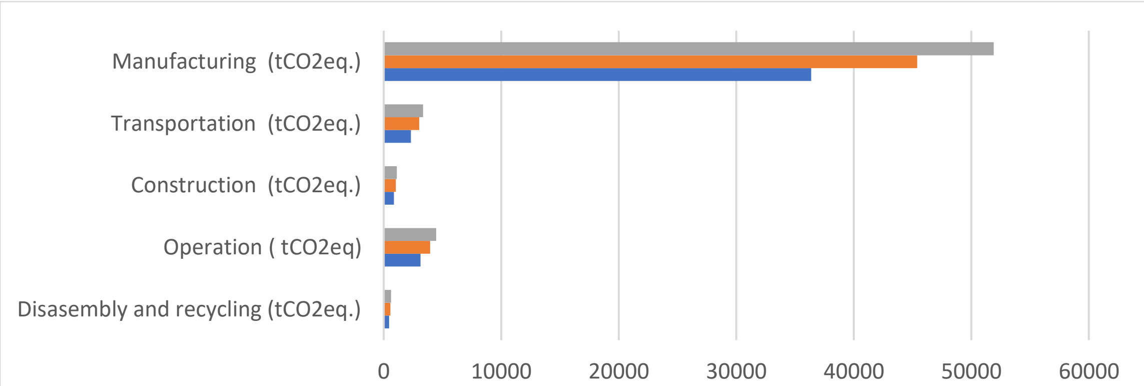


Figure 23. The lifetime carbon footprints of the case examples in comparison.

The most significant emissions in each case example come from the manufacturing phase. The differences in emission amounts between the case examples from this phase are due to the size differences of the projects which affect the manufacturing emissions of the components. However, it should be noted that CO_2 emissions are indicative, as manufacturing takes place abroad and no precise information is available on the emissions generated during component manufacturing. The travel distances may also differ in reality as the exact transport routes will be planned in more detail at a later stage in the development of the projects. The project areas of the case examples are in different starting situations and require different amounts of preparation before the actual construction phase can begin. This is why there are differences between the projects in emissions during the construction phase. The differences of the CO_2 emission amounts between the case examples is due to different number of components. There are no significant differences between the projects in the demolition and recycling phase.



	Disasembly and recycling (tCO2eq.)	Operation (tCO2eq)	Construction (tCO2eq.)	Transportation (tCO2eq.)	Manufacturing (tCO2eq.)
Case 3 (60MWp)	628	4477	1120	3356	51915
Case 2 (53.9 MWp)	566	3935	1031	3014	45402
Case 1 (43 MWp)	460	3124	871	2311	36385

Figure 24. Comparison of different phases between the case examples.

Emissions caused by tree cutting differ between the projects, depending on the size of the area that is logged in the area. In the project area of case 1, there are not many trees in the area due to its former utilization. The area has not had the opportunity to return to its natural state, as the area has been a gravel extraction area for several decades, and the quarrying activity has only recently ended. In addition, the area is not the most suitable for trees or other plants to grow on. In case 2, approximately 42 hectares of forest must be cut down to make way for the solar power plant. In case 3, approximately 25 hectares of forest is logged. However, the natural state of these areas is not significant.

In figure 25 below, the carbon sink losses of are all three case examples due to logging are illustrated in two scenarios. Scenario 1 is the forest area that will be cut in reality. Scenario 2 is hypothetical scenario where the whole project area would be forest and cleared for the solar power park. This figure illustrates the carbon sink losses in each case examples and in both cases. The carbon sink loss for both cases is calculated the same way. In scenario two, the entire area is assumed to have the same type of forest, so that the same growth coefficient value can be used for the entire area.

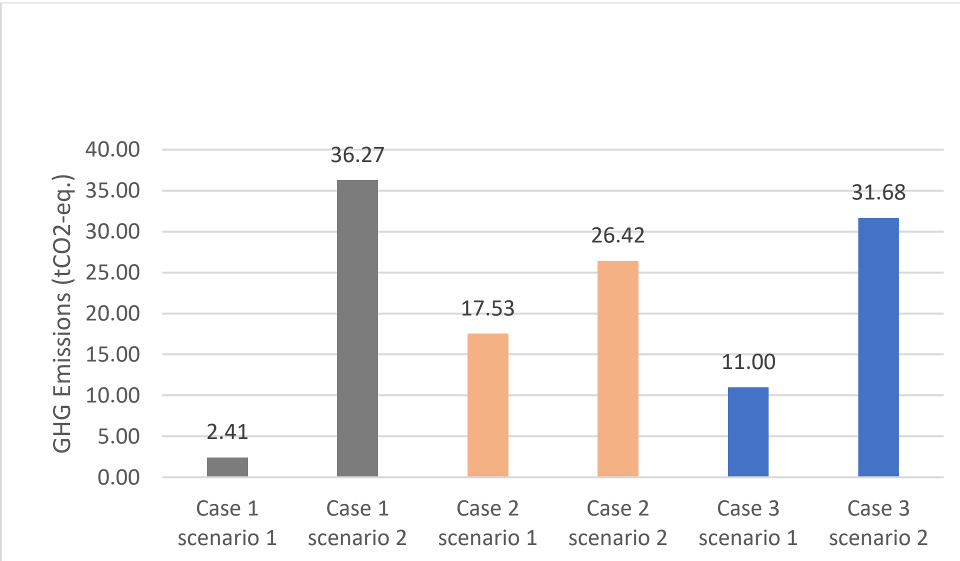


Figure 25. The carbon sink losses due to logging of each case example.

The most significant changes between the two scenarios is in case 1. This is because the project is the biggest in size and in the scenario 1, not much of clear cutting is needed. In the first scenario of Case 2, several hectares of forest will have to be cut down anyway, so from this point on the difference between the scenarios is not that significant. In case 3 some trees will be felled in scenario 1, but the difference compared to scenario 2 is still noticeable.

Finally, carbon dioxide emissions per megawatt hour were calculated for all three projects. As can be seen from the results in table 28, they do not differ significantly from each other.

Table 28. Comparison of CO_2emissions per kWh between the case examples.

Case examples	Emissions per kWh during the life cycle
Case 1	34.2 gCO_2/kWh
Case 2	34.9 gCO_2/kWh
Case 3	36.4 gCO_2/kWh

The emissions per kWh during the life cycle between the case examples do not differ significantly. However, the slight changes come from the size of the power plants. The initial data of the case examples are tabulated in table 5. Case 1 annual production is estimated to be 41849 MWh/a, estimated annual production of case 2 is 51564 MWh/a, and estimated annual production of case 3 is 56378 MWh/a.

When the emissions per kWh of each case are compared to previous studies, the results of each case are well within the same range and can be considered realistic. Dahl's master's thesis presents the results of several international studies on the life cycle carbon dioxide equivalent emissions of solar power in Table 3. For example, the study Life Cycle Assessment of Crystalline Photovoltaics in the Swiss Ecoinvent Database (2013) reported emissions of a power plant in Switzerland as 39–110 g CO_2-eq./kWh, the study Review on Life Cycle Assessment of Energy Payback and Greenhouse Gas Emission of Solar Photovoltaic Systems (2022) reported emissions of 29–45 g CO_2-eq./kWh, and the study Life Cycle Greenhouse Gas Emissions and Energy Footprints of Utility-Scale Solar Energy Systems (Canada) reported emissions of 98–149.3 g CO_2-eq./kWh (Dahl, A. 2024, p. 24). Compared to these literature values, the result of this work (34.18 g CO_2-eq./kWh) is at the lower end and is therefore comparable and realistic.

5.2 Habitat hectare

5.2.1 Case 1 – habitat hectare

The project area, where the solar power plant structures of case 1 will be built on, contains four habitat types: Esker Forest, Barren pine heath, Dry heath forest, and invasive species. The total area size where the components are built is approximately 45 hectares. In table 29 the calculated values for ecological status of the habitat types and the habitat hectare can be seen.

Table 29. Ecological status value and habitat hectare.

Habitat type	Ecological status value of a habitat type pattern (hha/ha)	Number of hectares the habitat type covers (ha)	Habitat hectare (hha)
Eskers forest	0.12	41	4.92
Barren pine heath	0.17	1.2	0.20
Dry heath forest	0.18	2	0.36

The habitats in the area are in very weak condition, and all habitats have almost completely disappeared. This is because the area has been heavily modified by humans due to its former use. The area has been used as a gravel extraction area, as a result of which the natural vegetation of the area no longer exists in the area.

Ecological status value of a habitat type pattern describes the value of the habitat type's status, i.e. how much of the area's natural state remains. and as can be seen from the results, at least 80-90% of all habitat types have been destroyed or lost. The number of habitat hectares of Eskers forests is higher compared to other habitat type, but that is because that habitat type covers most of the area, approximately 41 hectares.

The natural status of these habitat types cannot be improved in this project area, but it can be improved in the surrounding area, through ecological compensation. On the other hand, it can be noted that the loss of habitat types because of the construction of the solar power plant is not significant, as the natural values of the area are already very low. However, biodiversity can be increased in this area by introducing sun-lit species that are well-suited to solar power. They can withstand heat and sunlight, but they do not grow tall, so they do not cover the solar panels and interfere with their functionality. They also attract more insects and pollinators to the area.

5.2.2 Case 2 – habitat hectare

Three habitat types occur in the project area of case 2: Sub-dry heath forest, slightly drained peatland forest, and Sedge aapa mire. The total area size where the components are built is approximately 58.1 hectares. In table 30 the calculated values for ecological status of the habitat types and the habitat hectare can be seen.

Table 30. Ecological status value and habitat hectare.

Habitat type	Ecological status value of a habitat type pattern (hha/ha)	Number of hectares the habitat type covers (ha)	Ecological status value of a habitat type pattern (hha)
Sub-dry heath forest	0.41	36.5	14.97
Slightly drained peatland forest	0.29	7.7	2.23
Sedge aapa mire	0.59	1.9	1.12

The habitat types in the area are in weak to moderate condition. Sub-dry heath forest and slightly drained peatland forest types are in weak condition, over half of the natural state of the habitat types are lost in the area. Sedge aapa mire is in moderate condition in the area. Over half of the habitat type’s natural state has remained in the area.

Ecological status value of a habitat type pattern describes the value of the habitat type's status, i.e. how much of the area's natural state remains. The number of habitat hectares of Sub-dry heath forest is higher compared to other habitat types, but that is because that habitat type covers most of the area, approximately 36.5 hectares.

The natural status of all these habitat types cannot be improved in this project area. The forest types cannot be improved as no trees can crow in the project area as they might shade the panels. However, the mire might stay untouched if its too wet to build the solar power structures on. The water management of the area can be improved, as the bog could be restored by directing water there and this way improve its condition. The natural state of the forest types can be improved in the surrounding area, through ecological compensation. On the other hand, it can be noted that the loss of habitat types due to the construction of the solar power plant is not significant, as the natural values of the area are already quite low. However, biodiversity can be increased in this area also by introducing sun-lit species as in case 1.

5.2.3 Case 3 – habitat hectare

Four habitat types occur in the Case 3 project area: Barren pine heath, Dry heath forest, Herb-rich spurce swamp forest and Rock outcrop area. The total area size where the components are built is approximately 56.8 hectares. In table 31 the calculated values for ecological status of the habitat types and the habitat hectare can be seen.

Tale 31. Ecological status value and habitat hectare.

Habitat type	Ecological status value of a habitat type pattern (hha/ha)	Number of hectares the habitat type covers (ha)	Ecological status value of a habitat type pattern (hha)
Barren pine heath	0.45	6.5	2.92
Dry heath forest	0.54	18	9.72
Herb-rich spurce swamp forest	0.32	6.5	2.08
Rock outcrop area	0.6	2.8	1.68

The habitat types in the area are in weak to good condition. Herb-rich spurce swamp forest type and Barren pine heath type are in weak condition, as over half of the natural state of the habitat types are lost in the area. The dry heath forest type and rock outcrop type are between moderate and good condition. Over half of the habitat type’s natural state has remained in the area.

Ecological status value of a habitat type pattern describes the value of the habitat type's status, i.e. how much of the area's natural state remains. The number of habitat hectares of dry heath forest is higher compared to other habitat type, but that is because that habitat type covers most of the area, approximately 18 hectares.

The natural status of these habitat types cannot be improved in this project area. The forest types must be cleared, and the rock outcrop might ne affected by the levelling of the project area. However, the natural state of the habitat types can be improved in the surrounding area, through ecological compensation. On the other hand, it can be noted that the loss of habitat types due to the construction of the solar power plant is not significant, as the habitat types are not in natural states. However, biodiversity can be increased in this area also by introducing sun-lit species as in previous cases.

5.2.4 Comparison of the case examples

All three case examples are significant in size, and they all consist of 3-4 nature types. All nature types of each case has been weakened by previous utilization, and therefore no nature types are in natural state anymore. However, there were differences in the natural condition values of the habitat types between the study areas. In Case 1, the condition of the habitat types was non-existent in some parts and weak in others. The project is very strongly modified by humans, and for this reason, the construction of the solar power plant will not cause significant loss of nature in the area. It could even be improved due to the heat-resistant plants that will be planted there. In Case 2, the habitat types were in poor condition, and some were in moderate condition. In this project, a small decrease may occur during the land preparation phase, but by introducing new species to the area, the biodiversity of the area can be increased. In Case 3, the area had poor, moderate and good condition habitat types, this may mean that the area's biodiversity may decrease as a result of the construction of the solar power plant, but only slightly. However, the specific habitat types cannot be improved in the project areas. In these cases, ecological compensation in nearby areas should be considered.

In case 1, the natural state is so low that the construction of a solar power plant and the heat-tolerant species planted below the panels may even increase the biodiversity of the area. In areas 2 and 3, there are still some trees that need to be removed so that solar power parks can be built in the areas. This may at least temporarily weaken the surrounding conditions. Typical vegetation such as tall trees cannot be left near the panel fields, as they may shade the solar panels. However, the natural state of the area may improve over time, as during the life cycle of the solar power plant, the nature surrounding the panel field is allowed to grow in peace, as are the low plants under the panels.

There are differences between the projects, as their previous use has significantly modified their natural state. The ecological state of the project area of case 1 is significantly weaker compared to case 2 and 3. This is because the area has been used as soil extraction for many decades. The biodiversity of Cases 2 and 3 is at a better level, as the areas have vegetation that are typical of the natural type of the area. However, in all case examples, there are signs of human activity that is weakening the natural state. The natural state of all three projects has deteriorated from its natural state as a result of the former use of the areas.

The natural state of all three project areas can be improved by planting, for example, heat-tolerant species that do not grow tall and shade solar panels. Heat-tolerant species also bring insects and pollinators to the area, further enriching the biodiversity of the area. In addition, habitat hectare calculations can be used to calculate the need for compensation measures. Compensation measures can be implemented for similar habitat types in the surrounding area.

5.3 Limitations of the calculations

This chapter discusses the limitations associated with both the carbon footprint and habitat hectare calculations. Paragraph 5.3.1 addresses the specific limitations of the carbon footprint analysis, while paragraph 5.3.2 focuses on the limitations regarding the habitat hectare calculations.

5.3.1 Limitation regarding carbon footprint calculations

The carbon footprint calculations have been made based on the current plans that Nordi has made for the projects. The projects are still in the early stages, which means that the project plans may change, and therefore, for example, the size of the projects may still change. This directly affects the total emissions of the project area.

The final component models are selected once the project has all the permits and the project plans have been finalized. As a result, the emissions from the manufacturing of the components may change. Therefore, the calculations can be used as indication, until the real models of the components are known and the calculations are made based on those.

The lengths of the maintenance roads and cable routes are estimated based on the current best possible estimate. These lengths may also vary in reality, and therefore their results are an estimate. Their final locations and therefore lengths will also be clarified in the final plan of the projects.

The emissions from solar power plants during operation phase are based on the need for component replacement (solar panels and inverters). The inverter replacement requirement is estimated at 100% and the solar panels replacement requirement is estimated at 10%. The results may differ in the future, as technology is constantly evolving. The need for replacement of solar panels is taken into account due to the slight possibility of component breakdown.

Carbon sink losses caused by logging have been calculated based on the amount of forests in Finland. The number of forests is based on an estimate which is approximately 22,9 million hectares (MMM, n.d.). The carbon sink that Finnish forests form has been taken into account by only considering the growth and loss of trees, making forests a net sink of 13.2 Mt (LUKE, 2023). This was to limit soil emissions, which are larger than the carbon bonded in the forests and forests are in reality an emission source. The limitation was made due to the feasibility of the calculations.

5.3.2 Limitations regarding habitat hectare

The habitat hectare calculations have been made based on the guidelines in the "Luontotyyppien tilan aviointi ekologisessa kompensaatiossa" report. (Jalkanen, J., et al. 2025.) However, it is not made by experts who are familiar with the calculation of habitat hectares as the calculations typically are. The calculated model can be used as a basis, which can be further refined later. Therefore, the calculation results are indicative. The site visits for data calculation were conducted by the consultant and Nordi, and not by a third party. The assessment of natural conditions is based on maps and surveys conducted by a consultant in the area. A separate site visit was not conducted for the calculation data. In addition, some project areas have protective structures that currently limit Nordi's research in the area. In addition, the areas' special characteristics must be taken into account when operating in them, and for example, case 1 is located in a groundwater area that strongly guides Nord's operations in the area.

6 Conclusion

This thesis set out to examine four key questions: how can biodiversity impacts of solar power plants be evaluated, how can the biodiversity of a project-area be improved, how much carbon dioxide (CO_2) emissions are generated during the life cycle of industrial-scale ground-based solar power plants when the lants are built on different types of human -altered areas, and how do the biodiversity impacts differ between solar power areas built on human-altered areas and those built in commercial forests. The results show that these questions can be addressed through a combination of carbon footprint calculations and habitat hectare assessments, although both methodologies include limitations that make the results indicative rather than absolute. Despite this, these methods together provide a broad and meaningful overall picture of the ecological impacts of industrial-scale solar power development.

The life-cycle assessment revealed that the manufacturing phase of solar plant components generates most emissions. Because manufacturing mainly occurs in Asia, transparent and accurate emissions data are difficult to obtain, which complicates precise assessment. Nevertheless, by identifying which life-cycle stages contribute the most to total emissions, project developers can better target mitigation efforts. Transportation-related emissions can be reduced by optimizing logistics, while emissions during construction can be minimized by selecting sites that require little or no land preparation. The operation phase then remains nearly emission-free for decades. Although emissions during dismantling cannot be avoided entirely, recycling components can partially offset impacts through reduced demand for virgin raw materials.

The carbon footprint calculations of the case studies also highlighted the significant role of land-use choices. When solar farms are built on human-altered sites with low existing carbon stocks, carbon sink losses remain minimal, and compensation needs are far easier to manage. In contrast, establishing solar installations on forested areas leads to higher carbon sink losses, particularly where tree removal is required. These findings support the practice of prioritizing already degraded, low-biodiversity environments for solar power development.

The habitat hectare analysis provided further insight into the ecological conditions of the project areas. The results show that sites with low existing natural values face relatively small negative impacts from solar development and may even experience biodiversity gains. This was evident for example in Case 1, where planting sun-lit species between panel rows can improve ecological conditions beyond the pre-project state. In more forested cases, necessary tree removal may cause short-term decline, but long-term recovery is possible as low vegetation and surrounding habitats develop over the solar farm's lifespan. Additionally, continuing habitat hectare calculations could be used to determine the need for ecological compensation for specific habitat types, enabling targeted improvements in nearby areas.

Taken together, the thesis contributes new practical insights by presenting real examples of industrial-scale solar power projects and by deepening the understanding of how to design more sustainable and biodiversity-friendly solar energy systems. The work demonstrates that with careful site selection, transparent life-cycle consideration, and targeted ecological enhancement measures, solar power can be integrated into the landscape in a way that minimizes environmental harm—and in some cases even supports biodiversity.

The topic of this thesis is very broad and could have been developed even further, and the process of writing it has revealed several potential directions for future research. First, future work should focus on improving the traceability of carbon footprint calculations, as a more detailed breakdown of emissions across the different stages of the manufacturing process would enable a more reliable assessment of the total emissions associated with various panel types; similarly, transportation-related emission estimates would require closer scrutiny to ensure the accuracy of life cycle calculations. Another important avenue would be calculating the habitat hectare for a project in both its current state and its post-construction state once the solar power plant is built, allowing for a clearer understanding of how the natural condition of the area changes. Beyond this, further research could include more detailed comparisons between different solar power plant sites and their emissions, investigations into agrivoltaics and peatvoltaic concepts and their environmental impacts, and the optimization of power plant design and construction from a biodiversity perspective to support the development of lower-emission and ecologically sustainable solutions in the future.

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