Tradeoffs of 1GW solar PV on various landscapes in the Netherlands

(Solar Park-Lange Runde, taken on 29th July)

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Abstract

Solar Photovoltaics (PV) proliferates in the Netherlands as a significant source to substitute fossil energy with its abundance and ubiquitous. Nonetheless, the contribution of the solar PV is mimic, which implies that the significant increase is of necessity. In this sense, there are growing interests in the land-based solar PV, especially on the agricultural land due to the vast area available in the Netherlands. On the other hand, there are increasing concerns towards land occupation by large scale solar PV installations and insist on the use of the roof area. In compliance with the emerging social problems towards the solar PV, this research aims to provide preliminary information about various impacts. The impacts considered in the research including land-use impact, impact on the biodiversity and visual impact that are directly associated with the solar PV installations in the Netherlands. Moreover, the Levelized Cost of Energy (LCOE) with the national subsidy (SDE+) is calculated to compare the electricity generation in various landscapes, including roof, land, and water. The results show that the rooftop PV has the lowest impact among all the landscapes considered. However, the impacts of large-scale solar PV vary by the type of the landscape, and some impact remains unknown. Therefore, more research into the potential impacts associated with increasing solar PV is necessary.

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List of abbreviation

kW: kilowatt
KWh: kilowatt-hour
LCOE: Levelized Cost of Electricity
LULUCF: Land use, Land Use Change and Forestry
MW: Megawatt
GHG: Greenhouse gases
GW: Gigawatt
PBP: Payback period
PV: Photovoltaics
SDE+: Stimulering Duurzame Energieproductie (Stimulate sustainable energy production)
TWh: Terawatt-hour

1. Introduction

1.1 Background

Solar energy is considered of significance for achieving energy transition from the fossil energy, which is regarded as the significant anthropogenic contributor of greenhouse gas (GHG) emissions (IPCC, 2012) in light of its abundance and ubiquitous resources. (Sahu, Yadav, & Sudhakar, 2016)

Current installed solar photovoltaics (PV) in the Netherlands has reached 2.9 GW in 2017 and nearly doubled to 4.9 GW in 2018. Nonetheless, the current contribution of solar energy is mimic, which merely consists of 0.6% of total final energy consumption in 2018. (CBS, 2019c) When it comes to the national renewable target of achieving 20% by 2030 and energy-neutral by 2050, (Schoots, Hekkenberg, & Hammingh, 2017), there is an urgent need to increase the share of solar energy. It aims to achieve 6GW by 2020 (Bellini, 2019)

Even though rooftop PV owns the overwhelming capacity in the Netherlands, large scale PV continues to gain interests by the energy developers. The likely reason is the availability of higher energy output. (van der Zee et al., 2019) Moreover, the government provides a subsidy scheme of SDE+ (Stimulering Duurzame Energieproductie), which is to aid energy developers to generate heat, electricity, and gas from renewable sources by reducing the burden of high generation costs, undoubtedly it has created a friendly environment to develop large-scale solar PV in the Netherlands.

Generally, solar PV requires a massive area of land in order to get sufficient solar irradiance. (Pasqualetti, 2011) It intrudes the original function of the land and thus brings about the tradeoffs between the functions of the land. The intrusion of originality has led to the conflicts between energy developers and groups of people with different interests, such as environmentalists, ecologists, residents who concern about the unknown impacts of solar PV. These conflicts sometimes can sublimate into protests against the solar park, lead to the delay and even the termination of the projects, which is commonly identified during the construction of renewable energy facilities. (De La Cour, 2017; Turney & Fthenakis, 2011; Woody, 2009).

Accordingly, a significant increase in solar PV capacity in the future need, that is to say, the great use of land for solar PV development, may bring about the tremendous social problems.

1.2 Knowledge gap

Regardless of the importance of the renewables, lack of social acceptance is identified as the most barriers for achieving projects at the implementation level. (Wüstenhagen, Wolsink, & Bürer, 2007) The rejections are mainly due to the changes that renewables might bring to the original landscape and consecutive impacts on lifestyles. (Pasqualetti, 2011) Earlier in 2005, Tsoutos et al. (2005) already deemed that massive-scale deployment of solar energy can hinder its development with its potential deleterious impacts and environmental impact analysis with the focus on both positive and negative impacts (tradeoffs) of solar PV were investigated as a possible solution. Since then, there are increasing numbers of researches of environmental impact analysis of solar energy by Turney and Fthenakis (2011), Hernandez et al. (2014)

In the case of the Netherlands, limited literature is available regarding the impact study of solar PV with a conceivable reason that solar PV has not gained much attention in the past. Netherlands Enterprise Agency (RVO) with ROM3D published a report about the assessment framework of land-based solar PV with the potential land use impacts and feasible locations in the Netherlands for PV installation (RVO & ROM3D, 2015b) however, the limitation of this report is identified that it does not provide any other information regarding other impacts. With the ecological concern, Klaassen et al. (2018) identified the effects of the solar park on the biodiversity. Most recently, van der Zee et al. (2019) published the report with respect to the potential impacts of the solar park on the agricultural land in the Netherlands. It focuses on the use of agricultural land for solar energy development and concomitant impacts on the agricultural sector, biodiversity, and economics, which provides the first comprehensive study of the subject for the Netherlands.

The knowledge gap identified was current literature focus on one specific impact while lacking the comprehensive tradeoff studies of solar PV. Moreover, the existing literature is limited to the ground-mounted PV, while there is a higher capacity located on the roof (SOLARSOLUTIONS Int., 2018) and high potential on the water surfaces due to the limited land area available in the Netherlands.

1.3 Research aim and research questions

With the knowledge gap identified, this research aims to investigate the tradeoffs of solar PV on different landscapes by looking into various impacts.

Reflect on the research aim; the main research question is, therefore:

What are the tradeoffs of GW based solar PV on different landscapes in the Netherlands?

In order to answer the main research question, the following sub-questions are adopted.

1. What are the land-use impacts of a rooftop, land-based, and floating solar PV on different landscapes?
2. What are the impacts of the rooftop, land-based, and floating solar PV on biodiversity and ecology on different landscapes?
3. What are the visual impacts of the rooftop, land-based, and floating PV on landscapes?
4. What are the economic benefits for the rooftop, land-based, and floating PV?

The current solar capacity has reached 4.9GW. (Dutch New Energy Research, 2019) Therefore, the 1GW scale of solar PV is chosen in the main research question. sub-question represents the specific impact of solar PV on the landscapes, which can represent various aspects of the potential impacts, including environmental, aesthetic aspects of solar PV development. The last sub-question aims to investigate the profitability of solar PV installation with the aid of a national subsidy scheme. After all, the aggregation of the identified impacts provides the tradeoffs of solar PV on different landscapes.

1.4 Scientific and social relevance

The scientific relevance of the research is that the results will present potential tradeoffs of land-based PV, floating PV, and rooftop PV installation on the landscape in the Netherlands. By identifying what impacts are already known, what impacts should be supplementary for a more comprehensive understanding of the potential impacts on the ambient environments as well as the landscape, this research can provide the preliminary information for a future environmental impact study of GW based solar PV.

The results of the research will aid the energy developers with site selection on the landscape that conceivably has lower tradeoffs. Moreover, it will provide information for people who are already involved or to be involved in the solar PV project as stakeholders to learn about the general tradeoffs of solar energy on the landscapes.

1.5 Outline

This research begins with an understanding of the current status of each type of solar PV development in the Netherlands. Followed by the methodology used for the impact investigation. (Chapter 3) Next, the results of the findings are presented based on each impact category in the chapter 4. These findings helped investigate the tradeoffs in different landscapes in the Netherlands and further discussed in Chapter 5. The limitation of the research is addressed in chapter 6 and the paper ends with the conclusion in chapter 7.

2. Current status of solar PV in the Netherlands

This chapter aims to provide the background information of three major solar PV types in the Netherlands.

2.1 Rooftop solar PV

Rooftop is the dominant location for solar PV installation in the Netherlands with around 95% (SOLARSOLUTIONS Int., 2018) Typically, the capacity of the rooftop PV mounted on a residential building is about 5-20 kW whereas that on a commercial building can reach up to 100 kW. A distinctive advantage of the rooftop solar PV is no land requirement for the installation. (Sahu et al., 2016) General rooftop solar PV system consists of PV modules, inverters, mounting systems and cabling, and connectors. (Sahu et al., 2016) However, this signifies that the system requires a certain area of the roof. It is thus significant to investigate the roof area available in the Netherlands, which further enables to identify the potential capacity of rooftop solar PV. With this concern, PBL and DNV GL (2014) identified that technically 400km^2 of roof area available which corresponding to the capacity of 66GWp (50TWh). The more recent potential is identified by Deloitte (2018) with an 892 km^2 rooftop area.

2.2 Land-based solar PV

With the limited roof area and consequent low economic profits (benefits) from rooftop PV installation, energy developers seek for the land to install larger scale solar PV, which generally is MW- based and geographically centralized. (Hernandez et al., 2014) However, the current installed capacity of land-based PV in the Netherlands is 5% of the total installed solar capacity in 2017. (SOLARSOLUTIONS Int., 2018) Albeit the increasing interests for solar PV, the current achieved capacity of land-based solar PV is minimal compared to the rooftop PV. This circumstance shows the higher potential for solar PV development with the aid of land-based solar PV to achieve the target of 6GW by 2030.

In this sense, the appropriate use of land is of paramount importance. RVO and ROM3D (2015) indicate the use of "Ladder for sustainable urbanization" for identification for the preferred location for solar park installation. However, the motion of the House of Representatives describes that the ladder does not apply to the solar parks. (Peuchen, Gamboa Placios, & Dreijerink, 2019) Recently, Holland Solar introduces a Solar Ladder (Figure. 1) which has become a leading guideline in the field of solar energy. (Peuchen et al., 2019) However, it is not the formal element of the law in the Netherlands. (Bellini, 2017) The ladder indicates the area required for the realization of solar energy in the Netherlands. (Holland solar, 2018)

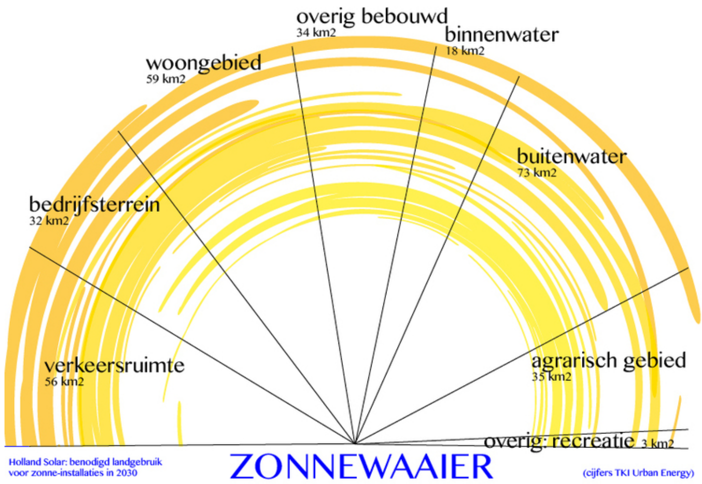


Figure 1. Potential area for solar PV installation in the Netherlands (Source: Holland solar)

2.3 Floating solar PV

The system consists of two parts: One is the component enables panels to float and keep them on the same position on the water surface, i.e., pontoon or separate floats, mooring system generally made of poly-materials. The other is electricity generation components, i.e., solar panels and cables, similar to the traditional land-based solar PV. (Sahu et al., 2016) Its primary purpose is to reduce the land-use conflict by using water surfaces. (Sahu et al., 2016) In this regard, the concept fits well in the Netherlands, as it has limited land area but sufficient water surfaces. Given the positive aspects of floating solar PV, the national consortium 'Sun on Water' (Dutch: Zon op Water) has launched and targets the use of 2000 hectares of water surfaces which can contribute to 2GWp floating solar parks by 2023 next to the rooftop PV and land-based PV. In this sense, Rijkswaterstraat also intends to use the Ijsselmeer for the floating solar PV to make space for solar energy development. (Bellini, 2017) In order to utilize the largest inland water in the Netherlands for energy purposes.

3. Methodology

This chapter introduces the methods conducted for the research. It combines both quantitative and qualitative method as different impact requires a different type of data.

3.1 Land-use impact

The primary method for the land use impact of solar PV was the quantitative analysis to get insights into land/surface occupation by 1GW solar PV installation. Moreover, with the focus on agricultural land, further impact on food production and the economic outputs was also investigated.

3.1.1 Roof area for the rooftop PV and comparison with the total roof area

Broersen et al. (2018) identified potential roof area to install rooftop solar PV in the Netherlands. However, one of the assumptions was that the monuments, which were forbidden to install solar PV by the policy, were not taken into account and when it does, the potential might be curtailed for a few percents. (Broersen et al., 2018) In this regard, the roof area available for rooftop solar PV installation in the monumental buildings was roughly calculated under the assumption that every type of building owns the same roof area. Based on the identified area of 892 km^2 (Broersen et al., 2018) and the numbers of the buildings provided by (CBS, 2019b) and (Cultural Heritage Agency of the Netherlands (RCE), 2019) for the monumental buildings, the area is calculated with the following formula (1), (2). Table 1. provides the data used for the calculation.

$$The\ roof\ area\ of\ the\ monumental\ buildings = 400 \times Stocks\ of\ monumental\ buildings/Total\ buildings \quad (1)$$

$$The\ potential\ capacity\ of\ the\ buildings = 160 \times Roof\ area \quad (2)$$

Table 1. Input data for the rooftop area calculation

Input data			Source
Stocks of the buildings	Total	8,976,744	CBS, 2019
	Historical buildings and monument stocks	61,908	RCE, 2019
Peak power per unit area of solar panel		160 w/m^2	Vreugdenhil, 2014
Potential roof area		892 km^2	Broersen et al., 2018

3.1.2 Land area for 1GW solar PV on land and water and comparison with land uses

Firstly, the land requirements for the 1GW land-based and floating PV were calculated with formula (3). Then, the proportion of the required land area for 1GW solar PV on the total land area of each landscape was calculated with the formula (4).

$$Land\ area = 1GW/land\ use\ requirement\ (MW/ha) \quad (3)$$

$$Land\ occupation(\%) = Land\ area\ for\ 1GW\ solar\ park/total\ area\ of\ specific\ landscape\ area \quad (4)$$

3.1.3 Impact on agricultural products and economic outputs

When occupying agricultural land, there is a possibility that the function of the land gets affected, which might result in reduced crops, vegetables, and the affected dairy livestock numbers. The calculation was under the assumption when 1GW solar PV is merely installed on one single type of crop farms or vegetable farms or the grazing area.

- Impacted arable crops and vegetables were calculated with the formula (5) and based on the current or most recent yield.

$$Impacted\ agricultural\ products = yield\ per\ hectare(kg/ha) \times Land\ area\ for\ 1GW\ solar\ park\ (ha) \quad (5)$$

- For the dairy farms, the potentially impacted livestock was calculated with the formula (6).

$$Impacted\ livestock = (Total\ number\ of\ dairy\ animals/Total\ grazing\ land) \times Land\ area\ for\ 1GW\ solar\ park \quad (6)$$

3.1.4 Impact on the economic outputs of various agricultural land

In addition to the impact on the crop or vegetable production, another impact can be anticipated followed by the land occupation is the economic profitability for the landowner (farmer) as loss of the land implies the loss of revenue from the food production. The functional unit chosen for the calculation is €/ha in order to compare with the compensation amount of 4000-8000 €/ha (van der Zee et al., 2019) provided by the energy developers. The comparison aims to identify if there is a loss or a benefit. Economic output for crop/vegetable farms and the dairy cow farm is calculated with formula 7 and 8, respectively.

$$Economic\ output\ for\ crops\ and\ vegetables\ (€/ha) = Total\ economic\ output\ of\ specific\ crop\ type\ /Farm\ area\ for\ specific\ crop\ type \quad (7)$$

$$Economic\ output\ for\ dairy\ cow\ (€/ha) = Total\ output\ per\ dairy\ cow\ per\ year \times Dairy\ cow\ numbers\ /Fodder\ area \quad (8)$$

Table 2 presents the input data used for 3.1.2 and 3.1.3.

Table 2. Input data for 3.1.2-3.1.3

Calculation	Input data	Quantity	Unit	Source
Impact on the total land area	Land use requirement for land-based solar PV	0.8	MW/ha	(RVO & ROM3D, 2015a)
	Land use requirement for floating solar PV	1	MW/ha	(Rosa-clot & Tina, 2018)
	Land area in the Netherlands	Appendix A.		(CBS, 2018)
Impact on agricultural land	Yield per hectare for crops and vegetables	Appendix B	Kg/ha	(CBS, 2019a)

	Total number of dairy cow	1700000		(ZuivelNL, 2017)
	Total number of dairy goat	400000		(ZuivelNL, 2017)
	Total grazing land	1100000	ha	(ZuivelNL, 2017)
Impact on the economic outputs	The economic output of crop	Appendix C	Euro	(Wageningen University & Research, n.d.)
	Farm area for the crop type		ha	
	Total output per dairy cow per year		Euro	
	Dairy cow numbers			
	Fodder area		ha	

3.1.5 Impact on CO_2 emission

Additionally, the impact on the CO_2 emission was investigated. Turney and Fthenakis (2011) consider that biomass removal in the forest might bring about further CO_2 emissions, which counteracts the aim of deploying solar energy. In the current research, various landscapes other than forests in the Netherlands are also included. Biocarbon stocks (M ton C) for different ecosystem units and corresponding areas (ha.) are available in the Lof et al. (2017) Different ecosystem units are combined to forest, cropland, grassland, wetland and other in accordance to the Land use, Land Use Change and Forestry (LULUCF) category to calculate average biomass density (M ton C/ha) in the major types of landscapes.

- Forest:

Given that the portion of removed woods in the forests might end up with long-term products that could be considered carbon sequestration, (Turney & Fthenakis, 2011) the different shares of the forestry products in the Netherlands were investigated.

Share of the removed biomass turn into the long-term (Logs) and short-term (pulpwood) products, wood fuel and wood residues are calculated with the data from “The Netherlands National Market Report 2017”. (Institute for Forestry et al., 2017) In Table 3, share of different forestry products are listed in the last column of the table. It is calculated by dividing the corresponding amounts (m^3) of each forestry product by the total removals from the forest. Share of industrial round wood is already available in the report, which is 38% and the share of wood fuel is assumed as a sum of industrial round wood and wood residue subtracted from the total removals.

Table 3. Forestry products and share of each type of product of total forest removal in 2016

Forestry products		Amounts (m^3)	Share of total removal
Industrial round wood			38%
Total removals from the forest in 2016		2300000	
Sawlogs and veneer logs (Sequestration)	Coniferous	300000	17%
	Non-coniferous	88000	
Pulpwood	Coniferous	297000	21%
	Non-coniferous	197000	
Wood fuel			20%
Wood residues	domestic-supply	971000	42%

Note: Shaded cells are the results of the Detailed calculation

- Cropland:

For the crop biomass, it was considered 62% of the biomass categorized as crops and 38% as above-ground residue. (Van den Born, van Minnen, Olivier, & Ros, 2014) When solar PV installed on the land, the vegetation should be removed in advance. Therefore, the residue will be removed when decided to install solar PV on agricultural land. Moreover, the report by Van den Born et al. (2014) provides the portion of the burned crop and residue from total biomass. Table 4. provides the proportion of burned biomass of the total biomass.

Table 4. Share of burned biomass for the cropland

Crop biomass	Share of the total crop biomass
Residue burned	32%
Crop burned	4.3%

For other lands, the CO_2 emissions were calculated with formula (7), while for the forest and cropland, it is calculated with formula (8) and (9), respectively.

$$CO2\ emission = Average\ biomass\ density \times\ Land\ area\ of\ 1GW\ solar\ PV \times \frac{44}{12}{}^{1} \quad (7)$$

$$CO2\ emission = [(Share\ of\ pulpwood\ +\ Share\ of\ wood\ fuel\ +\ Share\ of\ wood\ residues) \times Average\ biomass\ density\ +\ soil\ carbon\ density] \times\ Land\ area\ of\ 1GW\ solarPV \times\ 44/12 \quad (8)$$

$$CO2\ emission = (share\ of\ burned\ crop + share\ of\ burned\ residue) \times Average\ biomass\ density \times\ Land\ area\ of\ 1GW\ solar\ PV \times \frac{44}{12} \quad (9)$$

Next, CO_2 payback time was calculated next to the CO_2 emission in different landscapes to compare the CO_2 mitigation by substitution of fossil fuels and its direct emissions during the construction phase. For the landscape other than agricultural land, it is calculated with the formula (10),(11),(12), and Table 5 lists the variables used for the calculation.

$$\text{CO2 payback time } (year) = CO2\ emission // Annual\ CO2\ mitigation\ for\ 1GW\ solar\ park \quad (10)$$

$$Annual\ CO2\ mitigation\ for\ 1GW\ solar\ park = CO2\ emission\ factor\ of\ gray\ resources \times Annual\ electricity\ generation\ from\ 1GW\ solar\ park \quad (11)$$

$$Annual\ electricity\ generation\ from\ 1GW\ solar\ park = Full\ load\ hours\ (MWh/MWp/year) \times 1GW \quad (12)$$

Table 5. Input data for CO_2 PBP calculation

Input data	Quantity	Unit	Source
CO_2 emission factor for gray energy resources	0.56	kg/kWh	(CO2 emissiefactoren, 2015)

[1] 44 and 12 is a molar mass of CO_2 and C, respectively.

Full load hours	950	MWh/MWp/year	(Lensink, 2018)

However, for the agricultural land, additional benefits might be the avoidance of annual Greenhouse gas (GHG) emissions associated with the lifecycle of the agricultural practice, which can be avoided with the land-use change.

Kramer, Moll, & Nonhebel, (1999) investigated the lifecycle GHG emissions (kg CO_2 eq./kg products) of typical crop types in the Netherlands. However, one main limitation of the data is that the global warming potentials (GWP) used in the calculation was based on the IPCC 2nd report (21 for CH_4, 310 for N_2O). Therefore, the data correction was made by applying the latest GWP100 from the IPCC 5th report (34 for CH_4, 298 for N_2O). Table 6 lists the GHG emission per kg for various crops and vegetables. For the grassland, (grazing land) table 7. provides the average greenhouse gas emission per hectare of the land.

Table 6. Lifecycle GHG emission for various crop types in the Netherlands

Dutch crop products	**Kg CO_2 eq./kg products** (Kramer et al., 1999)	**Kg CO_2 eq./kg products**
Spring wheat	0.307	0.302
Winter wheat	0.399	0.391
Spring barley	0.347	0.343
Winter barley	0.326	0.321
Potatoes	0.147	0.145
Sugar beets	0.041	0.040
Spinach	0.198	0.199
Spinach (for the industry)	0.129	0.128
Cabbages	0.094	0.094

Table 7. Average greenhouse gas emission per hectare from the dairy farm

GHG	**Emission (kg/ha)**	**Source**
N2O	19	(Schils et al., 2007)
CH4	327	(Schils et al., 2007)
CO_2	1570	(Olesen, Schelde, Weiske, & Weisbjerg, 2006)

After that, the avoided GHG emissions by 1GW solar PV installation on the cropland was calculated by multiplying the impacted crop production identified in the previous section for different crop types. For the dairy farm, the impacted land area due to land-based solar PV was multiplied. Table 8 presents the result of avoided GHG when a 1GW solar park is installed on the agricultural land.

Table 8. Avoided GHG with 1GW solar park installation

Type of land	Avoided kg CO_2 eq
Cropland[1]	3.94×10^6
Grassland	2.28×10^7

Note 1: The average value of the various crops is used (Appendix E)

Lastly, the CO_2 payback time for the agricultural land is calculated with formula (13).

$$Time\ for\ compensation\ (year) = \frac{CO2\ emission}{Annual\ CO2\ mitigation\ for\ 1GW\ solar\ park + Avoidance\ GHG\ emission} \quad (13)$$

Here, the annual CO_2 mitigation is calculated formula (11), (12).

3.2 Impact on the biodiversity

The literature review was conducted to investigate the identified or potential impacts on the biodiversity directly caused by the solar PV facility. Both scientific and gray literature are used. Search engines for the scientific literature include: “google scholar," "Scopus," and "Wildcat" and gray literature is searched via the “Google” engine. Literature related to the impact of solar PV was selected. Then the contents of the documents were analyzed. Moreover, the references in each literature were also examined to identify additional relevant publications.

Main key-words for the literature reviews are: “Solar PV”, “rooftop solar PV”, “land-based PV”, “floating PV”, “environment”, “soil”, “microclimate”, biodiversity”, “wildlife”, “habitats”.

Moreover, in order to identify how large-scale solar PV in the Netherlands perceive the issue about the impact on biodiversity, the environmental permits for two projects were analyzed. The permits were available online.

- Solar Park Lange Runde
- Floating solar park Lingewaard

These documents were available online.

3.3 Visual impacts

In order to get insights regarding the landscape design and consequent visual impacts of the existing solar PV projects in the different landscapes, the interviews were conducted with several energy developers. Besides, Solar Park Lange Runde was visited to investigate how the solar park embedded in the original landscape. The solar park was photographed from different angles as it explicitly presents the visual impact of the solar park.

The procedure to choose the interviewee is as follows.
Large scale solar parks in the Netherlands are available on the website of Solar Plaza[2], where lists the top 50 largest solar parks in the Netherlands. The choice of solar park projects was located in different types of landscapes, which is identified through the website of each solar PV project. Regarding the rooftop PV, the program manager of

[2] https://thesolarfuture.nl/top-50-solar-projects-in-the-netherlands

the rooftop solar PV project at Utrecht University is interviewed. Table 9 lists the interviewee, projects, landscapes and the date when the interview was held.

Table 9. Lists of the interviewee and the project

Interviewee	Project	Landscape	Date
Jolt Oostra	UU rooftop	Roof Historical buildings (future interests)	25/07/2019
Wouter Guliker	Solar Park Andijk Solar park Veendam	Agricultural land Industrial land	24/06/2019
Niels van der Linden	Solar park Lange Runde	Horticulture land	11/07/2019

Process of the interview: The topic and the purpose of the research is introduced in the beginning. Then it is announced to the interviewer that the content of the interview will be used in the academic purpose. After the announcement, the interviewee made a brief introduction of the projects and relevant information about visual impacts about their design and consideration. The contents of the interviews were then analyzed.

3.4 Economics

Economic indicators considered in the research is the Levelized cost of electricity (LCOE), which is a useful application for the cost-benefit analysis. (Blok & Nieuwlaar, 2017) With the aid of the financial aid provided by the government, the actual generation cost for the electricity will be lower. Moreover, as from 2019 onwards, the SDE+ is distinct to the roof and land/water-based, (Lensink, 2018) which too implies that different energy generation costs can be anticipated in a different landscape.

3.4.1 Levelized cost of electricity

LCOE was calculated with the following formula.

$$LCOE = \frac{\alpha \cdot I + O\&M}{E} \tag{14}$$

$$\alpha = \frac{r}{1-(1+r)^{-n}} \tag{15}$$

Where:
α=capital recovery factor
r= discount rate
I=initial investment
O&M=annual costs for operation and maintenance
E=annual electricity production
R=discount rate
n= lifetime of solar PV

Data is available from Lensink (2018), and is listed in table 10.

Table 10. Economic inputs for the calculation

	PV≥15kWp <1MWp (roof-mounting)	PV ≥ 1 MW (roof mounting)	PV>=1 MW (Land or water)

The capacity of the project (MW)	0.25	1	1
Investment cost (€/MW)	770	750	740
Operational cost (€/kW/year)	17.1	13.76	13.13
Maintenance cost (€/kW/year)	2.41	2.42	2.42
Full load hours (MWh/MW/year)	950	950	950
Lifetime (year)	20	20	20
Discount rate	3%	3%	3%

The assumption of the calculation includes the discount rate, which adopted 3% for the research. (van Sark & Schoen, 2017) For the floating solar PV, the LCOE is assumed 9% higher than that of the land-based solar PV when the performance ratio is 5% higher. (World Bank Group ESMAP and SERIS, 2019)

3.4.2 Subsidy

The amount of subsidy that the project can get is calculated with the Maximum phase amount substrate provisional correction amount for the grid delivery and own use. The following table 11 provides the rates for SDE+ from Netherlands Enterprise Agency (2019)

Table 11. Rates for solar PV in different phases

	Phase 1	**Provisional correction amount**	
	Maximum base amount (€/kwh)	grid delivery	own use
Roof ≥ 15 kWp en < 1 MWp	0.09	0.041	0.069
Roof ≥ 1 MWp	0.09	0.041	0.06
Land and water ≥ 1 MWp	0.09	0.041	0.06

Several assumptions were made for calculating the applicable amount of SDE+.

1. Maximum base amount of phase 1 was used in the subsidy calculation
2. For the solar PV with the capacity between 15kWp and 1MWp, it is assumed 50% for own use and 50% for the grid delivery, and for the solar PV with capacity ≥ 1MWp, 10% for own use and 90% for the grid is assumed. This value is based on the calculation examples provided by the SDE+ brochure. (Netherlands Enterprise Agency (RVO), 2018, 2019) This assumption aims to consider the difference of subsidy for the rooftop PV capacity since the maximum base amount and grid delivery are the same for all types of solar PV.

4. Results

4.1 Land-use impacts of 1GW solar PV

4.1.1 Rooftop PV

Under the assumption of every building owns same roof area, the monument roof area was roughly calculated and the result is provided in table 11.

Table 11. The roof area of the monumental and residential, non-residential buildings

Type	Available roof area (km^2)	Capacity (GW)	Roof area occupied by 1GW rooftop PV
Monumental buildings	6.15	0.98	102%
Non-monumental buildings	885.85	141.74	0.71%

The available roof area calculated for the monumental buildings is 6.15 km^2 and this value only takes up 0.7%[3] of the identified roof area by Broersen et al. (2018), which means that even though all the monumental buildings forbid the rooftop PV installation, the impact is small due to most of the buildings are non-monumental. Remaining capacity indicates that huge area is available for the solar PV development.

4.1.2 Impact of land use on the land and water

With the land requirement of 0.8MW/ha and 1MW/ha for land-based and floating PV, it is calculated that 1250 hectare of the land and 1000 hectare of the water surface is required for the 1GW capacity, respectively. The required area is compared with the total area of different land types in table 12 to perceive the general idea of the land occupation.

Table 12. Occupied area by 1GW solar PV on major land types

Land use	Area (ha)	Land occupation
Traffic area	115563	1.08%
Built up area	235839	0.53%
Semi built-up area	49318	2.53%
Recreational area	105418	1.19%
Agricultural land	2236317	0.06%
Forest and natural area	498956	0.25%
Total Inland water	371941	0.27%

[3] 6.15 km^2 divided by the total available roof area of 892 km^2

Total open water	415264	0.24%

According to the results, the impact of 1GW solar PV on various landscape varies. Except for the traffic area, semi built-up area and recreational area, the occupied area is lower than 1%. Among those landscapes, Agricultural land has the minimum impact, of merely 0.06%.

4.1.3 Impacted agricultural production

Although the land use impact is low for the agricultural land, with its function, land occupation might lead to consequent effect on agricultural products. Table 13 presents the potentially reduced arable crops and vegetables. Table 14 shows the potentially affected livestock numbers associated with the grazing area reduction.

Table 13. Impact on arable crop (lighter gray) and vegetable (darker gray) productions

Crop/Vegetable types	Reduced production (ton/GW)	Reduced production/Total production in 2018
Green maize	49875	0.62%
Sugar beet	95500	1.47%
Total potato	45750	0.76%
Total ware potatoes	51500	1.64%
Total starch potatoes	42875	2.77%
Total seed potatoes	38750	2.88%
Total wheat	11000	1.12%
Winter wheat	10125	1.16%
Spring wheat	8750	7.91%
Seed onions (exclude loss)	41375	5.00%
Spring barley	8375	4.47%
Winter barley	11375	17.22%
Chicory for inulin	54250	39.76%
Winter carrot	78003	20.3%
Total cabbage	32245	11.6%
Spinach	26504	39.8%

Reduced production of crops, ranges from below 1% for major crop types to more than 17% for winter barley and even reaches about 40% for Chicory and Spinach due to the differences of the harvested areas. Typically, the affected production of vegetables is generally higher than most of the crop production. This result indicates that the future site selection for solar PV on the agricultural land should avoid the land that has higher production.

Table 14. Impacts on dairy animals

Impact on dairy animals	Total grazing area (ha)	Number of livestock	Livestock Density (number/ ha)	Impacted number per GW
Dairy cow	1100000	1700000	1.55	1931.82

Dairy goat	1100000	400000	0.36	454.55

When 1GW solar park occupied the grazing area, about 2000 dairy cows and 455 dairy goats might lose their sphere of activities, which might lead to the intensifying grazing activity or reduced livestock.

4.1.4 Impact on the economic outputs of agricultural land

Land renting from private landowners requires the energy developers to provide compensation amount. Moreover, it is acknowledged that even the land owned by the municipality, similar amount of compensation should be provided due to the competition between the agricultural sector. (van der Linden, Personal communication) This compensation amount was compared with the economic outputs in a different type of farm, to identify if there are benefits for the farmers with land rent. Table 15 presents the results, while in figure 2, the results are presented schematically.

Table 15. Economic outputs in agricultural lands

Output per ha (euro/ha)	2015	2016	2017
Wheat	1565	1280	1236
Barley	482	466	609
Seed potatoes	2903	2801	2575
Ware potatoes	2978	3484	1740
Starch potatoes	444	547	538
Sugar beets	3055	3086	3627
Onions	2718	1576	1845
Dairy farms	6029	5772	7282

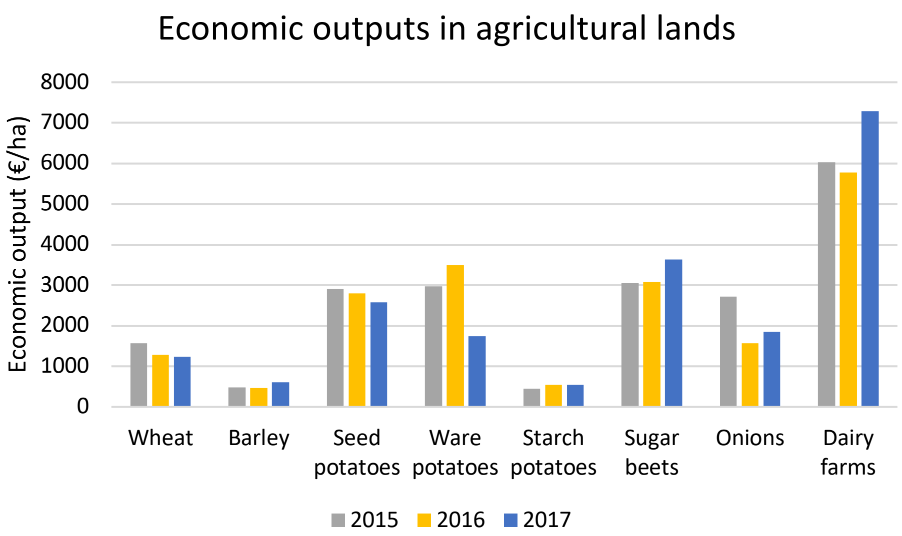


Figure 2. Economic outputs of crops in agricultural lands

Results show variations between the crop types and also between the agricultural type. Generally, the economic output of crop land is lower than the compensation amount of 4000-8000 €/ha. Notably, the farms cultivated barley, and starch potatoes have the lowest outputs per hectare of the land, the land lease for the solar PV may be economically profitable for the farmers. Regarding the dairy farms, the economic outputs from 2015 to 2017 range between 4000-8000 €/ha. Therefore, solar park installation on the dairy farm might have larger economic impact compared to the croplands.

4.1.5 GHG emission

The fundamental aim of solar energy is to mitigate CO_2 emissions. However, additional emissions associated with biomass removals in various landscapes can be anticipated during the construction of a solar PV facility. (Turney & Fthenakis, 2011) Table 16 displays the results of CO_2 emission associated with the biomass removal during the construction, and the CO_2 payback period. (PBP)

Table 16. Results of CO_2 emission and CO_2 PBP

Land Category	CO2 emission per GW (M ton/GW)	CO_2 PBP (year)
Forest	0.7424	1.40
Cropland	0.4517	0.84
Grassland	0.5400	0.97
Aquatic wetlands	0.0602	0.11
Settlement	0.4942	0.93
Dunes	0.0509	0.10

(Note: Settlement including greenhouses, public green space, and farmyards, and barn)

According to the table, most land categories except for the forest require less than one year to pay back the emitted CO_2 for the solar PV construction. It is because the mitigated CO_2 by energy substitution with 1GW solar energy overwhelms the emitted amount, which implies the significance of the energy transition. Dune landscape also shows the lowest CO_2 emissions and followed by the aquatic wetlands. High CO_2 emission in the cropland can also be attributed to the high soil carbon, and this research used the average of total carbon stocks including soil and biomass.

4.2 Impacts of solar PV on biodiversity

4.2.1 Rooftop PV

Rooftop PV does not have the prominent effects that are detrimental to biodiversity. (Hernandez et al., 2014) Distributed arrangement of the rooftop PV, due to the limited roof area, might minimize the impacts compared to the large-scale centralized system on the land. (Harrison, Lloyd, & Field, 2017) (Gasparatos, Doll, Esteban, Ahmed, & Olang, 2017) In this sense, hardly any literature is available for the impacts of rooftop PV on the biodiversity or specific species. Although potential threats such as glare risk of the solar panels and intrusion of the nesting sites primarily in the old buildings (Changeworks, 2009) are identified for the avian species, currently no data can substantiate to what extent the impact might be. Moreover, solar panels that adequately integrated into the concept of the green roof, which proposed to mitigate the negative impact of urbanization may increase the biodiversity. (Gasparatos et al., 2017; Shafique, Kim, & Rafiq, 2018; Vijayaraghavan, 2016) To sum up, owing to that there is no suitable environment on the roof which can provide a condition for the fauna and flora, the impacts on the biodiversity can be considered low for the rooftop solar PV.

4.2.2 Land-based solar PV

- Habitat fragmentation

Among the potential impacts of a large scale of solar PV on the biodiversity, habitat loss and fragmentation are considered as the dominant threats for the wildlife, which obstructs the movement of the species and disturb their lifestyle (Grippo, Hayse, & Connor, 2015; Hernandez et al., 2014; Turney & Fthenakis, 2011) It is identified from Agassiz's desert tortoise, which is one of the threatened species in the U.S. Albeit expected low impact with the relocation program, it came out the actual impact on the number of species was higher; thus the higher impact on habitat fragmentation, which had to pause the project. (Lovich & Ennen, 2011; Rule, 2014)

- Construction and decommission phases

The construction process generally requires the removal of vegetations to the bare ground (Guerin, 2017), which might put a risk on the insects, terrestrial, and subterranean animals. (Lovich & Ennen, 2011) Heavy vehicles will also result in the direct mortality of the species by the compressive force and collisions. (Lovich & Ennen, 2011) For the latter case, the mortality of the Myna and Apostle bird species were reported. (Guerin, 2017) Besides, dust generated from the vehicle activities and bare soil areas (Guerin, 2017) may have adverse effects on the vegetations and animals located in the near distance from the construction site. (Lovich & Ennen, 2011) The impact during the commission phase of the solar PV facility is considered similar to the construction process. (Lovich & Ennen, 2011)

- Operation phase

Throughout the operational phase, the vegetation should be removed frequently to prevent from casting shadows on the panels. (Turney & Fthenakis, 2011) One of the methods is by using herbicides which are detrimental to the environment and may have a long-term consequence on the biodiversity. (Hernandez et al., 2014) Another way is by grazing sheep on the site, which not only avoids the adverse impacts by using chemicals but also contributes to the dual-land use. Another dominant threat is collision risk, especially for the avian species, which results in severe injuries and even the mortality. (Grippo et al., 2015) Confusion with panels into the water surface is considered a possible reason for the collision. (Walston Jr., Rollins, Lagory, Smith, & Meyers, 2016) Another consequence of the collision is subsequent bird mortality by the predation due to the birds with the wound or injuries cannot escape from the predators. (Kagan, Viner, Trail, & Espinoza, 2014) Moreover, the shift of bird communities is identified in the solar park situated in arid Savanna, either in species and density of the birds on the ground of the land transformation from Savanna to grassland by vegetation removal. (Visser, Perold, Ralston-paton, Cardenal, & Ryan, 2019)

Regarding the insects, the only impact identified was that polarization light from solar panels might lead to the maladaptive behavior of the water insects to spawn on the panels instead of in the water. (HORVATH et al., 2010) However, it is unclear how this may affect the population of these insect species. During operation, the solar panels are situated above the soil, and it will hinder the penetration of the light and the rainwater, which will result in the microclimate change. (Armstrong, Waldron, & Whitaker, 2014) Altered microclimate may directly affect the temperature, moisture, and evapotranspiration of the soil, which further results in the vegetation change in the long term (Armstrong, Ostle, & Whitaker, 2016). Armstrong et al. (2016) verified that the PV arrays led to the variation of microclimate and the vegetations between the gap area (between solar arrays) and the control area, with one year period of data collection.

- Positive impacts

On the other hand, land-based solar PV can also provide positive impacts on biodiversity. Various species were identified in the solar park during operations. Comprehensive literature research, which reviewed different types of animals including mammals, birds, insects, amphibians, and reptiles observed in the solar parks, is well summarized in Van der Zee et al. (2019). For some animals, solar parks can function as the habitats due to that the fence with openings enables them to enter the park, and it may provide the sanctuary from their predators. (Turney & Fthenakis, 2011)

Furthermore, the solar park may be used by some birds as breeding places as well. Few bird nests are observed in the power plant and near infrastructures. (Rudman, Gauché, & Rudman, 2017) However, for the birds that prefer openness and views, such as meadow birds, or larger birds such as geese it is more likely that they do not breed and nesting around the solar PV facility. (van der Zee et al., 2019) These diverse reactions of the birds show different bird species react differently on the disturbance caused by the large scale solar PV.

Current mitigation measures for the impact on biodiversity regarding solar PV in the Netherlands focus on the identification of the species and habitats that are protected under the Nature conservation Act 1998, Flora and Fauna Act, and Habitat Directive and Bird Directive (under which is Natura 2000 area) with the aim to avoid detrimental impact on those species during the operation of the project. If found there possibly have an impact, then the proper mitigation measures should be adopted. Moreover, any project should ensure the avoidance of the breeding season of the bird species (March-July) during which they are more sensitive to the disturbances. (Gemeente Emmen, 2015) Nevertheless, there is no monitoring requirement provided for the solar PV projects in the environmental permits.

4.2.3 Floating solar PV

The overall impacts on the bird species and other biodiversity during site selection and construction are similar to the land-based solar PV. The mitigation measures identified for the land-based solar PV are also applied to the floating solar PV construction. Therefore, this section focused on the impact of water biodiversity.

- Impact on the water quality

The significant impact of floating solar PV on the biodiversity will be associated with the coverage of water surfaces by the panels as it might have potential impacts on the water quality. However, there is little research available regarding the impacts on the water quality, which is significant for the aquatic ecosystem. Paper on this topic is only available by Jones and Armstrong (2018), who provide the theoretical impacts of floating solar PV on the water quality. The summary of the paper is provided below. During summer periods when there is higher irradiation, surface water heats up while the deeper layer remains cool, thus inhibiting the vertical mixing of water, which results in the stratification of the water temperature and further differentiate the nutrients, oxygen concentration in different layers of the water. The existence of floating panels will possibly reduce the occurrence of stratification in a way that it reduces the temperature differences between the layers. However, there is another possibility that more stratification will occur in the water with floating panels due to the prevention of wind action, which can accelerate the mix of the water layers. Therefore, the degree of the effect with floating solar PV is uncertain. This paper concluded with the necessity of future research for the identification on which conditions the impact will be positive and in which condition it will be negative. The analytical tools are considered useful to shed light on the unknown impacts. (Jones & Armstrong, 2018) In the Netherlands, Stowa provides the model which can identify the impact of the coverage with solar PV on the water. The model has been tested with four different water bodies with different functions including, Ijsselmeer, Everstekoog (the sewage treatment plant), floodplain PLAS Havikerwaard, and the drinking water reservoirs in Biesbosch. (Loos & Wortelboer, 2018) The results confirmed that there are consequent impacts on the water temperature, oxygen concentration level, stratification, as a result of floating solar PV installation. However, except for the light intensity that is decreased around 90% in all four water bodies, the changes of the other water quality before and after floating panel installation showed variations in different water bodies. The results correspond to Jones and Armstrong (2018) that the location or the types of water bodies will affect the outcome of the water quality.

- Impact on the aquatic biodiversity

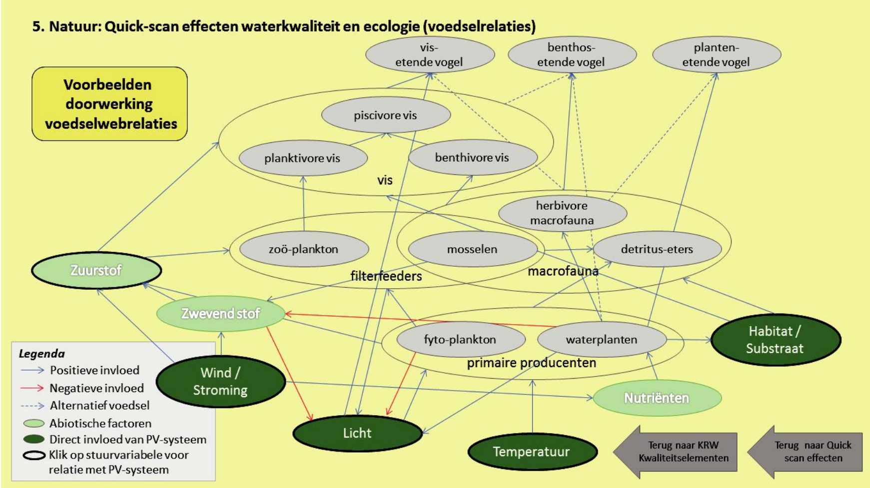
Reduced light permeability may impact submerged vegetation, whereas the algae are less affected as it is generally on the surface of the water. The increasing number of algae might increase the turbidity of the water, thus exacerbating the situation for the plants. Another potential consequence might be the decreasing algae formation (Sahu et al., 2016), macroinvertebrates and water plants (Loos & Wortelboer, 2018) as a result of water quality deterioration with reduced stratification.

There might be a temporarily detrimental impact on benthonic and other aquatic communities living on the bottom of the lake due to the anchoring and mooring by the increment of suspended solids or direct contact to the structure (Costa, 2017) Thus, natural lakes might be more affected than artificial lakes, ponds, or reservoirs.

Subsequently, the number of fish will get affected due to the food shortage. Buij et al. (2018) assumed that lack of food might induce the fish in the deeper water migrate to the shallower area for foraging, which will be significant in the freshwater area, such as the riparian zone. (Buij et al., 2018) However, the extent of these impacts is determined by the covered area (%) and light permeability. Thus, to minimize the potential impact, it is suggested the coverage should not be above 50%, while with less than 10% of coverage, the impact might be minimal. (Loos & Wortelboer, 2018)

As a result of the impact on aquatic species, further impacts on biodiversity can be speculated with the schematic figure 3, which presents the relationship between the water quality and aquatic biodiversity provided by Loos and Wortelboer. (2018) The population of Grebe (fish-eating bird), Krooneed (plant-eating bird) who eat submerged plants, and Tufted (macrofauna-eating bird) whose food is macrofauna that lives in the soil will get affected. (Loos & Wortelboer, 2018)

Figure 3. Effects of the water quality and ecology (Source: Loos and Wortelboer, 2018)



The results of the literature review suggest that there is a huge necessity to clarify the impacts associated with floating solar PV installation. For the water quality, although the model from Stowa provides the insights into the potential effects, the field data or lab data is also necessary to substantiate if the effect is positive or negative on the water quality, especially for the natural water bodies. Existing floating solar PV may provide the ideal condition for such research purposes.

To sum up this chapter, the potential impact of solar PV on biodiversity in different landscape is summarized. Besides, it is acknowledged that the impact mitigation effort in the Netherlands only includes the impacts associated with habitat fragmentation during site selection or disturbance for the bird species during construction. This result implies that more efforts should be paid to the monitoring process to facilitate the understanding of the overall biodiversity impact, especially on the natural area. Nevertheless, it can be assumed that when the landscape has higher biodiversity, the impact will be more prominent and significant. In this sense, it would be better to locate the PV in the areas with low biodiversities, such as degraded areas and urban areas for the land-based PV. (Visser et al., 2019) For the floating type, Choi (2014) suggested the use of water for mineral extraction after they are abandoned and avoid the water bodies with the function of fishery activity.

4.3. The visual impact of solar PV

A GW-scale solar PV installation might bring about enormous changes in the original landscapes. Thus, the visual impact is regarded as one of the significant adverse impacts of utility-scale solar PV. (Pimentel Da Silva & Branco, 2018; Turney & Fthenakis, 2011) This chapter presents how existing large scale solar PV project deal with its visual impact.

4.3.1 Rooftop PV

Rooftop PV project in Utrecht University does not require the visual consideration, either the environmental permit for installing project. Generally, the buildings on the campus, where it is out of sight from the street. Whereas in the lower buildings, the PV system might be visible. (Figure 4, Right) Therefore, the East-West orientation of the panel is preferred to reduce the aesthetic intrusion of the landscape. This orientation not only reduces the visibility with its lower angle in the sake of maximizing the light absorption from East to West but also can fully cover the roof surface to maximize using the available area. (Oostra, Personal communication, 2019)

Figure 4. Rooftop PV in the Uithof (Source: Utrecht University)

The fundamental aim of the PV installation at the University is to achieve energy-neutral by 2030. In this regards, the monumental buildings are also necessary for the contribution to the energy transition. (Oostra, Personal communication, 2019) In this case, the visual impact might be one of the biggest concerns which should be deliberately considered. Rooftop PV installation on the historical or monumental buildings requires to provide insightful information regarding the measures to avoid negative impacts on the aesthetics and cultural value of the buildings for obtaining the environmental permit. (Cultural Heritage Agency of the Netherlands (RCE), 2014) The possible way to mitigate the impact is to ensure the “invisibility” of the structure from the street. Alternatively, the use of the panels with colors to add aesthetics of the buildings may be another effective way. (Cultural Heritage Agency of the Netherlands (RCE), 2014)

4.3.2 Land-based solar PV

With the concern with the visual intrusion of the large-scale solar PV, lots of municipalities require the landscaping of the solar park to be embedded in the existing landscape as an additional component. (Guliker, personal communication, 2019) In order to get the environmental permit in these municipalities require the energy developers to provide the adjustment they had made for reducing the landscape invasion. (Guliker, personal communication, 2019) Solar Park Andijk, (Figure 5-Left) which is situated on the former agricultural land, has adopted the measure of planting various trees surrounding the solar park, which provide two additional functions. One is to block the visibility of the facility with the “green barrier,” and the other is enhance biodiversity on the area, as the trees might attract birds and insects. It is acknowledged that the municipalities are getting more critical in the detrimental issues, thus more challenging to get the permit. However, for their another project, Solar Park Veendam, situated in the industrial land, there was no visual consideration.

(Solar park Andijk) (Solar park Veendam)

Figure 5. Design of solar park (source: Chintsolar)

Interestingly, solar park Lange Runde, which is situated on the horticultural land, municipality Emmen did not require the landscaping consideration. (van der Linden, personal communication, 2019) Conceivably, the site is in the rural area, and few neighbors reside in the vicinity. Nevertheless, there was a complaint from one of the residents: about the view outside from the windows got affected with the solar park.

Fig 6. The views of solar park Lange Runde with different angles and distances

During the fieldwork, it is substantiated that the area is relatively secluded from the urban area, and fewer residents were living around the solar park. Moreover, it is invisible from a distance. (Figure 6-upper right).

Table 17. Summary of the visual impact

Landscape	**Project**	**Landscape design requirement**	**Mitigation measure**
Roof	Utrecht University	x	East-West orientation
Monumental building		√	East-West orientation The darker color of the panels Use the flat roof
Agricultural land	Andijk	√	Tree planting surrounding solar park
Agricultural land	Lange Runde	X	/
Industrial land	Veendam	X	/

To sum up, during the interview, it is identified that the requirement for landscape consideration mainly depends on the municipalities. Furthermore, even the solar park is installed in the similar type of the landscape, requirement of the landscaping is possibly determined by the number of neighbors around the area. Indeed, it is considered that when PV systems are situated in rural area, the concern of the visual impact might be ignorant. (Pimentel Da Silva & Branco, 2018) Table 17 lists the summary of the landscape consideration of the solar PV projects.

4.4 LCOE and subsidy of rooftop PV, land-based PV and Floating PV

This section aims to understand how the national subsidy scheme (SDE+) works on the Levelized Cost of Electricity (LCOE). The LCOE and subsidy are calculated for the roof, land, and the water, to compare the differences. Table 18 presents the results of the calculation.

Table 18. LCOE and available subsidy for each type of PV location

Location of solar PV	Capacity	LCOE (€/kWh)	Subsidy (€/kWh)
Roof	PV≥15kWp, <1MWp	0.075	0.035
	PV≥1 MW	0.07	0.047
Land	PV≥1 MW	0.069	0.047
Water	PV≥1 MW	0.075	0.047

The result of the LCOE calculation shows that there is no considerable difference between rooftop PV and land-based PV when it is a 1MWp scale. However, the LCOE of land-based solar PV is slightly lower than the rooftop PV (larger than 1MWp) and ranks the top implies that from the landscape perspective, for generating 1KWh electricity, less cost is required from the land. Moreover, the subsidy for the roof, and land or water are same amount, while only 0.037€/KWh for the smaller scale of rooftop PV electricity generation. It implies that with the aid of the subsidy, LCOE for land-based solar PV is the cheapest.

5. Discussion of the tradeoffs of 1GW solar PV in different landscapes

Based on the identified impacts in previous chapters, table 19. presents the overview of the impacts in various landscapes in the Netherlands. The chosen landscapes are focused on different functions of the land or water. Discussion of the tradeoffs in few landscapes is addressed below based on the results.

Table 19. Overall tradeoffs of 1GW solar PV on different landscapes

<table>
<tr><th></th><th>Landscape</th><th>Land Occupation (%)</th><th>CO₂ emission (Mton/GW)</th><th>Biodiversity</th><th>Visual</th><th>LCOE-Subsidy (€/kwh)</th></tr>
<tr><td rowspan="2">Rooftop PV</td><td>Monumental buildings</td><td>102[4]</td><td rowspan="2">0</td><td>Low</td><td>High</td><td rowspan="2">0.04 (small) 0.023 (large)</td></tr>
<tr><td>Non-monumental buildings</td><td>0.71</td><td>Low</td><td>Low</td></tr>
<tr><td rowspan="4">Land-based PV</td><td>Agricultural land</td><td>0.06</td><td>0.4520 (crop)-0.5400 (grassland)</td><td>High</td><td>Low</td><td rowspan="4">0.022</td></tr>
<tr><td>Natural area</td><td>0.25</td><td>0.0509 (Dunes)-0.7424 (Forest)</td><td>High</td><td>High</td></tr>
<tr><td>Industrial land / Business park</td><td>1.45</td><td rowspan="2">0.4942</td><td>Low</td><td>Low</td></tr>
<tr><td>Urban area</td><td>0.53</td><td>Low</td><td>High</td></tr>
<tr><td rowspan="3">Floating PV</td><td>Ijsselmeer/Markermeer</td><td>0.55</td><td rowspan="3">0.0602</td><td>High</td><td>High</td><td rowspan="3">0.028</td></tr>
<tr><td>Water for mineral extraction</td><td>80.52</td><td>Low</td><td>Low</td></tr>
<tr><td>Recreational water</td><td>6.43%</td><td>High</td><td>High</td></tr>
</table>

Before delving into the discussion, the explanation is necessary for the biodiversity and visual impact as they are the qualitative criteria. There are no suitable indicators to quantify these impacts, which implies the limitation of the current research. However, as provided in chapter 6, the landscape with low biodiversity might have a lower detrimental impact caused by the solar PV facility. In line with this idea, except for the urban area (including roof, industrial area, and traffic area) and industrial use of the water (water for mineral extraction), all landscapes were ranked as potentially high impact on the biodiversity. Visual impact was ranked based on the extent of the intrusion on the original function of the landscape. For instance, when the aesthetics and scenery is the significant function of the landscape, the visual impact was ranked high, these landscapes include monumental buildings, natural area, Ijsselmeer, and recreational water.

Moreover, it is identified that the number of residents in the vicinity to the facility determines the requirement of visual impact and further the landscaping requirement. Thus, the urban area, which has a higher population density than the rural area, also was ranked as high extent of the visual impact. In the table, the lowest value or considered the low impact in each impact category was colored to highlight its landscape(s).

[4] The value is larger than 1 due to the insufficient roof area for 1GW solar PV installation

1. **Tradeoffs of rooftop PV on the buildings**

Unquestionably, non-monumental rooftop PV is the best way to develop solar energy due to no CO_2 emission, a low impact on biodiversity, and low visual impact. Besides, it is identified that a sufficient roof area is available for solar PV development in the Netherlands. (Broersen et al., 2018) Thus, prioritizing the use of the roof might be the optimal option. However, the barrier might be the high energy generation cost compared to the utility scale. When the capacity is lower than 1MW, the amount is nearly double that of utility-scale. Moreover, when the capacity is even lower, LCOE reaches 1.33€/kwh. (van Sark & Schoen, 2017) This result suggests two things to successfully maximize the use of the roof area for solar PV development. One is the cost reduction for the rooftop PV to make it less costly. The other is the need to investigate the potential roof area that is available for the utility-scale (generally larger than 1MW) solar PV installation. As can be seen from the table, the generation cost for the 1MW rooftop PV is competitive with the land-based.

2. **Tradeoffs of land-based PV on the agricultural land**

Agricultural land is half of the total land area in the Netherlands, which implies that there is less impact on the total area when installing a 1GW scale solar PV. Generally, it is always an indication to inform the extent of the impact. (Bellini, 2018) However, the impact on agricultural land should not only focus on the area, but also the function of the land. This research calculated the potentially reduced food production for a 1GW solar PV. The result shows the extent of the impacts for the production differs by the types of crops and vegetables, which ranges from 0.6% for the maize farm to nearly 40% for spinach farm. Therefore, the type of crop produced in the former land should also be taken into account for the site selection, to avoid the land of which crop production might be profoundly affected and further threaten the food security, which is the common issue for the biomass. (Field, Campbell, & Lobell, 2007; Muller, Schmidhuber, Hoogeveen, & Steduto, 2008) From the farmer's perspective, land lease to the energy company might be an attractive way to earn profits since the compensation amount provided by energy developer is much higher than the economic outputs, especially for the farmers growing staple crops like Barley, Starch Potato and Wheat, which has low economic output (even not the income of the farmers). Diversified use of agricultural land will be economically profitable for these farmers. Indeed, dual land use is recommended by Hernandez et al. (2014) However, it is from the land-use perspective instead of the economic benefits.

Regarding the biodiversity, potentially high impact is anticipated with the criteria, but to what extent the biodiversity will virtually get affected by the solar PV remains unknown due to the lack of data to substantiate the identified impact. Therefore, the adoption of monitoring measures seems imperative for the sake of identifying the lifetime-period impact.

3. **Tradeoffs of land-based PV on the natural land**

From the result, land occupation by 1GW solar PV is also small, which is 0.25% of the total natural land area. However, it does not mean the area is suitable for the PV installation on the ground that it might have high biodiversity and visual impact. Currently, with the nature conservation objective, the permit for the solar park cannot be granted within the area of Natura 2000 or in the NNN (Natuurnetwerk Nederland). (van der Zee et al., 2019)

4. **Tradeoffs of land-based PV on the urban area/Industrial land**

The urban area has a denser population than the rural area. Therefore, albeit it has a low impact on land occupation and potentially low impact on the biodiversity, it is not as much suitable as the development in the rural area. Additionally, compared to the rural area, the urban area might have a smaller area that is available for solar PV installation and higher land price. However, among the limited available urban area, the industrial land is most suitable for the solar PV installation (RVO & ROM3D, 2015a) which coincides with the results from table 19. that industrial area has low tradeoffs for land-based solar PV installation.

5. **Tradeoffs of floating PV on various water**

As for the floating solar PV, this research has identified the “Aquatic wetland” is a favorable location for solar PV development due to that there is no need to remove vegetation thus low directive CO_2 emissions. From the land-use point of view, 1GW floating solar PV on the Ijsselmeer only takes up 0.55%, and around 6.5% on total recreational water. However, similar to agricultural land, the consideration of water function is also suggested as the way to inform people about the impact. With the focus on the Ijsselmeer, whose functions include freshwater supply, recreations, shipping, nature preservation (Natura 2000). (Loos & Wortelboer, 2018) When subtracting all potentially affected functional areas, the total area available for the floating solar PV might be lower. Therefore, it is significant to investigate the potential surface area and location that can be used by the PV installation and simultaneously pose no harm to any of the functions of the water body. However, since there is limited information regarding the potential impacts on the biodiversity and water quality, it is still quite a risk to install large scale solar PV on the Ijsselmeer. The existing model provided by Stowa may help to perceive the idea of possible consequences on certain aspects (water quality and water ecosystem), but the field research is still necessary for substantiating the actual impact. Fishery might be another concern which directly links to the unknown ecological impacts. With this concern, Sportvisserij Nederland published the report explicitly focusing on the recreational fishing but merely conveyed the need for the research and monitoring of the impact of floating solar on the water quality and fisheries, which indicates the lack of data. (van Emmerik, 2019) Additionally, aesthetics is the crucial perspective to be considered in the recreational water. The optimal way to reduce the visual impact is suggested by installing panels in East-West orientation, but it is more related to the type of recreational water. (Innovatie Recreatie&Ruimte & LeisureLands, 2019) It is possible that with the proper design and landscaping, it will provide additional attractions for the recreational water. (Pimentel Da Silva & Branco, 2018)

6. Limitation

There are significant limitations in the research on the grounds that the scope is too broad so that identifying proper indicators were difficult. Besides, the current floating solar PV is limited, lack of the data or report, such as compensation amount provided by energy developers for the fishery industry due to the surface occupation. Moreover, this research aims to provide an overview of the potential consequences after solar PV installations, there might be a huge deviations with the real situation, since the real impact is more likely to be location specific and solar park design specific. Next, the limitations identified during each impact investigation is addressed below.

1. Land-use impact

Main limitation of land-use impact on various landscapes is the lack of data to identify or estimate the impact of PV installation on the function of the land except for the agricultural land. Especially for the floating solar PV.

2. Biodiversity impact

With the aim to investigate and further compare the impacts of solar PV on the biodiversity in various landscape, the landscape specific issue (more generally ecological issue) was not considered, for instance the concern of the soil quality in the agricultural land.

Moreover, current research merely focused on the direct impact of solar PV facility thus did not investigated into the potential impact of increasing infrastructure concomitant to the solar PV development. In this research, the considered indicator for comparison of biodiversity impact is the level of the biodiversity in the landscape, which might have high uncertainty.

There is no monitoring program in the current solar park in the Netherlands, thus data collection for the impact analysis is not possible at the moment thus could not provide more meaningful information.

3. Visual impact

First of all, the interview with floating solar PV developers were not available thus how they considered this issue was not available in this paper.

Visual impact is more social issue, even though the solar PV project has considered the landscape issue or the landscape has lower significance to take the aesthetics into account, there will still be the social problems.

Therefore, it requires the understanding of social perception towards solar PV. Moreover, the requirement of the landscaping depends on the municipality instead of the landscapes. Which again corroborate the suitability of the impact study into more location specific.

4. Economic aspect

Economic aspect considered in the current research aims to understand which PV installation is more economically beneficial with the national subsidy scheme. However, this indicator has certain limitation in the way that the land price, additional cost for expanding infrastructure, which might vary with the type of the landscape, is not considered. Moreover, residential-scale solar PV is also not included in the research.

7. Conclusion

Following the research aim, this research investigated the various impacts of solar PV development in different landscapes and what measures are currently adopted to avoid detrimental impacts from the land occupation, especially for the large-scale PV in the Netherlands. The result shows that the rooftop PV has the lowest impacts on the landscape, and together with the substantial potential roof area available for solar energy development. Besides, different extents of tradeoffs can be anticipated in different landscapes as a consequence of the large scale deployment of solar PV either on land and on water. The function of the land should be well considered to avoid concomitant impacts, such as food production vs. energy generation in agricultural land. This result explains the reason why there is increasing opposition towards large-scale solar PV, albeit its sustainability. Conceivably, the broader scope of the impacts associated with the solar PV makes people worried and thus resistant to solar PV projects. In order to reduce the cognitive gap between people with different interests on the large-scale solar PV and ultimately the success on the energy transition, there is a need to provide people with more information instead of taking the land area for granted.

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Appendix A. Total land area and occupied area by 1GW solar PV

		Total Land area	Occupation
Land requirements			1250 ha (land) 1000 ha (water)
Total land		4154303	**0.03%**
Traffic area	Total	115563	1.08%
	Railway	8855	14.12%
	Traffic Road Terrain	104402	1.20%
	Airport	2276	54.92%
Built up area	Total	235839	0.53%
	Residential area	11437	10.93%
	Grounds for retail and hospitality	11823	10.57%
	Land for public facilities	16093	7.77%
	Land for sociocultural cons.	86336	1.45%
	Business park	86336	1.45%
Semi built-up area	Total	49318	2.53%
	dump	2191	57.05%
	Wrecks storage	475	263.16%
	Cemetery	4384	28.51%
	Mineral extraction site	3354	37.27%
	Building site	34949	3.58%
	Semi-paved other terrain	3966	31.52%
Recreation area	Total	105418	1.19%
	Park	30819	4.06%
	Sports ground	35962	3.48%
	Allotment garden	3606	34.66%
	Day recreational area	11810	10.58%
	Recreational site	23222	5.38%
Agricultural land	Total	2236317	0.06%
	Terrain for greenhouse horticulture	15511	8.06%
	Other agricultural land	2220806	0.06%
Forest and open natural area	Total	498956	0.25%
	Forest	341270	0.37%
	Dry natural open field	95055	1.32%
	Wet natural open field	62631	2.00%
Inland water	Total	498956	0.25%
	Ijsselmeer/Markermeer	371941	0.27%
	Rhine-Meuse-Scheldt delta	183138	0.55%

	Randmeer	18176	5.50%
	Recreation inland water	15548	6.43%
	Water for mineral extraction	1242	80.52%
	Liquid and or sludge field	10544	9.48%
	Other inland waterways	3434	29.12%
Open water	Total	107129	0.93%
	Waddenzee, Eems, Dollard	415264	0.24%
	Oosterschelde	254947	0.39%
	Westerschelde	34588	2.89%
	Noordzee	29830	3.35%

Appendix B. Yield per hectare for crops and vegetables

Crop types	Total production in 2018 (ton)	Harvested area (ha)	Yield (ton/ha)
Green maize	8104172	203252	39.9
Sugar beet	6508142	85218	76.40
Total potato	6029734	164689	36.60
Total ware potatoes	3136982	76151	41.2
Total starch potatoes	1546009	45073	34.3
Total seed potatoes	1346742	43465	31
Total wheat	985297	111697	8.8
Winter wheat	874709	96009	8.1
Spring wheat	110588	15689	7
Seed onions (exclude loss)	827863	24995	33.1
Spring barley	187368	27777	6.7
Winter barley	66055	8200	9.1
Chicory for inulin	136451	3142	43.4
Vegetable types	Total production in 2018 (ton)	Harvested area (ha)	Yield (ton/ha)
Tomatoes	910000	1788	508.95
Cucumbers	410000	563	728.24
Winter carrot	384900	6168	62.40
Peppers	355000	1311	270.79
Total cabbage	278700	10804	25.80
Source: CBS			

Appendix C. Input data for the impact on economic output calculation

		2015	2016	2017
Output of the crops (Euro)	Wheat	31300	23100	23600
	Barley	5400	4400	5000
	Seed potatoes	53900	49800	48700
	Ware potatoes	43800	48500	24600
	Starch potatoes	15600	19100	18100
	Sugar beets	27400	29900	42000
	Onions	25900	15100	17800
Area of the crop farm (ha)	Wheat	20	18.05	19.1
	Barley	11.2	9.45	8.21
	Seed potatoes	18.57	17.78	18.91
	Ware potatoes	14.71	13.92	14.14
	Starch potatoes	35.13	34.92	33.63
	Sugar beets	8.97	9.69	11.58
	Onions	9.53	9.58	9.65
Dairy farm (cow)	Fodder area (ha)	51.8	54	54.6
	Dairy cow numbers	96.8	103	102.6
	Total output per dairy cow per year (€)	3226	3026	3875

Source: Agro&Food Portal, Wageningen

Appendix D. CO_2 emission calculation for the construction of 1GW solar park

Category	Area (ha)	Carbon stocks (M ton C)				Total carbon stocks (M ton C/ha)	Carbon emission (M ton)	CO_2 emission (M ton)	Time to compensate CO_2 (year)
		Total	Biomass	Mineral soil	Peat(y) soil				
Forest	326000	21.5	9.4	9.6	2.5	1.7515 $\times 10^{-4}$	0.2025	0.7424	1.40
		13.4	6.6	6.5	0.2				
		20.3	10	9.9	0.5				
		1.9	1.3	0.5	0				
Cropland	860000	77.5	1.6	65.7	10.3	1.0058 $\times 10^{-4}$	0.1232	0.4517	0.84
		9	1.3	6.9	0.8				
Grassland	1372000	113.4	1.9	74.6	36.9	1.1781 $\times 10^{-4}$	0.1473	0.5400	0.97
		4.6	0.1	2.6	1.9				
		4.9	0.3	3.8	0.8				
		31.3	0.6	25.4	5.3				
		7.1	0.2	6.8	0				
	54000	6.7	0.1	4.2	2.4		/		
Aquatic wetlands	803000	5.7	0	3.5	2.2	1.3142 $\times 10^{-5}$	0.0164	0.0602	0.11
		0	0	0	0				
		0.4	0	0.4	0				
	34000	4.9	0	3.3	1.6				
Settlement	115000					1.0783 $\times 10^{-4}$	0.1348	0.4942	0.93
		1.3	0	1.1	0.2				
		7.3	0.4	6	0.9				
		3.8	0	3.1	0.7				
Dunes	36000	0.4	0	0.4	0		0.0139	0.0509	0.10

Appendix E. Reduced GHG of typical Dutch crops per GW solar park

Dutch crop products	kg CO_2 eq
Spring wheat	2.65×10^6
Winter wheat	4.45×10^6
Spring barley	2.87×10^6
Winter barley	3.25×10^6
Potatoes	6.66×10^6
Sugar beets	3.85×10^6
Spinach	5.25×10^6
Spinach (for industry)	3.42×10^6
Cabbages	3.03×10^6